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Examining associations between urban design attributes and transport mode choice for walking, cycling, public transport and private motor vehicle trips

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ABSTRACT

Objective: Many research papers examine the relationship of the built environment on transport behaviour using only one mode of transport. Yet to inform policy makers, a broader examination of transport mode choice across different transport modes is required. Here, associations between urban design attributes and transport mode choices including transport walking, transport cycling, public transport and private motor vehicle use were explored.

Methods: Secondary analysis was conducted on 16,890 participants aged 18 years or older who participated in the Victorian Integrated Survey of Travel Activity 2009–2010 (VISTA09) in metropolitan Melbourne, Australia. Adjusted multilevel logistic regression models were used to explore the relationship between urban design attributes and transport-walking, cycling, public transport and private motor vehicle use.

Results: Taking transport-walking, cycling or public transport trips was positively associated with the housing diversity score and gross dwelling density. Taking private motor vehicle trips was negatively associated with street connectivity, land use mix, local living score, housing diversity score, gross dwelling density and proximity to supermarkets.

Conclusion: The study found that environments that neighbourhoods with gross residential densities exceeding 20 dwellings per hectare, a well-connected street network, access to 9 or more local living destinations and short distances to public transport services (i.e., ≤ 400 m for bus and ≤ 800 m for train) encourage walking, cycling and public transport use, while discouraