EVIDENCE REVIEW



# A rapid review of evidence

# The effects of urban form on health: costs and benefits

#### A rapid review of evidence The effects of urban form on health: costs and benefits

An Evidence Review commissioned by the NSW Ministry of Health and brokered by the Sax Institute for The Australian Prevention Partnership Centre.

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**Disclaimer:** This evidence review is not necessarily a comprehensive review of all literature relating to the topic area. It was current at the time of production (but not necessarily at the time of publication) and is based on sources believed to be reliable.

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#### **Executive summary**

Cross-sectional evidence suggests that particular attributes of the built environment (urban form), such as the walkability of neighbourhoods and access to green space, are related to health and economic outcomes through their impact on physical activity. This report summarises recent Australian evidence, and uses modelling to estimate the economic value of specific changes in urban form in the Australian context.

Two separate systematic reviews focused on the evidence for the link between:

- 1. Physical activity to economic outcomes
- 2. Urban form attributes to physical activity.

After applying the agreed selection criteria, the first review included nine studies. Of these, eight reported monetary values resulting from health gains associated with an increase in walking and cycling. The monetary value of the health-related benefits associated with each additional kilometre walked varied between \$1.04 and \$2.08. The monetary value of health-related benefits attributable to an additional kilometre cycled ranged from less than \$0.02 to \$1.12.

After applying the agreed selection criteria, the second review included 29 studies. Sufficient evidence was found to associate urban form with physical activity outcomes among adults. The same conclusions could not be drawn for children given the lack of evidence from the recent Australian literature.

Evidence of a positive association with physical activity was found for:

- Shorter distance to transit
- Neighbourhood walkability, which typically included measures of density, land use mix and connectivity
- The number of destinations within walking or cycling distance, such as transport nodes, shops and recreational facilities
- Greater diversity in land use.

No studies in this review directly linked specific urban form attributes to economic outcomes. Evidence from the second review and economic modelling was therefore used to estimate the economic value of changes in urban form. This was done for 23 different scenarios. Economic outcomes were found to be greatest for increasing destinations within the neighbourhood, which are associated with health-related benefits worth an average of \$14.65 per adult annually (range \$0.42 to \$42.50), while for improvement in neighbourhood walkability, the average economic value was most modest at an estimated \$1.62 per adult, per year (range \$0.11 to \$15.73).

The wide variability of results is due to the different measurements and assumptions in the effect estimates as well as the modelling. More precise measurement of urban form attributes and physical activity, including who benefits most, would enable estimates with greater certainty.

Nevertheless, the combined body of evidence currently available shows that urban form attributes are associated with physical activity patterns and in turn increased physically active among individuals translates into positive economic outcomes at the population level.

#### Key messages

- Within the Australian context, there is sufficient evidence that increased walking and cycling have positive monetary health-related benefits.
- Each additional kilometre walked has been estimated to result in health-related benefits that range in value from \$1.04 to \$2.08. Each additional kilometre cycled results in health-related benefits that range in value from less than \$0.02 to \$1.12.
- There is compelling Australian evidence linking attributes of the urban form with physical activity among adults. There is insufficient evidence to draw conclusions for children and adolescents.

In this report, 'health related monetary benefits' or 'economic outcomes' represent the value of improved duration and quality of life, reduced healthcare costs, and increased production associated with an increase in physical activity.

- Attributes of the urban form that increase physical activity among adults are the number of destinations within walking or cycling distance, greater diversity in land use, shorter distance to transit, and neighbourhood walkability. Broadly, the literature suggests that if people are to walk and cycle, they need destinations within walking or cycling distance.
- Economic outcomes were found to be greatest for increasing destinations within the neighbourhood, which are associated with health-related benefits worth an average \$14.65 per adult annually (range \$0.42 to \$42.50), depending on the destination and context. The economic value of increasing neighbourhood walkability was found to be worth an average \$1.62 per adult annually (range \$0.11 to \$15.73).
- The health-related economic benefits of changes in urban form are modest at an individual level, but when multiplied for whole populations, these figures are significant.

#### **1. Background and introduction**

The Centre for Population Health of the NSW Ministry of Health commissioned a review to estimate the health-related economic value of changes in urban form that impact on physical activity. This review and modelling exercise will allow the Centre to provide other government departments with the information needed to include these health externalities in the development of cost-benefit analyses for land use planning.

Physical inactivity is associated with a number of health conditions.<sup>1,2</sup> It represents a burden for individuals, governments and societies, in terms of adverse health and economic outcomes. A 10% increase in the proportion of physically active people in Australia has been estimated to lead to benefits worth \$258 million.<sup>3</sup> Of this, 37% is attributable to a reduction in annual healthcare costs and the rest to improvements in production outcomes estimated over the life course (5% economic production, 26% home-based production and 32% in the value of leisure time).

Urban form incorporates the building and transportation design of a city<sup>4</sup>, including factors such as open green spaces, bikeways and sidewalks, shopping centres, business complexes and residential accommodation. The built environment has a significant impact on physical activity<sup>5</sup> and therefore health. However, to date the inclusion of health outcomes related to physical activity in transport and urban planning cost-benefit analysis is uncommon.<sup>6</sup>

Cost-benefit analysis is the preferred method to evaluate options in land use planning. However, health benefits are not easily included in a cost-benefit analysis. The main reasons are a lack of readily available, evidence-based, context-specific (Australian) estimates of the association of urban form characteristics and physical activity, and an absence of agreed methods for the incorporation of the economic value of changes in specific urban form indicators.

A number of health impacts, or externalities, are associated with urban form, as shown in Figure 1. In economics, an externality is the cost or benefit that affects a party who did not choose to incur that cost or benefit. For the purpose of this review 'health externalities' refers to the benefits or costs to society arising from urban form impacts on physical activity. These externalities include healthcare costs, the value of reducing mortality and morbidity, and changes in production that are attributable to changes in physical activity.

This report aims to assign a dollar value to these health externalities. The logic model is as follows:

- Change in urban form indicator affects physical activity indicator
- · Change in physical activity indicator affects health indicator
- Change in health indicator causes a change in overall societal economic outcomes (over a specified period).



Figure 1. Logic framework for the effect of urban form on benefits and costs

Specifically, in this review we aim to answer the following research questions:

- 1. What is the evidence regarding the economic benefits/costs to society as a whole arising from the impact of urban form on physical activity?
- 2. What are the changes in urban form that most benefit physical activity?
- 3. What is the dollar value of the health externalities associated with changes in urban form?

In the following sections we present methods and results for the evidence reviews that address the first two research questions. Then, we present methods and results for the economic modelling exercise, followed by conclusions and recommendations.

#### 2. Evidence review

#### Methods

#### Search strategy and data sources

The literature searches were conducted by one reviewer (BZ) who examined the English language peerreviewed and grey literature from 2009 to date. The following academic databases were searched: Web of Science, Scopus, EBSCOHost (which includes Business Source Complete, CINAHL, MEDLINE, SportDiscus and Econlit), GeoRef and Leisure Tourism. Google was used to search for government reports and experts in the field were consulted to ensure that all relevant literature was included.

#### **Inclusion criteria**

- 1. Published in English from 1 January 2009 to 15 March 2015
- 2. Study conducted in the Australian context
- 3. Primary study or review
- 4. Presented evidence on the direct association of
  - a. Physical activity with economic outcomes
  - b. Urban form with physical activity
- 5. All age groups considered.

Reviews were used to search for additional studies that met the inclusion criteria.

Studies targeting special groups, such as patients with a disability or health condition, were excluded. We further excluded studies comparing physical activity outcomes after relocation without direct association to a particular urban form (e.g. change in walking after relocating to a new neighbourhood that meets land-planning legislation). Studies assessing mediating variables in the association between urban form and physical activity were also excluded, since a direct interpretation of effect is not possible.

#### Search results

Figure 2 (next page) shows the search results independently for each literature search.



Figure 2. Summary of search results

# Research question 1: What is the evidence regarding the economic benefits/costs to society as a whole arising from the impact of urban form on physical activity?

#### Evidence review: Urban form and economic outcomes

We found 17 studies, however we only report those that estimated the economic value attributable to built-environment features that facilitate physical activity (n=9). Table 1 (Appendix) gives additional information on the studies that estimate the economic value of physical activity (n=8). All research that we included assessed the economic value of additional walking and/or cycling at the population level. All but two studies<sup>6,7</sup> were from the grey literature.

Two approaches have been taken in the literature to evaluate the health benefits of walking and cycling due to infrastructure:<sup>6,8</sup> monetised values per person taking up physical activity, or per additional kilometre walked or cycled. We only observed the second approach<sup>6,8-14</sup> and an alternative to the first<sup>7</sup> in the included literature.

Gunn and colleagues expressed outcomes in terms of the average costs of infrastructure per extra person who moves above a walking threshold.<sup>7</sup> In this study, it costs \$674 in sidewalk investment to move one person above the 60 minutes-per-week threshold and \$2330 for the 150 minutes-per-week threshold.

Estimates of the value of health-related benefits per additional kilometre cycled ranged from less than \$0.02 to \$1.12 (Figure 3). For walking, values ranged from \$0.52 to \$2.08 (Figure 4). The wide range of values can be explained by differences in cost categories included (e.g. direct healthcare costs, indirect costs), data sources (e.g. sources of costs), value of statistical life approach (e.g. willingness to pay or human capital) and computational techniques. In Table 1 we present a summary of the included studies. More detailed information can be found in Table 2 (Appendix). For instance, the comparatively low estimate of the value of a kilometre cycled of \$0.014 only included premature mortality and heart-attack-related costs for men, whereas both estimates of \$1.126,<sup>8</sup> used the same method but included direct (healthcare costs) and indirect (disability) costs of physical inactivity. The study by AECOM<sup>9</sup> used the value of \$0.227, but only included mortality outcomes and a low estimate of production outcomes related to the indirect cost of physical inactivity, based on values from the literature.<sup>16</sup> By including only a restricted set of benefits, the lowest two estimates in Figure 3 are almost certainly underestimates. Health benefits were assessed as being the improvement in health from becoming physically active because of the intervention<sup>6,8,10,13</sup> and by assessing the marginal improvement in health attributable to more cycling.<sup>9,12</sup> In one study methods were not clearly specified<sup>11</sup> and in another, values were taken from the literature.<sup>14</sup>

The per-kilometre approach offers the advantage of being easily included in the economic evaluation of transport infrastructure, as this is commonly performed on per-kilometres basis.<sup>6</sup> However, there are a number of challenges. There is a lack of literature indicating who takes up physical activity as a consequence of improved or additional cycling and walking infrastructure, hence, assumptions are required. Past literature has distributed the incremental estimated kilometres walked or cycled as a consequence of the new or improved infrastructure across physical activity categories equally (sedentary, insufficiently active and active).<sup>8, 17</sup> This method is referred to as a "weighted per-kilometre health benefit".<sup>6</sup> The common assumption is that the additional physical activity lifts some sedentary and insufficiently active people to the sufficiently active category.<sup>17</sup> As highlighted by Mulley and colleagues,<sup>6</sup> this method has been adopted in parts of Australia and New Zealand by the Victorian Department of Transport and the New Zealand Transport Agency. Additional physical activity resulting from infrastructure improvements could replace other forms of physical activity, but this is difficult to assess and in general, not considered in the literature.

<sup>1</sup>Three alternatives were assessed; here we present results for the minimum investment of building new sidewalks in streets without them.<sup>7</sup>

<sup>2</sup>"The value of statistical life is an estimate of the financial value society places on reducing the average number of deaths by one. A related concept is the value of statistical life year, which estimates the value society places on reducing the risk of premature death, expressed in terms of saving a statistical life year."<sup>15</sup>

The value proposed by Sinclair Knight Merz (SKM) and Pricewaterhouse Coopers (PwC)<sup>8</sup> of \$1.12 per kilometre cycled, also recommended in the study by Mulley et al,<sup>6</sup> seems the most plausible value to be applied in economic evaluations of cycling infrastructure. These estimates include mortality and morbidity, and data sources and estimation methods are clearly stated. Likewise, with the value per kilometre walked, the estimate by SKM and PwC is the most plausible at \$1.68 per kilometre. Both values are in line with those proposed by the NSW Department of Transport in a previous review of the literature: \$1.05 (range \$0.06 to \$1.12) for cycling and \$1.68 (range \$0.38 to \$2.10) for walking.<sup>14</sup>

Given that most of these studies are not peer-reviewed, we have limited confidence in the size of benefits attributed to walking and cycling. However, it is well accepted that physical activity is associated with health benefits and thus represents an economic value. This association partly answers research question 1. The next section addresses which attributes of the built environment are most strongly associated with increased physical activity.

	Physical activity	Health outcome	Production outcome
Transport for NSW 2013 <sup>14</sup>	Walking and cycling	Range of values from the literature.	Values from the literature includes AECOM <sup>9</sup> which estimates production outcomes.
SKM and PwC 2011 <sup>8</sup>	Walking and cycling	<b>Mortality and morbidity:</b> Direct healthcare cost (\$171 indexed to 2010 AUD) <sup>18</sup> and indirect cost (\$1941 indexed to 2010 AUD) and disability adjusted life years attributable to diabetes, cardiovascular disease and cancer <sup>19</sup> multiplied by the value of a statistical life year (\$85,302). Distributes benefits per kilometre walked or cycled with benefits only accruing to sedentary and physically inactive people. Applies the weighted per-kilometre benefit methods. <sup>17</sup> All additional physical activity of physically inactive groups is attributed to the new infrastructure.	
PwC 2009 <sup>12</sup>	Cycling	<b>Mortality (adults):</b> Health cost savings associated with a reduction in premature deaths from heart attacks for men who cycle more than six hours per week. WHO-HEAT tool for sensitivity analyses.	
Mulley C et al 2013 <sup>6</sup>	Walking and cycling	Mortality and morbidity (adults): Same as SKM and PwC 2011.8	
Ker 2014 <sup>11</sup>	Cycling	Mortality and morbidity: Sources not provided in study.	
Fishman et al 2011 <sup>10</sup>	Walking and cycling	<b>Mortality and morbidity (adults):</b> Applies values recommended by the New Zealand Transport Agency (document not found, but based on Genter et al <sup>17*</sup> ) adjusted to Queensland physical activity levels.	
AECOM 2010 <sup>9</sup>	Cycling	<b>Mortality:</b> Relative risk of mortality of workers who cycle to work versus general population <sup>20</sup> (WHO-HEAT approach) adjusted to Sydney, multiplied by the value of a statistical life year (\$160,659 indexed to 2010 AUD) and divided by the average kilometres cycled.	<b>Absenteeism and presenteeism:</b> Measured as the difference in working days lost of a physically active person compared to a physically inactive person (\$487.30 indexed to 2010 AUD) <sup>16</sup> divided by kilometres cycled per year and adjusted for contribution of average cycling in Sydney to achieve sufficiently active threshold.
PwC 2010 <sup>13</sup>	Walking	<b>Mortality and morbidity:</b> Replicates methodology by Genter et al <sup>17</sup> replacing equivalent Australian values for value of a statistical life year, disability adjusted life years, prevalence of physical inactivity and healthcare costs.	
* Utilises an average of r This generates a range of	mortality ratio (costs of m of per-kilometre benefit fo	ortality associated with insufficient physical activity) and disability adjusted life years or either attaining or maintaining a level of physical activity which leads to improved	s compared to prevalence of current activity status in society. health outcomes

#### Table 1. Summary of studies measuring the economic value per kilometre walked or cycled



#### Economic value per kilometre cycled

Figure 3. Economic value per kilometre cycled



#### Figure 4. Economic value per kilometre walked

# Research question 2: What are the changes in urban form that most benefit physical activity?

#### Evidence review: urban form and physical activity outcomes

#### Methods

#### Coding of evidence

We grouped urban form indicators into seven categories; five of the '6 Ds'\* proposed by Ewing and Cervero,<sup>21</sup> plus safety and aggregated neighbourhood characteristics. We subdivided broad categories (design and destinations) given the heterogeneity of measures of urban form included in them. Indicators falling under each category are presented in Table 2 with the expected direction of the association, based on past literature.<sup>23,25</sup>

Category	Urban form indicators	Expected direction of association					
Density	Population density/job density.	Positive					
Diversity	Land use mix/non-residential zone.	Positive					
Design	Street network: street connectivity/cul-de-sacs/space syntaxmeasures (e.g. local and control integration)/traffic slowing devices/pedestrian crossing/road traffic volume (decrease)/presence of busyroads (decrease)/active transport route options.Transport infrastructure: sidewalks/bikeways/street lights/aesthetics and attractiveness.Green and recreational space: area/ number/distance (shorter)/quality/attractiveness/maintenance/aesthetics.	Positive					
Destination	Transport related: shorter distance to neighbourhood destinations, retail, school/better job accessibility by public transport/job accessibility by car (less). Recreation related: shorter distance to recreational destinations.	Positive					
Distance to transit	Shorter distance to bus stops/train stations.	Positive					
Safety	Crime/traffic safety/neighbourhood lighting/park safety.	Positive					
Aggregated neighbourhood characteristics	Walkability index/environmental score.	Positive					
*Note: Ewing and Cervero have a sixth D, demand for parking, which has been excluded from this list as no relevant research was found for it.							

#### Table 2. Categorisation of urban form indicators

For most of the included studies, multiple entries for an association were imputed as a result of different domains of physical activity assessed (transport, recreation and all), outcomes evaluated (e.g. walk to, or within, a park), neighbourhood definition (e.g. 15-minute walk, 1600m area) and spatial area evaluated (e.g. within 200m/800m/1600m of residence). Similar approaches were taken in older literature.<sup>23,26</sup> Results were coded in terms of whether the association was in the expected direction (+), in the opposite direction (-), or not statistically significant (0). We present results both for studies in which urban form was objectively measured, and in which urban form variables were based on perceptions. All assessed associations were also classified by domain of physical activity (transport, recreational and all). Results are presented separately for adults, adolescents and children.

All variables assessed are for the neighbourhood area which has been defined differently in the included studies including: 1.6km service area around participant's address, 1km radius around participant's address and 15 minutes walking area around participant's address.

We calculated the percentage of associations in the expected direction of the total number of relationships for each urban form indicator. We only considered as sufficient evidence urban form attributes that were investigated in at least three independent studies, using three different datasets.<sup>27</sup> We interpreted the results following rules used in the past; only those indicators for which 50% of all associations were in the expected direction were classified as convincing evidence of a positive relationship with physical activity outcomes.<sup>23, 27</sup>

#### **Summary of findings**

#### Adults, objective urban forms

Convincing evidence of a positive relationship was found for availability of destinations, with seven out of 10 cases showing an effect in the expected direction (Table 3). The majority of the evidence covers transport-related destinations (6/8) within the neighbourhood, such as retail zones, services, post offices, food stores, transit stops and public open spaces such as parks. Shorter distance to transit also showed convincing evidence, with 80% of the studies in the expected direction. It should be noted that many of the studies included in 'destinations' take into account transit as well, however it was not possible to disaggregate what was in the variables. Despite this crossover, the overall evidence suggests that having access to a wide variety of destinations within the neighbourhood has a positive impact on physical activity outcomes.

Convincing evidence was also found for the impact of diversity measures, including land-use-mix indicators and measures of non-residential zones, with four of six studies showing associations in the expected direction (67%). Lastly, aggregated neighbourhood measures such as walkability indices, which typically include measures of density, connectivity and land use mix, provided convincing evidence of having a positive relationship with physical activity outcomes (74%). Recent Australian studies do not provide convincing evidence to indicate that design and density variables are associated with physical activity outcomes. However, density and connectivity (a design measure) are commonly included in aggregated neighbourhood measures which showed convincing evidence of having a positive relationship with physical activity outcomes. Design variables related to public open areas, such as green spaces, are included in measures of transport destinations within the neighbourhood, which also indicated sufficient evidence of association with physical activity in a positive direction.

For measures of safety, there was not enough evidence to draw conclusions. It is important to note that we present adjusted associations for other urban forms, which helps to explain the lack of convincing evidence for the case of density. As highlighted in previous literature,<sup>28,29</sup> density per se is unlikely to be related to physical activity outcomes, but higher density makes mass transit and commercial destinations viable and therefore tends to increase the number of potential destinations within walking or cycling distance. In adjusting for these other variables, which are on the causal pathway from density to physical activity, there is a risk of over adjustment and explaining away real associations.

#### Adults, subjective urban forms

Associations of physical activity with perceived urban forms were not always in agreement with similar studies that used objective measures of the built environment. For design variables, convincing evidence was found, with 54% of the association in the expected direction. The major contributors to this positive result were measures related to the street network and transport infrastructure. Measures of destination supported objective results with 71% of cases in the expected direction. For cases of distance-to-transit and neighbourhood-aggregated measures, there was not enough evidence to draw conclusions. Contrary to objective measures, safety indicated enough evidence to draw conclusions. However, this evidence was not convincing to draw conclusions (33%).

#### **Evidence from international systematic reviews**

Our findings are restricted to the recent Australian context. However, they are in line with internationally conducted reviews. Recent reviews found that availability of destinations (overlapping with land use mix) and walkability measures are facilitators of physical activity. McCormack and Shiell<sup>30</sup> conducted a systematic review of the international literature including only studies that controlled for self-selection. Their findings indicated consistent associations with physical activity outcomes in the expected direction for land use mix, composite walkability indices and neighbourhood type. A study focusing only on European countries found convincing evidence of an association with physical activity outcomes for walkability, access to shops/services/work and environmental quality.<sup>27</sup> Grasser and colleagues<sup>31</sup> found consistent results for density (population, housing, intersections) and walkability indices.

Characteristics of studies can be found in Table 3 of the Appendix and decisions regarding associations included in Table 3 are presented in Table 4 of the Appendix.

#### Table 3. Summary of associations between urban form and physical activity for adults

Domain						۸*	D*	C*	D*	<b>F</b> *	<b>E</b> *
indicators	Transport		Leis	ure	All domains	A	D	C		E	
Density						4	3/9	33%			
Population	0 (32)/ 0 (33)/ + (34)		0 (32)		0 (32)/ + (35)/ 0 (36)/ 0 (36)	4	2/8				
Job density	+ (34)					1	1/1				
Diversity						3	4/6	67%			
Land use mix and non-residential zone	+ (32)/ + (37)/ + (33)/ + (34)		0 (32)		0 (32)	3	4/6				
Design						6	8/29	28%	4	14/26	54%
Street network						5	4/11	36%	3	7/9	78%
Connectivity/space syntax measures: local integration and control integration/cul-de-sacs	+ (32)/ + (38)/ + (33)	0 (39)	0(32)/ - 40/ - (40)	+ (41)/ + (41)/ + (39)	0 (32)/ + (35)/ 0 (36)/ 0 (36)	4	4/10		2	3/4	
Traffic slowing devices, pedestrian crossings, road traffic volume and busy roads		+ (42)/ + (42)							1	2/2	
Functionality/route options				+ (42)					1	1/1	
Street density	0 (34)					1	0/1				
Transport infrastructure						2	2/5	40%	4	6/11	40%
Sidewalks/bikeways	0 (44)	+ (42)	0 (44)	0 (41)/ 0 (41)/ 0 (45)	+ (44)/+ (35)	2	2/4		3	1/4	
Street lights		0 (39)		+ (39)/ + (45)/ 0	0 (35)	1	0/1		4	5/7	
Aesthetics/attractiveness		/+ (42)		(46)/ + (41)/ + (41)							
Green and recreational space						3	4/19	21%	2	2/8	25%
Green space/POS/sports facilities – area/presence			0 (40)/ 0 (45)/ 0(45)/0 (48)/ 0 (48)/+ (48)	0 (48)/ + (48)	+ (47)/ + (47)	3	4/9		1	1/2	
Green space/POS/sports facilities – <b>distance</b>			0 (40) 0 (45)/ 0 (45)	0 (40) / 0 (48) + (48)		1	0/3		2	1/3	
Green space/POS/sports facilities – number			0 (40)/ 0 (40)/ 0 (48)/ 0 (48)			2	0/5				
Space syntax measure: integration public open space			0 (45)/ 0 (45)			1	0/2				
Green space /quality/ attractiveness/aesthetics/ maintenance				0 (48)/ 0(48)/ 0 (40)					2	0/3	

Tudiastava	Domain						۸*	D*	C*	D*	<b>F</b> *	г*
Indicators	Transpo	Transport L		isure All domains			A	D			E	
Destinations							4	7/10	<b>70</b> %	3	10/14	71%
Transport related							4	6/8	75%	3	5/6	83%
Transport-related destinations	+ (28)/ 0 (33)/0 (33)	+ (28)/ 0 (39)/ + (33)/ +(33)/ + (38)		+ (39)	+ (36)/ + (36)/ + (35)		3	4/6		3	5/6	
Job accessibility by public transport	+ (34)						1	1/1				
Job accessibility by car	- (34)						1	1/1				
Recreation related							2	1/2	50%	3	5/7	71%
Recreation related destinations' distance (places of interest, recreation, parks)		0 (39)/ + (33)	+ (28)	+ (28)/ + (39)/ 0 (41)/ + (41)/ 0 (41)/+ (41)	0 (35)		2	1/2		3	5/7	
Distance to transit							3	4/5	80%	1	1/2	<b>50</b> %
Bus stops/train stations	+ (33)/ + (33)/ + (33)/ + (34)	0 (33)/ + (33)			0 (35)		3	4/5		1	1/2	
Safety							2	2/6	33%	3	3/9	33%
Safety from crime		0 (39)	+ (40)/ 0 (39)/ 0 (41)/ 0 (41)		+ (49)/ + (49)/ + (36)/ - (36)/ - (36)/ - (36)/ - (36)		2	2/6		3	2/5	
Traffic safety				+ (40)/ 0 (41)/0 (41)						3	1/4	
Aggregated neighbourhood							3	14/19	74%	1	1/1	100%
measures												
Walkability index	+ (32)/ + (50)/ + (50)/ + (50)/ + (44)/ + (51)/+ (54)		0 (32)/ 0 (50)/ + (50)/ + (50)/ 0 (51)/ 0 (44)	+ (52)	+ (32)/ 0 (44)/ + (53)/ + (53)/+ (53)/+ (53)		3	12/19			1/1	

Regular font = subjective built environment (BE). Bold font = objective BE.

\* A: Independent studies, objective BE; B: Associated records divided by all records, objective BE; C: % evidence in expected direction, objective BE; D: Independent studies, subjective BE; E: Associated records divided by all records, subjective BE; F: % evidence in expected direction, subjective BE.

#### Table 4. Summary of associations between urban form and physical activity for children (≥12 years)

Tedicatore			Domain								
Indicators	Trans	port		Leisure	All domains	A*	B*	C*	D*	E*	F*
Diversity						1	0/2	0%			
Land use mix and non-residential zone	- (56)/ 0 (56)					1	0/2	0%			
Design											
Street network						1	3/5	60%	2	10/12	83%
Connectivity/cul-de-sacs	+ (57)/+ (58)					1	2/2				
Traffic slowing devices, pedestrian crossings, road traffic volume and busy roads	0(59)/- (57)/+ (58)	+ (56)/ + (56)/ + (57)/ + (58)/+ (58)/+ (56)/+	/+ (57)/ + (57)/ + (58)/ - (56)/ 0 (56)/ 0 (56)			1	1/3		2	10/12	83%
Transport infrastructure						2	0/3	0%	1	2/2	100%
Sidewalks/bikeways/walking facilities	0 (56) /0(56) /0(59)	+ (56)/ + (56)				2	0/3	0%	1	2/2	100%
Green and recreational space						1	6	0%	1	0/4	0%
Green space/public open spaces/sports facilities				0 (60) /0 (60) /0(60) /0(60) /0(60) /0 (60)	0 (61)/0 (61)/0 (61)/0 (61)	1	6	0%	1	0/4	0%
Destinations									1	2	100%
Distance to school		+ (56)/+ (56)							1	2	2/2
Distance to transit						2	4	100%			
Bus stops/train stations	+ (59)/+ (56)/+ (56)/+(57)/+(58)					2	4	4/4			
Safety									1	0/4	0%
Stranger safety					0 (61)/ 0 (61)				1	0/2	0%
Traffic safety		+(57)/+(57)/+(58)			0 (61)/ 0 (61)				1	0/2	0%
Aggregated neighbourhood measures						1	0/1	0%			
Walkability index	0 (59)					1	0/1	0%			

Regular font = subjective built environment (BE). Bold font = objective BE

\* A: Independent studies, objective BE; B: Associated records divided by all records, objective BE; C: % evidence in expected direction, objective BE; D: Independent studies, subjective BE; E: Associated records divided by all records, subjective BE; F: % evidence in expected direction, subjective BE.

#### **Children and adolescents**

A summary of results of studies investigating the association between urban form attributes and physical activity outcomes is presented in Table 4. For children, none of the studied associations had enough evidence to draw conclusions regarding their impact on physical activity, as per recent Australian literature.

For adolescents, only one study was found, which assessed safety and distance to parks. Again, more evidence is needed before conclusions can be drawn (Table 5, Appendix).

#### **Evidence from international systematic reviews**

We examined recent international reviews to provide an indication of which urban form factors are more likely to determine physical activity among youth.

Ding and colleagues<sup>23</sup> found consistent evidence of a number of factors influencing physical activity outcomes among children, including: recreation facilities (access/density/proximity), land use mix/ destinations, residential density, walkability measures, traffic/speed volume, pedestrian safety structures and vegetation. For adolescents, only land use mix/destinations and residential density were consistently associated with physical activity. Pont et al<sup>55</sup> found consistent evidence that greater distance to destinations was associated with lower levels of active transport for young people (5–18 years old). The presence of walking and cycling paths and parks was found to possibly determine active travel behaviours.

We ranked urban form indicators that measured the built environment objectively and showed sufficient evidence to draw conclusions on their association with physical activity outcomes. In summary, for adults, there is convincing evidence of a positive association with physical-activity outcomes for urban form indicators related to: accessibility to destinations, shorter distance and greater availability of transit, greater walkability and diversity of land uses (Table 5).

Ranking of indicators – adults							
1	Distance to transit	4/5	(80%)				
2	Aggregated neighbourhood measures	14/19	(74%)				
3	Destination	7/10	(70%)				
4	Diversity of land uses	4/6	(67%)				
5	Density	3/9	(33%)				
6	Design	8/29	(28%)				
Insufficient evidence for ranking							
7	Safety	2/6	(33%)				

#### Table 5. Ranking of urban form indicators

#### 3. Modelling exercise

## **Research Question 3: What is the dollar value of the health externalities associated with changes in urban form?**

#### Methods

We estimated the economic outcomes of changes in selected urban form attributes (quality score more than 35%) that indicated convincing evidence of an association in the expected direction (diversity, destinations, distance to transit and aggregated neighbourhood measures). We intended to pool results of effect estimates per urban form indicator by applying a meta-analysis method that accounts for the quality of studies.<sup>62</sup> Given the heterogeneity of exposure and outcome measures, this was not possible. Instead, we based the selection of effect estimates to model on studies that met a quality threshold. However, given the wide diversity of economic outcomes per modelled category, we calculated the weighted average by applying the MetaXL quality effects model.<sup>62</sup>

#### **Quality assessment**

We developed and applied a tailored tool that was based on others used in past related reviews.<sup>31, 63, 64</sup> We did not apply existing tools, as they were missing important components. For example, we did not find any criteria that assessed for self-selection, which has been widely recognised as inflating the association of physical-activity outcomes with urban form in cross-sectional studies.<sup>30</sup> Our quality-criteria tool was discussed with a group of experts in the field for agreement on items and weights.

#### Table 6. Quality score

Rankii	Ranking of indicators – adults						
No.	Quality item	Score					
	Study design – causality						
1.1	Cross-sectional	0					
1.2	Longitudinal	1					
1.3	Quasi-experiment	2					
1.4	Experiment	3					
Partic	ipation rate – sample representativeness						
2	Participation rate >50%	1					
Data	collection – precision of estimate						
3.1	Measurement of physical activity –	0					
	not stated						
3.2	Measurement of physical activity –	1					
	validated questionnaire						
3.3	Measurement of physical activity –	2					
	objectively measured						
Data	analysis						
4.1	N>1000	1					
4.2	Statistical control for covariates: socio-	1					
	demographic characteristics						
4.3	Statistical control for covariates: other urban	1					
	forms						
4.4	Controls for self-selection	0.5					
Repo	rting of results – uncertainty						
5.1	Inexact p-values (e.g. p≤0.1, 0.05, 0.001)	0.5					
5.2	Exact p-values given	1					
5.3	Confidence intervals given	1					
Maxir	num total	10.5					

#### **Economic model**

The monetary value of health and production gains associated with an increase in physical activity consequent to improvements in urban form attributes were modelled with an updated and adapted version of the method developed in the Australian study 'Assessing Cost-Effectiveness in Prevention' (ACE-Prevention).<sup>65</sup> Specifically, we used the model to assess cost-effectiveness of physical activity intervention.<sup>66</sup> The model is based on a multi-state, multi-cohort life table Markov model, which calculates health outcomes resulting from changes in population physical-activity levels. The multi-state life table includes five physical-activity-related diseases (breast cancer, colon cancer, diabetes type 2, ischaemic stroke and ischaemic heart disease) and estimates changes in morbidity and mortality for each cohort by age (starting with an 18–22 year cohort and continuing in age brackets of five years) and by sex. Each cohort by age and sex is simulated until death or 100 years of age.

We model the health impact of changes in physical activity only for one year, which results in estimates in annual terms. Produced estimates include healthcare cost savings, additional healthcare costs due to prolonged life, monetised disability adjusted life years and production outcomes. The results are expressed as values per year, per adult living in the area affected by the change in urban form.

#### **Economic exercise results**

We modelled 23 scenarios for indicators showing convincing evidence of having a positive impact on physical activity outcomes from nine studies that met the quality criteria threshold (quality criteria results Appendix, Table 6).<sup>5</sup>

There was large variability in the economic outcomes that can be achieved by each of the indicators. However, in all of them, monetised disability adjusted life years make up approximately 97.5% of the total economic value. In Table 7 we present a summary of the estimated economic value per person per year for changes in selected urban form indicators. Figures 5, 6, 7 and 8 depict the results for the total economic value associated with each modelled indicator. Complete outcome tables with estimates per 100,000 people can be found in the Appendix (Tables 7–10) as well as modelled economic outcomes for categories without convincing evidence of a positive association (density and design) and without enough evidence to draw conclusions (safety) (Appendix, Tables 11–13).

Category	Changes in urban form indicator/study authors	Mean (95% uncertainty interval)					
	+ 1 transport destination (Giles-Corti et al 2013)	\$14.01 (\$13.43 to \$14.31)					
	1 transport destination within 0.2km (compared to 1km) (Wilson et al 2011)	\$7.84 (\$2.39 to \$13.09)					
Destinations	+ 1 recreational destination (Giles-Corti et al 2013)	\$42.51 (\$40.76 to \$43.41)					
	1 park within 0.2km (compared to 1 km) (Wilson et al 2011)	\$1.31 (-\$2.61 to \$5.42)					
	4–7 transport destinations (ref=<3) (Knuiman et al 2014)	\$0.41 (-\$1.14 to \$1.99)					
	8–15 destinations (ref=<3) (Knuiman et al 2014)	\$1.83 (-\$0.11 to \$3.81)					
	Bus stops 15–19 (ref=0–14) (Knuiman et al 2014)	\$3.97 (\$2.22 to \$5.79)					
Distance	Bus stops =>30 (ref=0–14) (Knuiman et al 2014)	\$4.98 (\$2.87 to \$7.01)					
to transit	Train stations within 1.6km (Knuiman et al 2014)	\$3.33 (\$3.19 to \$3.40)					
	Transit within 0.2km (compared to 1km) (Wilson et al 2011)	\$4.20 (-\$0.11 to \$8.18)					
	WI + 1SD (Christian at al 2011)	\$3.08 (\$0.82 to \$5.33)					
	WI-High neighbourhood scale (ref=low) (Learnihan et al 2011)	\$7.47 (\$3.47 to \$11.61)					
	WI-High CCD scale (ref=low) (Learnihan et al 2011)	\$11.17 (\$7.60 to \$14.94)					
	WI-High 15 minutes walkable scale (ref=low) (Learnihan et al	\$15.73 (\$12.09 to \$19.30)					
Aggregated	2011)						
neighbourhood	WI-Increase 1 SD (McCormack et al 2012)	\$0.11 (-\$0.28 to \$0.55)					
measures	WI + 1 SD 200m buffer (Villanueva et al 2014)	\$0.35 (\$0.23 to \$0.44)					
	WI +1 SD 400m buffer (Villanueva et al 2014)	\$0.26 (\$0.15 to \$0.37)					
	WI + 1 SD 800m buffer (Villanueva et al 2014)	\$0.18 (\$0.08 to \$0.28)					
	WI + 1 SD 1600m buffer (Villanueva et al 2014)	\$0.27 (\$0.19 to \$0.34)					
	WI-Low compared to high (Owen et al 2010)	\$2.15 (\$0.79 to \$3.57)					
	+ 1 SD LUM (Christian et al 2011)	\$7.49 (\$2.49 to \$12.44)					
Diversity	+ 1 decile LUM (Duncan et al 2010)	\$12.90 (\$5.86 to \$20.17)					
	+ 1 SD LUM (Knuiman et al 2014)	\$1.60 (\$0.92 to \$2.29)					
CCD: census collector district, WI: walkability index, SD: standard deviation, LUM: land use mix.							

## Table 7. Summary of economic value, per person per year, for selectedurban form indicators

<sup>5</sup> The study by Foster et al 2014 was not modelled as it was not possible to translate effect estimates provided into model inputs.

#### Destinations

The modelled economic value ranged from \$0.41 (95% UI -\$1.14 to \$1.99) for four to seven destinations within the neighbourhood to \$42.52 (95% UI \$40.76 to \$43.41) for an increase in one recreational related destination per adult, per year. On average, an increase in destinations translates into annual economic outcomes per person of \$14.65.



#### Economic value of changes in destinations per adult, per year

#### **Distance to transit**

The estimated economic value of increased physical activity attributable to changes in distance to transit ranged from \$3.33 (95% UI \$3.19 to \$3.40) for having a train station within the neighbourhood area to \$4.98 (95% UI \$2.87 to \$7.01) for an increase from less than 14 bus stations per adult within the neighbourhood area to more than 30, annually. On average, per year, shorter distance to transit destinations was valued at \$3.33 per person.



#### Economic value of changes in distance to transit per adult, per year

Figure 6. Economic value per adult, per year, of changes in distance to transit within the neighbourhood area

Figure 5. Economic value per adult, per year, of changes in destinations within the neighbourhood area

#### Neighbourhood aggregated measures

The economic value of increasing neighbourhood walkability ranged from \$0.11 (95% UI -\$0.28 to \$0.55) to \$15.73 (95% UI \$12.09 to \$19.30) annually per adult. The mean economic value was estimated at \$1.62, per person per year. Walkability indices are a composite measure including mainly density, connectivity and land use mix. Changes are generally in terms of moving from the lowest walkable category to the highest, or in terms of changes in standard deviation on the index, and therefore may not be directly comparable.



#### Economic value of changes in walkability measures per adult per year



#### Diversity

The economic value of increasing measures of land use mix for an adult living within a neighbourhood area ranged from \$1.60 (95% UI \$0.92 to \$2.29) to \$12.90 (95% UI \$5.86 to \$20.17) per year. The average economic value was estimated at \$1.79, per person per year. The studies assessing diversity measures used composite indicators of land use, which include a variety of elements which we were not able to decompose. Direct interpretation is in terms of increases in one standard deviation<sup>32, 33</sup> or one decile in the indicator.<sup>37</sup>



#### Economic value of changes in diversity measures per adult per year

Figure 8. Economic value per adult, per year, of changes in diversity within the neighbourhood area

#### 4. Conclusion and recommendations

This evidence review and economic-modelling exercise was conducted to provide information on the association between urban form attributes and physical activity outcomes and the economic value of changes in urban form, via its impact on physical activity in the contemporary Australian context.

As a whole, the body of recent Australian evidence confirms an effect of urban form on physical activity for adults, with a wide range of indicators showing an association with various forms of physical activity. This report ranks broad categories of indicators by the proportion of associations that show a statistically significant relationship with physical activity in the expected direction.

Built environment attributes showing convincing evidence of an association with physical activity outcomes include destinations within walking or cycling distance of residence, diversity of land uses, distance to bus stops, train stations, ferry terminals, etc. and measures of walkability. The recent Australian evidence for children and adolescents was not sufficient to draw conclusions.

The Australian literature provides a range of values to quantify the health benefits per kilometre walked or cycled. However, these are based on reports prepared for government bodies and other grey literature. We only recommend those values for which we could trace data sources and methods and were comprehensive (included mortality and morbidity of a range of physical activity related diseases). SKM and PwC<sup>8</sup> estimated \$1.12 per kilometre cycled and \$1.68 per kilometre walked. These values were also proposed in the study conducted by Mulley et al<sup>6</sup> and are in line with recommendations from the NSW Department of Transport.

We estimated the potential economic value of changing selected urban form indicators that indicated convincing evidence of having a positive impact on physical activity. We only modelled the best quality studies, since meta-analysing the associations to provide a single effect-estimate was not possible due to heterogeneity in outcomes and exposure measures. Overall impacts of up to \$42.51 (95% CI \$40.76 to \$43.31) were estimated for an increase in one recreational destination within the neighbourhood area.

Strengths of this study include the systematic review of evidence that is recent and directly applicable to the Australian context, the ascertainment of study quality, the use of an established model with results that have been published in high-ranking peer-reviewed journals, and the integration of these various elements to answer questions of direct policy relevance.

In all, this review shows there is Australian and international evidence for an association of urban form characteristics with physical activity behaviours, and of physical activity with health and health-related economic outcomes.

#### Limitations

The diverse ways different studies use to report the relationship between urban form and physical activity outcomes hinder comparison and pooling, and in some cases insufficient information is provided to enable meaningful interpretation. More precise measurement of relevant exposures is likely to show stronger effects in future research, and more uniform measurement methods would facilitate pooling of results. Similarly, the limited accuracy with which physical activity is measured in past studies probably results in sizeable underestimation of the impact on disease outcomes in our model (regression dilution bias<sup>67</sup>).

Moreover, the great majority of research is based on cross-sectional studies, which does not allow for a direct causal interpretation. The association can be due to the built environment influencing physical activity; this is the hypothesis underlying this research. Alternatively, it could be due to physically active people choosing to live in neighbourhoods that facilitate that behaviour.

By adjusting for self-selection, some studies try to avoid this reverse causal interpretation. McCormack and Shiell<sup>30</sup> systematically reviewed the international literature and found that adjusting for self-selection tended to diminish the strength of the associations, but only to a small extent.

Finally, the associations could be due to other (observed or unobserved) factors causing both. Most studies use statistical adjustment to minimise the impact of measured factors. It is unclear what unobserved factors could explain the associations. In the model, the proportion of the population that is sufficiently active (~30%) receives no benefit from additional physical activity, which may have led to underestimation of effects. The modelled economic impacts do not include the production losses that result from absenteeism and presenteeism attributable to physical-activity-related diseases.

#### 5. Recommendations

- Physical-activity-related impacts on health and health-related economic outcomes should be included in cost-benefit analyses in urban planning.
- Joint research involving both health researchers and urban planners is required to select urban form indicators that are most suitable for use in planning and cost-benefit analysis, and to establish guidelines on the calculation of the associated economic values. Initial efforts could usefully focus on indicators for destinations within walking distance of residence, diversity of land use, distance to transit and street connectivity. The current research methods can assist in such research.

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#### **EXPLANATION OF ABBREVIATIONS**

BMI: body mass index	GP: general practitioner	PA: physical activity
CI: confidence interval	HCA: human capital approach	POS: public open spaces
DALY: disability adjusted life year	ICC: Interclass correlation	QALY: quality adjusted life year
FCA: friction cost approach	coefficient	SA: sufficiently active
CCD: census collector district	MET: metabolic equivalent of task	
GIS: geographic information system	MVPA: moderate to vigorous physical activity	

Study chara	cteristics		Methodology		O	utcome		Addition	al notes
Author, year, country, study design, sample size/ demographic	Objective	Change in PA	Proportion shift	Confounders measured	Benefits/costs to society	Benefits to society from DALYs/QALYs	Base year/ currency/ discount rate/time horizon	Level of evidence	Other comments
Amarasinghe 2010 Australia Modelling West Australian adults 18 years plus (n=3361) <sup>1</sup>	To evaluate the cost effectiveness of a GP based PA prescription subsidy program.	Walking included. Percentage of those deemed SA (150 minutes of moderate PA over five sessions per week or 60 minutes of vigorous PA per week). Hypothetical shift, assuming that probability of becoming SA when given advice (GA) =P(GA SA)*P(SA).	Hypothetical scenario that 20% of population could be moved from insufficiently active to sufficiently active. Examined patient compliance (10% – 100% compliance with PA subscription by those given advice).		Healthcare cost offsets from diseases avoided: colon cancer, type 2 diabetes, heart disease, stroke and depression.	<ul> <li>Full compliance (20% shift from physically inactive to active):</li> <li>(1) 6286 DALYs averted per year.</li> <li>(2) \$53 million annual health care cost savings.</li> <li>(3) \$5 million net savings (after costs of program subtracted).</li> <li>(4) \$810 (100% compliance, \$20 subsidy) cost per DALY.</li> <li>10% compliance:</li> <li>(1) 697 DALYs averted per year.</li> <li>(2) \$5 million annual health care cost.</li> <li>(3) \$164,896 (10% compliance, \$50 subsidy) cost per DALY.</li> </ul>	AUD 2003	Based on estimates and assumptions for compliance. Gives good table for different scenarios of cost effectiveness given different compliance and subsidy rates.	
Beavis & Moodie 2014 Australia Modelling Melbourne metropolitan households (n=29,840) <sup>2</sup>	To estimate the health and economic benefits of potential changes in transport behaviours.	Walking and cycling. Time spent in active travel, proportion of people meeting 30 minutes per day through active transport.	10% of car users change to public transport. 10% of car users change to cycling.	Gender, age group, income level, main activity, occupation, urban sub- region, access to vehicle and payment of vehicle running costs for logistic regression undertaken to determine key behavioural associations	10% change to cycling in Melbourne metropolitan area (4.7% shift from physically inactive to active): (1) 770 (428–1207) production gains (losses) (\$'000). 2) 5217 (3927–6780) leisure based production (\$'000). (3) 4693 (3998–5388) home based production (\$'000). 4) 5753 health sector costs (\$'000). 10% change to public transport in Melbourne Metropolitan area (3.3% shift	<ul> <li>10% change to cycling in</li> <li>Melbourne metropolitan area</li> <li>(4.7% shift from physically inactive to active):</li> <li>(1) 1635 DALYs saved per year.</li> <li>(2) 32,600 days per lifetime (95% CI 29, 900–35,500) of home based and leisure based production savings.</li> <li>10% change to public transport in Melbourne metropolitan area</li> <li>(3.3% shift from physically inactive to active):</li> <li>(1) 1148 DALYs saved per year.</li> <li>(2) 22,900 days per lifetime (95% CI 22,100–23,550) of home-based</li> </ul>	AUD 2008	Hypothetical shifts to active transport based on assumptions	Outcomes for Melbourne's population of 3.9 million in 2008. Sensitivity analysis for 3% increase in incidental PA in outer suburbs.

#### Table 1. Summary of extracted information for studies assessing economic value of physical activity

Study chara	acteristics		Methodology		Outc	ome		Additio	nal notes
Author, year, country, study design, sample size/ demographic	Objective	Change in PA	Proportion shift	Confounders measured	Benefits/costs to society	Benefits to society from DALYs/QALYs	Base year/ currency/ discount rate/time horizon	Level of evidence	Other comments
				with active transport.	from physically inactive to active): (1) 541 (301–848) production gains (losses) (\$'000). (2) 3663 (2757–4761) leisure based production (\$'000). (3) 3295 (2807–3783) home based production (\$'000). (4) 4040 health sector costs (\$'000).	and leisure-based production savings.			
Cadilhac et al 2011 Australia Modelling Australian population <sup>3</sup>	To estimate the health and economic benefits of reducing the prevalence of physical inactivity in the 2008 Australian adult population.	From physically inactive to sufficiently PA.	Hypothetical scenario of 10% reduction in physical inactivity. Sensitivity analysis: 5% reduction in physical inactivity.		10% reduction in physical inactivity (1) \$162 million (95% CI \$136–\$192) total production lifetime opportunity cost savings FCA. (2) \$288 million (253–326) HCA. (3) Healthcare cost savings \$96 million.	<ul> <li>10% reduction in physical inactivity:</li> <li>(1) 6000 reduction of incidence of PA related diseases.</li> <li>(2) 2000 deaths attributable to physical inactivity avoided.</li> <li>(3) 25,000 DALYs averted.</li> </ul>	AUD 2008 Discount rate 3% Lifetime horizon	Evidence for hypothetical reduction in physical inactivity from evidence from the literature.	
Cobiac et al 2009 Australia Modelling Australian population <sup>4</sup>	To evaluate the cost- effectiveness of interventions to promote PA. Part of Assessing Cost	Walking and cycling. Change in MET minutes per week as a result of the interventions. Effect sizes from relevant literature for each	GP prescription: 25% of sedentary and 10% of insufficiently active population aged 40–79 years.		Intervention costs, GP prescription and referral interventions also included time and travel costs. Cost offsets Pedometer: \$480 million (\$820–\$200). Mass media: \$440 million (\$820–\$140).				

Study chara	octeristics		Methodology		Outco	ome		Additio	nal notes
Author, year, country, study design, sample size/ demographic	Objective	Change in PA	Proportion shift	Confounders measured	Benefits/costs to society	Benefits to society from DALYs/QALYs	Base year/ currency/ discount rate/time horizon	Level of evidence	Other comments
	Effectiveness - Prevention study.	intervention, effect in the target group: GP prescription: 160 MET minutes per week. GP referral: 238 MET minutes per week. Media campaign: 148 MET minutes per week. Internet: 129 MET minutes per week. Pedometers: 574 MET minutes per week. TravelSmart: 57 MET minutes per week.	GP referral: 8% of sedentary and 3% of insufficiently active population aged 60+ years. Media campaign: 100% of population aged 25–60 years. Internet: 2% of population (internet users) aged 15+ years. Pedometers: 13% of population aged 15+ years. TravelSmart: 57% of population (urban) aged 15+ years.		TravelSmart: \$220 million (\$550 – \$30). GP prescription: \$170 (\$340 –\$26). GP referral: \$54 (\$94–\$27). Internet: \$17 (-\$45–\$2.4). Median ICER Pedometer: Dominant (Dominant – Dominant) Mass media: (Dominant – Dominant). TravelSmart: \$18,000/DALY (Dominant – \$330,000). GP prescription: \$11,000/DALY (Dominant – \$140,000). GP referral: \$75,000/DALY (\$37,000–\$150,000). Internet: \$2000/DALY (Dominant – \$210,000).	Averted DALYs: Pedometers: 20,000 (9100–33,000). Mass media: 23,000 (7600–40,000). TravelSmart: 9300 (21,400-22,000). GP prescription: 7100 (1000–13,000). GP referral: 1900 (1000-3000). Internet: 740 (110–1900).	AUD 2003 Lifetime horizon	Evidence of effect taken from the literature, transparent reporting of sources.	Effect decay analysed in sensitivity analysis
Moodie et al 2009 Australia Modelling School-aged children (prep-grade 2) (n=7840) <sup>5</sup>	To assess the cost effectiveness of a walking- to-school bus program as an obesity prevention measure.	Walking. MET minutes increase as a result of the intervention.	Assumed 50% of those participating in intervention were new to active transport.		Cost savings through diseases averted: ischaemic heart disease, ischaemic stroke, hypertensive heart disease, type 2 diabetes, osteoarthritis, endometrial cancer, colon cancer, post- menopausal breast cancer and kidney cancer. Cost offsets from diseases averted: \$0.24 million (\$0.05 -\$0.86) Net cost per DALY averted \$0.76 million (\$0.23 - \$3.32 million)		AUD 2001 Discount rate 3% Lifetime horizon (or 100 years)	Evidence of effectiveness considered weak. Quality of evaluation good.	Effect decay not considered.

Study char	acteristics		Methodology		Outcom	e		Additio	nal notes
Author, year, country, study design, sample size/ demographic	Objective	Change in PA	Proportion shift	Confounders measured	Benefits/costs to society	Benefits to society from DALYs/QALYs	Base year/ currency/ discount rate/time horizon	Level of evidence	Other comments
Moodie et al 2011 Australia Modelling School-aged children (grade 5–6) (n=267,700) <sup>6</sup>	To assess the cost effectiveness of TravelSmart program as an obesity prevention measure.	MET minutes increase as a result of the intervention.	Pre-post intervention modal shift Walking: 41.3– 43.7% Public transport: 3.4–2.9% (decrease) Cycling: 13.1– 25.2%.		Cost savings through diseases averted: ischaemic heart disease, ischaemic stroke, hypertensive heart disease, type 2 diabetes, osteoarthritis, endometrial cancer, colon cancer, post-menopausal breast cancer and kidney cancer. Intervention costs Cost offsets from diseases averted: \$750,000 (-\$300,000– \$1.9 million). Net cost per DALY averted: \$117,000 (Dominant – \$1.06 million).		AUD 2001 Discount rate 3% Lifetime horizon (or 100 years)	Weak (pre-post survey with low response rate).	Effect decay not considered.
Peeters et al 2014 Australia Longitudinal Australian women born 1946–1951 (n=6108 at baseline) <sup>7</sup>	To examine the total Medicare costs associated with prolonged sitting and physical inactivity in middle-aged women.	MET minutes per week.		BMI, survey year, area of residence, marital status, level of education, smoking status, BMI (if no interaction was found) and depressive symptoms.	Median health-related costs per annum: (1) \$94 higher for physically inactive compared to active.		AUD 2010		

Study char	acteristics		Methodology		Outcon	ne		Additio	nal notes
Author, year, country, study design, sample size/ demographic	Objective	Change in PA	Proportion shift	Confounders measured	Benefits/costs to society	Benefits to society from DALYs/QALYs	Base year/ currency/ discount rate/time horizon	Level of evidence	Other comments
Zheng et a 2010 Australia <sup>8</sup>	To estimate the economic benefits of walking interventions for coronary heart disease in Australia.	Walking. 30 minutes of normal walking per day for 5–7 days per week deemed sufficient.			Direct healthcare expenditure cost savings on cardiovascular heart diseases. 30 minutes walking per day (5–7 days per week) by sufficient walking population: \$126.73 million. 60 minutes walking per day (5–7 days per week) by all the inactive adult population: \$419.90 Walking shoe costs: \$50. Walking related injury costs: Injury costs derived from the total sports injury cost for 2006/2007 in Australia (Medibank Private 2007).		AUD 2004		

#### Table 2. Summary of extracted information for studies assessing urban form – economic outcomes

Study char	acteristics	Metho	dology		Outcome		Additional notes
Author, year, country, study design, sample size/ demographic	Objective	Urban form measured	РА Туре	PA domain	Benefits/costs to society	Base year/currency/ discount rate/time horizon	Level of evidence
AECOM 2010 Australia Modelling Adult residents of 26 Sydney statistical local areas <sup>9</sup>	To examine the economic impact of the Inner Sydney Regional Bicycle Network, to inform future development and project funding.	Proposed bicycle network consisting of radial and cross-regional bicycle links. Combination of separated and shared paths.	Cycling.	Transport.	<ol> <li>All-cause mortality, using value of a life year: \$0.06 per person per cycle km.</li> <li>Absenteeism and productivity saving of \$0.167 per cycle km.</li> <li>Total \$0.227 per cycle km.</li> </ol>	AUD 2010 Discount rate 7% for costs and benefits Evaluation period 30 years	Based on validated demand modelling. Values taken from the literature, but reported clearly and transparently. Sensitivity analyses included variation of the discount rate (to 4% and 10%), variation in health benefit value, journey ambience value, accident costs value, construction costs, demand and capping distance at cycle trips less than 12km only.
Fishman et al 2011 Australia Queensland <sup>10</sup>	To provide an overview of potential impacts of active transport investment in Queensland.		Walking and cycling.		Mortality and morbidity health and fitness benefits: Walking per km benefit \$1.04 per km, taking into account the rule of half, sensitivity analysis uses \$2.07 per km. Cycling per km benefit \$0.52 per km takes into account the rule of half. Sensitivity analysis uses \$1.04 per km and adjusted for Queensland.	AUD 2010	Bases per km health and fitness values on evidence from the literature based on both mortality and morbidity, adjusted for Queensland population. Based on evidence from the literature (Genter et al, New Zealand Transport Agency).
Gunn et al 2014 Australia Cross-sectional WA residents (n=1394) <sup>11</sup>	To examine the cost- effectiveness of installing sidewalks to increase levels of transport walking.	Sidewalk installation under three scenarios: (1) Sidewalk on street segments without sidewalks; (2) Sidewalks on opposing side of street of existing sidewalks (3) All street segments with two sidewalks (hypothetical).	Walking.	Transport.	Cost per person who moves above the walking threshold. Incremental cost-effectiveness ratios for the 150 min PA threshold: \$2330, \$3743 and \$3661 for scenarios 1, 2 and 3 respectively. Incremental cost-effectiveness ratios for the 60 minutes PA threshold were: \$674, \$2105 and \$2136 for scenarios 1, 2 and 3 respectively.	AUD 2012	Controls for confounders: Demographic and built environment variables associated with transport walking.
Ker 2014 Australia <sup>12</sup>			Cycling.		Per cycle km benefit \$0.49.	AUD 2010	

Study c	haracteristics	Methodology		Outcome		Additional notes	
Author, year, country, study design, sample size/ demographic	Objective	Urban form measured	РА Туре	PA domain	Benefits/costs to society	Base year/ currency/ discount rate/ time horizon	Level of evidence
Mulley et al 2013 Australia Stated preference survey Residents of inner Sydney (n=635) <sup>13</sup>	To quantify the mortality and morbidity related effects of active transport and to estimate parameters that could be used in Australian cost benefit analysis.		Walking and cycling.		Weighted benefit of \$1.68 per km for walking (\$1.23–\$2.50) and \$1.12 per km for cycling (\$0.82–\$1.67) including both mortality and morbidity changes that result from a sufficiently active lifestyle.		Direct healthcare costs of physical inactivity per insufficiently active individual per annum of \$171, taken from the literature. Cost in terms of DALYs (monetised using the value of statistical life and the undiscounted cost of a year's life if an individual was to live from the average age of all residents in Queensland to the average life expectancy age) per insufficiently active individual per annum of \$1941.
Pricewaterhouse Coopers 2009 Australia <sup>14</sup>	Assess the net benefits of investing in missing links in the Sydney Metropolitan Strategic Cycle Network.	Bikeways links.	Cycling.		Health benefit of \$0.0142 per cycle km. New users only. Uses an RTA method to estimate the expected health cost savings per bike km associated with a reduction in premature deaths from heart attacks for men that cycle more than six hours per week. Then uses the HEAT tool for a sensitivity analysis. Use of the RTA method is a much more conservative estimate. New users only.	AUD 2008 20-year time horizon Discount rate 7%.	
Pricewaterhouse Coopers 2010 Australia NSW <sup>15</sup>	To document a set of appraisal parameters and values that can be consistently applied to the costs and benefits of walking initiatives.		Walking.		Health benefits \$207.80 per km walked for leisure or transport.	AUD 2010	Not clear in document how value of \$207.80 per km walked was reached, apart from referencing studies by Genter et al and Land Transport New Zealand that had similar values (which based estimates on costs of mortality associated with physical inactivity and DALYs compared to prevalence of current activity).

Study cl	haracteristics	M	ethodology		Outcome		Additional notes
Author, year, country, study design, sample size/ demographic	Objective	Urban form measured	РА Туре	PA domain	Benefits/costs to society	Base year/ currency/ discount rate/ time horizon	Level of evidence
Sinclair Knight and Pricewaterhouse Coopers 2011 Australia Queensland population, 15 years+16	To determine Queensland specific estimates to be used in cost benefit analysis of active transport appraisals and to then apply these benefits to projects.	Cycle ways and transport corridors, upgrades.	Walking and cycling.	Not clearly specified, could be both.	Mortality and morbidity: Benefit per previously physically inactive person that becomes active as a result of the intervention. Health benefit of walking: \$1.68 per km (\$1.23– \$2.50). Health benefit of cycling: \$1.12 (\$0.82–\$1.67).	AUD 2010 Time horizon 30 years 7% discount rate	Based on intercept surveys and assumptions to estimate effectiveness, fairly weak. Direct healthcare costs and indirect costs taken from the literature (Genter et al).

Author	Study design	Sample recruitment	Project	Sample characteristics	PA variable	Built environment variables (objective/ perceived)	Residential selection adjustment	Confounding variables
Astell- Burt, Feng <sup>18</sup>	Cross-sectional. Australia.	Respondents randomly selected from the Medicare Australia database (national provider of universal health insurance). Response rate: 18%	45 and Up Study	(n=203,883) Adults (≥45 years), 61.5 years, 53.2% women, 32% household income less than \$20,000.	<ul> <li>(1) Walking and MVPA for at least 10 minutes at least once per week.</li> <li>(2) Number of times participated in MVPA. Self-reported.</li> <li>Tool: Active Australian Survey.</li> <li>Satisfactory levels of test-retest reliability.</li> </ul>	Objective: Neighbourhood green space	No	Socio-demographic: age, gender, ethnicity, country of birth, BMI, annual household income, education level, economic status, couple status, psychological distress, time spent outdoors and language other than English spoken at home. Others: measures of social interaction, neighbourhood affluence and neighbourhood remoteness.
Astell- Burt, Feng <sup>19</sup>	Cross-sectional. Australia.	Respondents randomly selected from the Medicare Australia database (National provider of universal health insurance). Response rate: 18%	45 and Up Study	(n=203,883) Adults (≥45years), 61.5 years, 53.2% women, 32% household income less than \$20,000.	Number of times participated in MVPA. Self-reported. Tool: Active Australian Survey. Satisfactory levels of test-retest reliability.	Objective: Crime	No	Socio-demographic: age, gender, marital status, psychological distress, educational qualifications and annual household income and employment status. Others: neighbourhood affluence and geographical remoteness.
Christian, Bull <sup>20</sup>	Cross sectional cohort of people in WA building homes in 74 new developments.	Respondents selected based on plans to relocate into new developments. Random selection of household member. Baseline data: 33.4% response rate. Two more waves of data collection undertaken: 12 and 36 months after relocation.	RESIDE	Neighbourhood selection sample (n=1703) Adults (≥18years), 39.9±11.9 years, 59.5% women.	Walking in the neighbourhood for transport, leisure and any purpose. Outcomes for three thresholds (≥0minutes per week, ≥60 minutes per week and 150 minutes per week). Self-reported duration of walking in a usual week. Tool: Neighbourhood Physical Activity Questionnaire. Acceptable reliability.	Objective: Walkability index composed of: density, land use mix and residential density. Analysis for the index and each element.	No	Socio-demographic variables: Gender, age, education level, marital status and presence of children at home. Urban form variables: density, connectivity and land use mix were fitted simultaneously, thus adjusting for each other.

#### Table 3. Summary of studies' characteristics for urban form-physical activity association for Australia

Author	Study design	Sample recruitment	Project	Sample characteristics	PA variable	Built environment variables (objective/ perceived)	Residential selection adjustment	Confounding variables
Cleland, Ball <sup>21</sup>	Cross- sectional. Victoria.	Random selection of urban and rural areas in the bottom third of the Socio-Economic Index for Areas. Women randomly identify in each area. Response rate: 44%.	Resilience for Eating and Activity Despite Inequality (READI)	(n=3765) Adults, 34.6±8.2 years, 100% women.	Leisure time PA: >1 minute per week, >120 minutes per week and >280 minutes per week. Self- reported: International PA Questionnaire (long form). Acceptable reliability.	Perceived: Environmental score	No	Socio-demographic: Age, number of children, country of birth, employment status, marital status, smoking status and injury/illness/disability.
D'Haese, Timperio <sup>22</sup>	Cross- sectional (baseline). Melbourne.	Stratified random sampling to select schools. Families selected from schools. Response rate: 44% (parents responded survey).	Children Living in Active Neighbourhoods	(n=929) Children (10–12 years), 11.53±0.61 years, 53.9% girls.	MVPA during weekdays and weekends. Objectively measured PA with accelerometer.	Perceived: Traffic safety, absence of stranger danger, availability of places to be active and sports venues	No	Socio-demographic: Child age and sex, maternal and paternal education, area-level socio- economic status, number of siblings and family status. Others: Accelerometer wear time.
Duncan, Winkler <sup>23</sup>	Cross- sectional. Adelaide.	Resident of CCDs of the top and bottom walkability index (objective) randomly selected. Baseline data. Response rate: 11.5%	PLACE	(n=2506) Adults (20-64 years), 44.3±12.3 mean years, 64% women, household income \$31,200-\$77,999 median.	<ol> <li>Minutes walking for transport per day;</li> <li>Session per week. Self- reported. PA Questionnaire (long form). Reporting for the previous seven days.</li> </ol>	Objective: Land use mix	No	Socio-demographic: Age, gender, education, employment, household income, number of adults, presence of children in the household, and CCD-level median weekly household Income.
Edwards, Giles- Corti <sup>24</sup>	Cross- sectional. Rural WA.	All high schools in large rural Western Australia participated. All students present on the day of data collection whose parent's participated. Response rate: 92%		(n=1304) Adolescents (12–15 years), 51% female.	Use park/beach in summer and winter. Self-reported. Tool: The Adolescent Physical Activity Recall Questionnaire. Good reliability and validity for students 13 years and over.	Objective: Road barriers and proximity		Socio-demographic: Age, gender and ethnicity. Urban form: Other included variables.

Author	Study design	Sample recruitment	Project	Sample characteristics	PA variable	Built environment variables (objective/ perceived)	Residential selection adjustment	Confounding variables
Foster, Knuiman <sup>25</sup>	Cross-sectional. Perth.	Stratified random sample	Life course Built Environment and Health	(n=3487) Adults (25–65 years), 47.4±10.5, 61.8% female.	Self-reported times walked in the last week. Tool: WA Health and Wellbeing Surveillance System.	Objective: Crime	No	Socio-demographic: Age, gender, marital status, educational qualifications, annual household income and employment status. Others: Neighbourhood affluence, geographical remoteness and psychological distress.
Giles- Corti, Bull <sup>26</sup>	Longitudinal, cohort of people in WA building homes in 74 new developments. Data after 12 (T1) and 36 months (T2) of relocation.	Respondents selected based on plans to relocate into new developments. Random selection of household member. Response rate: T1 36.4%, T2 28.8%.	RESIDE	(n=1437) Adults (>18years), T1: 37.2±11.8 years, 52.3% women. T2: 40.7±11.8 years, 37.6% women.	Change in mean minutes walked. Self-reported. Tool: Neighbourhood PA Questionnaire.	Objective: Number out of seven of key transport-related walking destinations (range 0e7) that increased from T1 to T2. Number out of three of key recreation-related walking destinations (range 0e3) that increased from T1 to T2. Perceived: Perceived access to mixed use and services, fewer cul-de-sacs, having footpaths on most streets; neighbourhood aesthetics, shorter intersection distances, many alternative routes, slower traffic speeds, traffic slowing devices, accessibility of local parks or nature reserve, traffic safety, crime safety, infrastructure and safety for walking and local footpaths, hilly streets, the presence of major barrier.	Yes, self- reported reasons for moving into a new neighbourhood as proxy of characteristics of importance in the built environment.	Socio-demographic: Baseline age, gender, education level, marital status, having children under 18 years at home and baseline total minutes of recreational or transport related-walking. Transport related walking models included changes in work status, number of hours worked weekly and time to travel to work, while recreational walking models included changes in educational level.

Author	Study design	Sample recruitment	Project	Sample characteristics	PA variable	Built environment variables (objective/ perceived)	Residential selection adjustment	Confounding variables
Giles- Corti, Wood <sup>27</sup>	Cross- sectional. Perth.	Selection of schools based on walkability index and socio- economic status. Schools response rate: 69% (n=25 schools). Random selection of a grade from 5, 6 and 7. Children's response rate: 57%. Parents' response rate: 88.88%.	Travel Environment and Kids study (TREK)	(n=1480) Children (grades 5, 6 and 7, 9–11 years old). 51.3% girls. (n=1314) Parents.	<ul> <li>=&gt; than six walking trips to school.</li> <li>Reported by parents. Acceptable (i.e. good to excellent) reliability (kappa or an ICC ≥0.6) (tested in pilot survey).</li> </ul>	Objective: Distance to school, connectivity and road traffic volume.	No	Socio-demographic: Individual level demographic characteristics and SES of school. Urban form: School walkability, distance (km and km2).
Heesch, Giles- Corti <sup>28</sup>	Cross- sectional. Brisbane.	Participants randomly selected using a two-stage cluster design (CCD and within CCD). CCD CCDs stratified by socio-economic status. Response rate: 68.5%.	HABITAT	(n=10,233) Adults (40–65 years). 45–49 median years, 55.6% women, 66.1% household income greater than \$41,600.	<ol> <li>No cyclists: If reported recreational cycling less than monthly (last 12 months).</li> <li>Recreational cyclist: If they reported recreational cycling at least monthly and no minutes of utilitarian cycling).</li> <li>Utilitarian cyclists: If any minutes of transport cycling were reported, additional to having reported recreational cycling.</li> <li>Participants reported:         <ol> <li>Recreational cycling: frequency (six options from 'never' to 'more than once per month'.</li> <li>Transport cycling: time spent. No validation of tool provided.</li> </ol> </li> </ol>	Perceived: Neighbourhood aesthetics, cul-de-sacs, recreational facilities and transport destinations.		Socio-demographic: Age, sex and household composition. Urban form: Models adjust for other included urban forms. Others: Psychological disposition.

Author	Study design	Sample recruitment	Project	Sample characteristics	PA variable	Built environment variables (objective/ perceived)	Residential selection adjustment	Confounding variables
Knuiman, Christian <sup>29</sup>	Longitudinal, cohort of people in WA building homes in 74 new developments.	Respondents selected based on plans to relocate into new developments. Random selection of household member. Baseline data: 33.4% response rate.	RESIDE	Baseline (n=1703) 1 year (n=1273) 3 years (n=1150) 7 years (n=504) Adults (≥18years). 39.9 $\pm$ 11.9 mean years, 59.5% women, household income \$50,000–\$69,000 median.	Walking for transport for more than 10 minutes in a week. Dichotomised. Mean times: 1.2 per week. Self-reported duration of walking in a usual week. Tool: Neighbourhood PA Questionnaire. Acceptable reliability.	Objective: Connectivity, residential density, land use mix, number of bus stops, number of train stations. Perceived: Access to bus stops, access to railway stations, access to services/ convenience stores/public open spaces.	Yes, three models presented, models 2 (logistic mixed model) and 3 (conditional logistic model) allowed for assessing the impact of self- selection.	Socio-demographic variables: Gender, age, education level, marital status, occupation, hours of work per week, annual income, number of adults living in the house, children living in the house and access to motor vehicle. Urban form: Other objective/perceived forms included.
Koohsari, Kaczynski <sup>30</sup>	Cross- sectional. Melbourne.	Respondents selected from three different neighbourhood patters (grid, mixture of regularity and irregularity and hierarchical layout). The socio-economic index for area was applied to control for socio-economic status in the selection of households. Response rate: 35.3%.		<ul> <li>(n=335, n=320</li> <li>provided usable</li> <li>data).</li> <li>Adults (≥18years).</li> <li>44±15 mean years;</li> <li>56% females;</li> <li>39% annual income</li> <li>more than \$80,000.</li> </ul>	<ul> <li>(1) Walking to and within POS.</li> <li>(2) Amount of walking in minutes per week.</li> <li>Self-reported. Questions adapted from the PA Questionnaire and the Neighbourhood PA Questionnaire.</li> <li>Reporting for the previous seven days.</li> </ul>	Objective: Distance/ number/area POS, neighbourhood local integration and control. Perceived: Attractiveness POS, neighbourhood facilities for walking, aesthetics, safety from crime.	Yes, the variable 'Closeness to POS' used to control for self-selection (reported).	Socio-demographic: Age, gender, employment status, income, education level, dog ownership and children in the household.
Koohsari, Karakiewicz <sup>31</sup>	Cross- sectional. Melbourne.	Respondents selected from three different neighbourhood patters (grid, mixture of regularity and irregularity and hierarchical layout). The socio-economic index for area was applied to control for socio-economic status in the selection of households. Response rate: 35.3%.		<ul> <li>(n=335, n=320</li> <li>provided usable</li> <li>data).</li> <li>Adults (≥18years).</li> <li>44±15 mean years;</li> <li>56% females;</li> <li>39% annual income</li> <li>more than \$80,000.</li> </ul>	<ul> <li>(1) Some walking to POS.</li> <li>(2) Some walking within POS. Self-reported.</li> <li>International PA Questionnaire (long form). Reporting for the previous seven days.</li> </ul>	Objective: Distance/ number/area/integration POS.	Yes, the variable "Closeness to POS" used to control for self-selection (reported).	Socio-demographic: Age, gender, employment status, income, education level, dog ownership and children in the household. Urban form: Neighbourhood quality (perceived), and POS attractiveness (perceived).

Author	Study design	Sample recruitment	Project	Sample characteristics	PA variable	Built environment variables (objective/	Residential selection	Confounding variables
						perceived)	adjustment	
Koohsari, Sugiyama <sup>32</sup>	Cross- sectional. Adelaide.	Resident of CCDs of the top and bottom walkability index (objective) randomly selected. Response rate: 11.5%.	PLACE	(n=2506) Adults (20–64 years), 44.3±12.3 mean years, 64% women. Household income \$31,200–\$77,999 median.	Days of walking for transport. Self-reported. International PA Questionnaire (long form). Reporting for the previous seven days.	Objective: Street connectivity. Perceived: Number of utilitarian destinations.	No	Socio-demographic: Age, gender, education attainment, work status, marital status, having children in the households, annual household income, car ownership and neighbourhood economic status.
Learnihan, Van Niel <sup>33</sup>	Cross- sectional. Perth.	Respondents selected based on plans to relocate into new developments. Random selection of household member. Baseline data. Response rate: 33.4%.	RESIDE	(n=1753) Adults (>18years). 38 years, 60% women.	<ol> <li>Doing any walking in the neighbourhood for transport or leisure (yes/no).</li> <li>Meeting 150 minutes per week walking general and transport.</li> <li>Tool: Neighbourhood PA Questionnaire.</li> </ol>	Objective: Walkability index composed of connectivity, residential land use and land use mix.	No	Socio-demographic: Age, gender, education and household income.
Leslie, Cerin <sup>34</sup>	Cross- sectional. Greater Geelong, Victoria.	12 local parks selected (six parks pairs). Participants randomly selected from a 500m buffer around the centroid of each selected park. Response rate: 19.7%.		(n=502) Adults. 47.7±11.4 years, 64% women.	Monthly visits to a specific park. Self-reported. Neighbourhood PA Questionnaire tool has been found to be reliable for assessing different types of walking (recreation, ICC: frequency =0.92, duration = 0.90; transport, ICC: frequency = 0.92, duration = 0.96) and total walking (ICC duration = 0.91) within local neighbourhood areas.	Perceived: Park maintenance/ attractiveness/ opportunities/ functionality/lighting/ aesthetics.		Socio-demographic: Age, children in household, gender, working status, self-reported health status, education attainment and dog ownership.

Author	Study design	Sample recruitment	Project	Sample characteristics	PA variable	Built environment variables (objective/ perceived)	Residential selection adjustment	Confounding variables
McCormack, Shiell³⁵	Cross-sectional, cohort of people in WA building homes in 74 new developments.	Respondents selected based on plans to relocate into new developments. Random selection of household member. Baseline data: 33.4% response rate. Two more waves of data collection undertaken: 12 and 36 months after relocation.	RESIDE	Neighbourhood selection sample (n=1681) Adults (≥18 years), 40.16±11.96 years, 58.7% women.	<ol> <li>Participation in walking versus no participation (binary outcome).</li> <li>In those who walked, walking minutes (non- randomly self-selected) for leisure, for transport and total walking. Self-reported duration of walking in a usual week.</li> <li>Tool: Neighbourhood PA Questionnaire. Acceptable reliability.</li> </ol>	Objective: Walkability index and sidewalk length. Perceived: Access to recreation/schools/ services, pedestrian/ cycle friendly streets and house affordability/ variety.	Yes, self- reported reasons for moving into a new neighbourhood as proxy of characteristics of importance in the built environment	Socio-demographic: Gender, age, education. Attitudes: Attitudes towards walking. Neighbourhood attitude. Other urban form variables: Walkability, sidewalks.
McKibbin <sup>36</sup>	Cross-sectional (not specified, but data sources are cross-sectional). Greater Sydney region.				Non-car mode share (public transport, cycling and walking). Not clear data source and method of measurement.	Objective. Density (population/jobs), diversity, design, destination accessibility (walking/by car) and distance to transit.	No	Socio-demographics: Income, car ownership and destination of work trips.
Owen, De Bourdeaudhuij <sup>37</sup>	Cross-sectional. Adelaide.	Resident of CCDs of the top and bottom walkability index (objective) randomly selected. Baseline data. Response rate: 11.5%.	PLACE	(n=2194) Adults 20-65 years, 5.5±11.8, 56% women, 51.2% income >\$41,600 annually.	Bicycle use at least once per week for more than 10 minutes. Self- reported. Questions from the International PA Questionnaire (long form).	Objective: Walkability index.	No	Socio-demographic: Age, gender, education, working status, and area level socio-economic status.

Author	Study design	Sample recruitment	Project	Sample characteristics	PA variable	Built environment variables (objective/ perceived)	Residential selection adjustment	Confounding variables
Pont, Wadley <sup>38</sup>	Cross- sectional. Logan, Queensland.	Three-stage sampling to select CCDs with high and low supportive environments for active transport to school. Two sites selected. A: highly supportive of active transport and B: poorly supportive of active transport. Response rate: A=8.44%, B:8.14%.		Site A: (n=80) Children 10.1 years (SD 9.89–10.31); 51.25% girls. Site B: (n=126) Children (8–12 years) parents responded survey. 10.35 years (SD 10.19–10.53). 52.38% girls.	Active travel to school at least once in the past week. Self-reported by children's parents. Test- retest reliability. Overall agreement was 95.39% (range 88.46–100%).	Objective: Roads with footpath. Perceived: Busy roads, roads with footpath, pedestrian crossing.	No	Socio-demographic: Child's grade at school and maternal education.
Prins, Ball <sup>39</sup>	Cross- sectional (follow-up). Melbourne.	Stratified random sampling to select schools. Families selected from schools. Response rate: 45% of the older cohort at baseline.	Children Living in Active Neighbourhoods	(n=415) 14.5 years (SD 0.6), 54.1% female.	Average minutes spent on MVPA > objectively measured via accelerometer.	Objective: Number of sport facilities and parks.	No	Socio-demographic: Gender, parental education and population density.
Shimura, Sugiyama <sup>40</sup>	Longitudinal. Adelaide.	Resident of CCDs of the top and bottom walkability index (objective) randomly selected. Baseline data and four years follow-up. Response rate baseline: 11.5%. Follow up: 41.4% of those who completed baseline.	PLACE	(n=504) Adults (20-65 years), 57 (median age), 54% women, 53.8% income >\$41,600 per year.	Changes in time spent walking (transport and recreation separately). Self-reported. International PA Questionnaire (long form).	Objective: Walkability index.	No	Socio-demographic: Age, gender, work status, household income and BMI. Other: Time spent in walking for transport and recreation at baseline.

Author	Study design	Sample recruitment	Project	Sample characteristics	PA variable	Built environment variables (objective/ perceived)	Residential selection adjustment	Confounding variables
Sugiyama, Cerin <sup>41</sup>	Cross-sectional. Adelaide.	Selection of neighbourhood to participate based on walkability index. Participants from each selected neighbourhood invited to participate.		(n=2650) Adults (18–66 years).	Minutes of walking for recreation. International PA Questionnaire Have good test retest reliability (ICC $\frac{1}{4}0.46-0.96$ ) and fair-to-moderate criterion validity (median $\rho$ =0.30) compared accelerometer measures.	Perceived: aesthetics. Self-reported.		Socio-demographic: Age, gender, marital status, educational attainment, work status, neighbourhood and SES. Urban form: perceived environmental characteristics (residential density score, land use mix, connectivity, infrastructure and safety, safety from traffic, safety from crime, few cul-de-sacs, no major barriers and proximity to parks).
Sugiyama, Giles-Corti <sup>42</sup>	Longitudinal, cohort of people in WA building homes in 74 new developments. Baseline data and after 12 months of relocation.	Respondents selected based on plans to relocate into new developments. Random selection of household member. Response rate: 33.4%.	RESIDE	(n=681) Adults 48.6±10.2, 60.9% women, 53.5% income >\$41,600.	(1) Initiated recreational walking from baseline to after 12 months. (2) Maintained recreational walking from between baseline and 12 months after. Tool: Question of walking frequency for more than 10 minutes in the previous seven days. Instrument not specified.	Objective: POS area/ size/number. Perceived: POS presence/quality/ proximity.	No	Socio-demographic: Gender, age, work status, marital status, walking for transport and TV viewing time. Others: The index of facing the sea (only for GIS measure).
Sugiyama, Leslie <sup>43</sup>	Cross-sectional. Adelaide.	Resident of CCDs of the top and bottom walkability index (objective) randomly selected. Response rate: 11.5%.	PLACE	(n=2194) Adults (20-65 years), 45.5±11.8, 56% women, 51.2% income >\$41,600 annually.	Number of days that participants used streets near home for moderate to vigorous PA for recreation or exercise in the last month. Variable dichotomised at the median. Self-reported number of days in the past month of MVPA.	Perceived: Neighbourhood attractiveness, street connectivity and presence of sidewalks.		Socio-demographic: Age, gender, educational attainment, work status and annual household income.

Author	Study design	Sample recruitment	Project	Sample characteristics	PA variable	Built environment variables (objective/ perceived)	Residential selection adjustment	Confounding variables
Trapp, Giles- Corti <sup>44</sup>	Cross-sectional. Perth.	Selection of schools based on walkability index and socio-economic status. Schools response rate: 69% (n=25 schools). Random selection of a grade from 5, 6 and 7. Children's response rate: 57%. Parents' response rate: 88.88%.	Travel Environment and Kids (TREK) study	(n=1480) Children (grades 5, 6 and 7, 9–11 years). (n=1314) Parents.	<ul> <li>&gt; one cycle trip to school per week. Self-reported in travel diary kept by children.</li> <li>Diary tool reliability. Kappa or ICC &gt;0.60.</li> </ul>	Objective: Ped shed (connectivity), road traffic volume, distance to school. Perceived: Busy roads, neighbourhood safety for cycling.	No	Socio-demographic: Child's grade and highest level of maternal education. Urban form: Other urban forms (objective and perceived).
Trapp, Giles- Corti⁴⁵	Cross-sectional. Perth.	Selection of schools based on walkability index and SES status. Schools response rate: 69% (n=25 schools). Random selection of a grade from 5, 6 and 7. Children's response rate: 57%. Parents' response rate: 88.88%	Travel Environment and Kids (TREK) study	(n=1480) Children (grades 5, 6 and 7, 9–11 years). (n=1314) Parents.	=> six walking trips to school. Self-reported in travel diary kept by children. Diary tool reliability. Kappa or ICC >0.60.	Objective: Ped shed (connectivity), road traffic volume, distance to school. Perceived: Busy roads, neighbourhood safety for cycling,	No	Socio-demographic: Child's grade and highest level of maternal education. Urban form: Other urban forms (objective and perceived).
Villanueva, Knuiman <sup>46</sup>	Cross- sectional. Perth metropolitan area, WA.	Stratified random sample.	Life Course Built Environment and Health	(n=2964) Adults.	Walking continuously for at least 10 minutes per week. Self-reported. Tool: WA Health and Wellbeing Surveillance System.	Objective: Walkability index.	No	Socio-demographic: Gender, age, education, socio- economic status.
Wilson, Giles-Corti <sup>47</sup>	Cross-sectional. Brisbane Local Government Area.	Participants randomly selected using a two stage cluster design (CCD and within CCD). CCDs stratified by socio-economic status. Response rate: 68.5%.	HABITAT	Baseline (n=10,286) Adults (40-65 years). 45-49 median years, 55.7% women, household income \$41,600-51,999 median.	Total minutes walked in the past week (thresholds: 30 minutes per week, $\geq$ 30–<90, $\geq$ 90-<150, $\geq$ 150-<300 and $\geq$ 300). Questionnaire: Active Australian survey. Tested for middle-aged women. Retest reliability (p=.58) and validity (p=.29; p<.001).	Objective: Connectivity, density (residential), hilliness, tree coverage, bikeways, streetlights, river to coast (distance), public transport (distance), shops (distance) and parks (distance).	No	Socio-demographic: Index of relative socioeconomic disadvantage, age, sex, household type, education level and household income.

#### Table 4. Decisions for inclusion of associations in Tables 3 and 4 main text

If associations were presented in terms of odds ratios and dose-response for the same outcome (e.g. walking in the neighbourhood), reported association refers to odds ratio.

If two dose-response associations were given: (1) minutes per week and (2) sessions per week, only (1) is reported.

If a study presents results of mediating effects on the built environment/PA association, here only direct results are presented, not mediating effects.

When outcomes are in terms of multiple PA thresholds (=>30 minutes, =>60 minutes, etc.), only the association for the minimum threshold is presented.

When two outcomes are presented for POS: (1) walking to POS and (2) walking within POS both are presented.

When two outcomes are given (1) initiated walking and (2) maintained walking, both outcomes are presented.

When independent variables are presented in multiple categories, here only association for the extreme categories are reported (e.g. lowest versus highest).

When z-scores are presented in categories (low, medium, high) and continuous, results presented here are for the continuous score.

When two outcomes are reported (1) walking to POS and (2) walking within POS, both are presented.

When different buffer zones within the neighbourhood were reported (200m, 400m,..., 1600m), all are presented. Similar to different conceptualisation of neighbourhood (1.6km buffer zone, 15 minutes walking area, CCD, etc.).

When multiple statistical models are presented, the authors selected the best design for the study purposes.

### Table 5. Associations between objective urban form and physical activityfor adolescents

Indicators	Geographical level	Number of	PA outcome			Significant associations	
		studies		Transport	Leisure	All domains	
Destination (r	ecreational space	es)					
Major road	Not disclosed.	1	Use of park		+24		1/1
barriers to			for PA in				
park.			summer.				
			Use of park		+24		1/1
			for PA in				
			winter				
Proximity to	Not disclosed.		Use of park		+24		1/1
park.			for PA in				
			summer				
					+24		1/1
						Total	4/4

<b>Table</b>	6.	Quality	score	urban	form-	physical	activity	studies
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	Cross-sectional	Longitudinal	Quasi-experiment	Experiment	N>1000	Participation rate >50%	Measurement of PA – not stated	Measurement of PA – validated questionnaire	Measurement of PA – objectively measured	Statistical control for covariates: socio-demographic characteristics	Statistical control for covariates: other urban forms	Level of statistical significance expressed as p-values p=<0.1, 0.05, 0.001	Exact p-values given	Confidence intervals given	Controls for self-selection	Total	Max attainable	Without elasticity criterion
Astell-Burt, Feng <sup>18</sup>	0				1			1		1				1		4	10.5	38%
Astell-Burt, Feng <sup>19</sup>	0				1			1		1				1		4	10.5	38%
Christian, Bull <sup>48</sup>	0				1			1		1	1			1		5	10.5	48%
Duncan, Winkler <sup>23</sup>	0				1			1		1				1		4	10.5	38%
Edwards, Giles-Corti <sup>24</sup>	0				1	1			1	1	1			1		6	10.5	57%
Foster, Knuiman <sup>25</sup>	0				1			1		1	1			1		5	10.5	48%
Giles-Corti, Bull <sup>49</sup>			2		1			1		1		0.5		1	0.5	6	10.5	57%
Giles-Corti, Wood <sup>27</sup>	0				1	1		1		1	1			1		6	10.5	57%
Knuiman, Christian <sup>29</sup>			2		1			1		1	1			1	0.5	7.5	10.5	71%
Koohsari, Kaczynski <sup>30</sup>	0							1		1	1			1	0.5	4.5	10.5	43%
Koohsari, Karakiewicz <sup>31</sup>	0							1		1	1		1		0.5	4.5	10.5	43%
Koohsari, Sugiyama <sup>32</sup>	0				1			1		1	1			1		5	10.5	48%
Learnihan, Van Niel <sup>33</sup>	0				1			1		1				1		4	10.5	38%
McCormack, Shiell <sup>35</sup>	0				1			1		1	1			1	0.5	5.5	10.5	52%
McKibbin <sup>36</sup>	0						0			1	1	0.5				2.5	10.5	24%
Owen, De Bourdeaudhu <sup>37</sup>	0				1			1		1				1		4	10.5	38%
Pont, Wadley <sup>38</sup>	0							1		1	1			1		4	10.5	38%
Prins, Ball <sup>39</sup>	0								2	1	1			1		5	10.5	48%
Snimura, Sugiyama <sup>40</sup>		1						1		1				1		4	10.5	38%
Sugiyama, Giles-Corti <sup>42</sup>		1			1			1		1				1		5	10.5	48%
Trapp, Giles-Corti <sup>44</sup>	0				1	1		1		1	1			1		6	10.5	57%
Trapp, Giles-Corti <sup>45</sup>	0				1	1		1		1	1			1		6	10.5	57%
Villanueva, Knuiman <sup>46</sup>	0				1			1		1				1		4	10.5	38%
Wilson, Giles-Corti <sup>50</sup>	0				1	1		1		1				1		5	10.5	48%

Table 7. Annual average economic benefits of changes in diversity per100,000 adults living in an area, assuming effects apply to ages 20–64years only (95% uncertainty interval)

Indicator/ Study	Outcome	Changes in indicator	Healthcare costs savings	Healthcare cost expenditure of increased life years	Monetised DALYs	Production savings (human capital)	Production savings (friction costs)
Diversity (LUM1) Christian et al. (2011) (RESIDE) Diversity (LUM2) Duncan el at. (2010) (PLACE)	All walking >0 minutes per week. Minutes walked per day for transport purposes.	Increase in 0.15 units in the LUM entropy measure (mean 0.26). Increase in one decile in LUM. Median LUM=0.09.	\$22,156 (\$5996 - \$40,773) \$38,056 (\$12,826 - \$65,770)	-\$20,412 (-\$35,782 - -\$5140) -\$35,164 (-\$57,772 - -\$13,488)	\$730,147 (\$183,572 - \$1,274,088) \$1,257,730 (\$485,933 - \$2,061,567)	\$16,917 (\$4,267 - \$29,608) \$29,141 (\$11,107 - \$47,869)	\$587 (\$148 - \$1027) \$1012 (\$384 - \$1,665)
Diversity (LUM3) Knuiman et al. (2014) (RESIDE)	Walking for transport (yes/ no) per week within the neighbourhood.	Increase in 0.15 units in the LUM entropy measure (mean 0.26).	\$4732 (\$2,247 – \$7,615)	-\$4356 (-\$6546 – -\$2277)	\$155,832 (\$80,942 – \$233,258)	\$3610 (\$1888 – \$5,433)	\$125 (\$65 – \$189)

1. LUM includes residential, retail, office, health, welfare and community, entertainment, culture and recreation. The size of the area this applies to is not reported. 2. Includes: commercial, residential and industrial/institutional). Residential includes non-private facilities such as hotels as well as private dwellings. CCDs are the spatial unit assessed. 3. Applies same LUM measure as Christian et al. (2011) weighted centroid of each CCD.

Table 8. Annual average economic benefits of changes in destinationsper 100,000 adults living in an area, assuming effects apply toages 20–64 only (95% uncertainty interval)

Indicator/ Study	Outcome	Changes in indicator	Healthcare costs savings	Healthcare cost expenditure of increased life years	Monetised DALYs	Production savings (human capital)	Production savings (friction costs)
(transport related) <sup>1</sup> Giles-Corti et al. (2013) (RESIDE)	iotal walking (change) within the neighbourhood.	extra transport destination.	\$41,455 (\$31,240 – \$51,733)	-\$38,188 (-\$40,349 – -\$35,981)	\$1,366,021 (\$1,293,951 - \$1,438,749)	\$31,651 (\$29,871 – \$33,353)	\$1039 (\$1037 – \$1156)
Destinations (distance to retail) <sup>2</sup> Wilson et al. (2011) (HABITAT)	All walking =>30 minutes per week -<90 compared to walking <30minutes per week.	Comparison between furthest to closest distances to retail $(\leq 0.2 \text{km to})$	\$23,247 (\$4945 – \$44,577)	-\$21,382 (-\$37,570 – -\$4749)	\$764,866 (\$168,145 – \$1,341,346)	\$17,724 (\$3959 – \$31,202)	\$615 (\$137 – \$1082)
Destinations (recreational related) <sup>3</sup> Giles-Corti et al. (2013) (RESIDE)	Total walking (change).	Per one recreation related destination that changed favourably.	\$125,794 (\$94,798 – \$156,984)	-\$115,881 (-\$122,438 - -\$109,184)	\$4,145,196 (\$3,926,515 - \$4,365,890)	\$96,043 (\$90,644 – \$101,209)	\$3335 (\$3146 – \$3509)
Destinations (distance to parks) <sup>4</sup> Wilson et al. (2011) (HABITAT)	All walking =>30 minutes per week -<90 compared to walking <30minutes per week.	Comparison between furthest to closest distances to retail (>0.2km – >1km).	\$3862 (-\$8888 – \$17,813)	-\$3561 (-\$15,692 – \$8429)	\$127,326 (-\$300,083 – \$566,639)	\$2955 (-\$7029 – \$13,086)	\$103 (-\$243 – \$454)
Destinations⁵ Knuiman et al. (2014) (RESIDE)	Walking for transport (yes/ no) per week within the neighbourhood.	Destinations (ref:= < 3) 4 - 7. Destinations (ref:= < 3) 5 - 15.	\$1210 (-\$3,867 - \$6,531) \$5426 (-\$985 - \$12,690)	-\$1109 (-\$5866 - \$3591) -\$4995 (-\$10,968 - \$945)	\$39,696 (-\$128,639 – \$209,305) \$178,681 (-\$33,785 – \$393,032)	\$919 (-\$2983 - \$4891) \$4139 (-\$786 - \$9133)	\$32 (-\$104 - \$169) \$144 (-\$27 - \$317)

 Post office, bus stops, delicatessens, supermarkets within 800m of each participant's home and train stations, shopping centres or CD and DVD stores within 1.6km.
 Street network distance in kilometres from each participant's home to the nearest retail-zoned land.
 Beaches within 800m of each participant's home, and parks and sports fields within 1.6km.
 Street network distance in kilometres from each participant's home to the nearest park zoned land.
 Services, convenience stores and public open spaces accessible along the street network within 1.6km from each participant's home. Table 9. Annual average economic benefits of changes in distance to transit per 100,000 adults living in an area, assuming effects apply to ages 20–64 years only (95% uncertainty interval)

Indicator	Outcome	Changes in indicator	Healthcare costs savings	Health care cost expenditure of increased life years	Monetised DALYs	Production savings (human capital)	Production savings (friction costs)
Distance to transit (bus	Walking for transport (yes/	Bus stops 15-19 (ref:	\$11,769	-\$10,832	\$387,473	\$8976 (\$4526	\$312
stops)	no) per week	0-14).	(\$3376 – \$19,464)	(-\$10,403 – -\$5420)	(\$194,534 - \$589,661)	(\$4330 - \$13,706)	(\$137 - \$477)
Knuiman et al. (2014)	neighbourhood.	Bus stops	\$14,745	-\$13,583	\$485,884	\$11,257	\$391
(RESIDE)		(ref: 0-14).	(\$7210 – \$23,025)	(-\$19,931 — -\$7107)	(\$254,185 – \$713,570)	(\$5926 – \$16,583)	(\$206 – \$577)
Distance to transit (train station) <sup>1</sup> Knuiman et al. (2014) (RESIDE)	Walking for transport (yes/ no) per week within the neighbourhood.	No presence train station to presence train station.	\$9759 (\$7501 – \$12,390)	-\$9072 (-\$9592 – -\$8560)	\$324,578 (\$306,844 – \$341,401)	\$7522 (\$7112 – \$7943)	\$261 (\$240 – \$275)
Access	All walking	Comparison	\$12,441	-\$11,435	\$409,048	\$9476	\$329
to public transport <sup>2</sup> Wilson et al. (2011) (HABITAT)	=>30 minutes per week <90 compared to walking <30minutes per week.	between furthest to closest distance to transit (>0.2km – >1km).	(-\$1892 – \$28,028)	(-\$23,709 – \$1707)	(-\$60,774 – \$843,210)	(-\$1412 – \$19,647)	(-\$49 – \$682)

1. Train station accessible along the street network within 1.6 km from participants home. 2. Street network distance (in kilometres) from each participant's home to the nearest Brisbane City Council bus stop or railway station.

# Table 10. Annual average economic benefits of changes in measures of walkability per 100,000 adults living in an area, assuming effects apply to ages 20–64 only (95% uncertainty interval)

Indicator	Outcome	Changes in indicator	Healthcare costs savings	Healthcare cost expenditure of increased life years	Monetised DALYs	Production savings (human capital)	Production savings (friction costs)
Walkability index Christian et al. (2011) (RESIDE)	Transport walking >0 minutes per week.	Per one standard deviation change in walkability index.	\$9104 (\$1582 – \$17,986)	-\$8385 (-\$15,237 – -\$1470)	\$299,955 (\$52,768 – \$178,209)	\$6951 (\$1230 – \$12,667)	\$241 (\$43 – \$439)
Walkability index Learnihan et al. (2011) (RESIDE)	Transport walking	Highly walkable compared to low (suburb scale).	\$22,040 (\$8786 – \$38,487)	-\$20,359 (-\$33,041 -\$8089)	\$728,305 (\$289,272 – \$357,724)	\$16,878 (\$6667 – \$27,450)	\$586 (\$232 – \$950)

Walkability index Learnihan et al. (2011) (RESIDE)	Transport walking	Highly walkable compared to low (CCD scale).	\$33,013 (\$19,253 – \$50,415)	-\$30,454 (-\$42,448 – -\$19,368)	\$1,089,416 (\$693,497 – \$474,080)	\$25,250 (\$16,123 – \$35,280)	\$877 (\$560 – \$1223)
Walkability index Learnihan et al. (2011) (RESIDE)	Transport walking	Highly walkable compared to low (15-minute scale).	\$46,474 (\$30,769 – \$66,402)	-\$42,862 (-\$54,564 – \$31,714)	\$1,533,390 (\$1,129,236 - \$616,268)	\$35,536 (\$26,335 – \$45,255)	\$1234 (\$913 – \$1569)
Walkability index McCormack et al. (2012) (RESIDE)	Transport walking	Per one standard deviation change in walkability index.	\$327 (-\$1007 – \$1849)	-\$306 (-\$1608 – \$893)	\$10,954 (-\$31,970 – \$17,795)	\$254 (-\$741 – \$1339)	\$9 (-\$26 – \$47)
Walkability index Villanueva et al. (2014) (Life Course Built Environment and Health)	All walking	Per one unit increase in walkability index (200 m buffer).	\$1023 (\$596 – \$1486)	-\$944 (-\$1260 - \$599)	\$33,769 (\$21,521 – \$14,470)	\$783 (\$497 – \$1045)	\$27 (\$17 – \$36)
Walkability index Villanueva et al. (2014) (Life Course Built Environment and Health)	All walking	Per one unit increase in walkability index (400 m buffer).	\$782 (\$363 - \$1252)	-\$720 (-\$1072 \$372)	\$25,763 (\$13,379 – \$12,072)	\$597 (\$304 – \$881)	\$21 (\$11 - \$31)
Walkability index Villanueva et al. (2014) (Life Course Built Environment and Health)	All walking	Per one unit increase in walkability index (800 m buffer).	\$531 (\$195 – \$914)	-\$490 (-\$788 – -\$182)	\$17,515 (\$6462 – \$8565)	\$406 (\$153 – \$652)	\$14 (\$5 – \$23)
Walkability index Villanueva et al. (2014) (Life Course Built Environment and Health)	All walking	Per one unit increase in walkability index (1600 m buffer).	\$791 (\$479 – \$1139)	-\$730 (-\$954 – -\$496)	\$26,112 (\$17,732 - \$10,608)	\$605 (\$415 – \$790)	\$21 (\$14 - \$27)
Walkability index Owen et al. (2010)	Cycling	Highly walkable compared to low.	\$6377 (\$1615 – \$11,975)	-\$5869 (-\$10,209 — -\$1678)	\$209,945 (\$60,252 – \$110,386)	\$4866 (\$1415 – \$8514)	\$169 (\$49 –\$296)

Table 11. Annual average economic benefits of changes in density per 100,000 adults living in an area, assuming effects apply to ages 20–64 only (95% uncertainty interval)

Indicator/ Study	Outcome	Changes in indicator	Healthcare costs savings	Healthcare cost expenditure of increased life years	Monetised DALYs	Production savings (human capital)	Production savings (friction costs)
Density (residential) Christian et al. (2011) (RESIDE)	Transport walking >0 minutes per week within the neighbourhood.	Increase in 8 dwellings per ha (mean=15)	\$1,732 (-\$3435 – \$6851)	-\$1592 (-\$6340 – \$3037)	\$56,952 (-\$108,343 - \$225,771)	\$1320 (-\$2517 – \$5228)	\$46 (-\$87 – \$182)
Density (residential) Knuiman et al. (2014) (RESIDE)	Walking for transport (yes/ no) per week within the neighbourhood.	Increase in 8 dwellings per ha (mean=15)	-\$634 (-\$3402 – \$2347)	\$581 (-\$2037 — \$3079)	-\$20,793 (-\$110,185 – \$72,697)	-\$482 (-\$2577 – \$1680)	-\$17 (-\$89 – \$59)
Density (residential) Wilson et al (2011) (HABITAT)	All walking =>30 - <90 minutes per week, compared to walking <30 minutes per week.	Decrease from 9205 m2 (highest quintile) to 650 m2 (lowest quintile) average size of residential zoned land within a 1 km radius of residence.	\$12,462 (\$2501 - \$23,754)	-\$11,487 (-\$20,970 – -\$2133)	\$410,842 (\$75,750 - \$749,275)	\$9522 (\$1769 – \$17,388)	\$331 (\$62 – \$603)

Table 12. Annual average economic benefits of changes in measures of design per 100,000 adults living in an area, assuming effects apply to ages 20–64 years only (95% uncertainty interval)

Indicator/Study	Outcome	Changes in indicator	Healthcare costs savings	Healthcare cost expenditure of increased life years	Monetised DALYs	Production savings (human capital)	Production savings (friction costs)
Design (Connectivity) <sup>1</sup> Christian et al. (2011) (RESIDE)	All walking >0 minutes per week.	Increase of 18 (mean 62).	\$6067 (\$1393– \$11,654)	-\$5580 (-\$9884 – -\$1342)	\$199,597 (\$48,358 – \$353,025)	\$4624 (\$1119 – \$8242)	\$161 (\$39 – \$285)
Design (Connectivity) <sup>2</sup> Koohsari et al. (2014) (PLACE)	Days of walking for transport in the last week.	Increase of 10 (mean 245).	\$19,466 (\$9815 – \$29,942)	-\$17,929 (-\$25,878 – -\$9546)	\$641,353 (\$341,843 – \$929,648)	\$14,857 (\$7941 – \$21,588)	\$516 (\$276 – \$747)
Design (Connectivity) <sup>1</sup> Knuiman et al. (2014) (RESIDE)	Walking for transport (yes/ no) per week within the neighbourhood.	Increase of 18 (mean 62).	\$3580 (\$1733 – \$5903)	-\$3296 (-\$5022 – -\$1627)	\$117,906 (\$58,786 – \$179,512)	\$2732 (\$1351 - \$4164)	\$95 (\$47 – \$144)
Design (Connectivity <sup>)3</sup> Wilson et al (2011) (HABITAT)	All walking =>30 - <90 minutes per week, compared to walking <30 minutes per week.	Increase from 4 (mean lowest quintile) to 51 (mean highest quintile).	\$15,023 (\$3,980 – \$26,942)	-\$13,869 (-\$24,350 – -\$3,642)	\$496,143 (\$129,050 – \$868,239)	\$11,495 (\$3,005 – \$20,209)	\$399 (\$105 – \$702)
Design (Sidewalk length <sup>35</sup> ) McComack et al (2012) (RESIDE)	Walking for all purposes.	10 km increase in sidewalk.	\$154 (-\$307 – \$620)	-\$141 (-\$553 – \$292)	\$5,028 (-\$10,445 – \$19,731)	\$117 (-\$243 – \$470)	\$4 (-\$8 – \$16)
Design (off-road bikeways) <sup>5</sup> Wilson et al (2011) (HABITAT)	All walking =>30 - <90 minutes per week, compared to walking <30 minutes per week.	Increase from 0 km (lowest quintile) to 7 km (highest quintile).	\$11,917 (\$1,962 – \$22,865)	-\$10,985 (-\$20,115 – -\$1,753)	\$392,998 (\$62,382 – \$717,686)	\$9,104 (\$1,458 – \$16,630)	\$316 (\$51 – \$578)
Design (Green spaces) <sup>6</sup> Astell-Burt & Feng (2014)	Walking for at least 10 minutes per week.	20% increase in green space <sup>.7</sup>	\$474 (\$309 – \$645)	-\$436 (-\$542 – -\$328)	\$15,602 (\$11,670 – \$19,398)	\$361 (\$273 – \$446)	\$13 (\$9 – \$16)
Design (Green spaces) <sup>6</sup> Astell-Burt & Feng (2014)	MVPA for at least 10 minutes per week.	20% increase in green space <sup>7</sup>	\$651 (\$448 – \$875)	-\$599 (-\$722 – -\$482)	\$21,434 (\$17,393 – \$25,876)	\$497 (\$400 – \$600)	\$17 (\$14 - \$21)

1. The measure is a ratio of the count of three (or more) way intersections over the area (km<sup>2</sup>). 2. Number of threeway or more intersections to the land area of a CCD. 3. Four-way or more intersections within a 1km radius of each participant's residence. 4. Sidewalk availability within a 1.6km service area within the road network buffer of the respondents' residential location. 5. Total metres of off-road bikeways within a 1km radius around each participant's residence. 6. Area of green space within a 1km radius around the population weighted centroid of each CCD. 7. From 0–20% to 21–40%. Table 13. Average economic benefits of changes in safety per 100,000adults living in an area, assuming effects apply to ages 20–64 only (95%uncertainty interval)

Indicator	Outcome	Changes in indicator	Healthcare costs savings	Healthcare cost expenditure of increased life years	Monetised DALYs	Production savings (human capital)	Production savings (friction costs)
Total crime <sup>1</sup> Astell-Burt & Feng (2015)	Participation in MVPA.	High crime compared to zero.	\$948 (\$302 – \$1691)	-\$875 (-\$1472 – -\$280)	\$31,297 (\$10,070 - \$52,714)	\$725 (\$231 – \$1227)	\$25 (\$8 – \$43)
Total crime <sup>2</sup> Astell-Burt & Feng (2015)	Participation in MVPA.	High crime compared to low.	\$269 (\$87 – \$491)	-\$248 (-\$417 – -\$82)	\$8868 (\$2936 - \$14,924)	\$205 (\$68 – \$348)	\$7 (\$2 - \$12)

1. Sum of non-domestic violent assaults, break and enter, malicious damage to a property and stealing, theft and robbery at the CCD level. 2. Same as one but at the Statistical Local Area level.

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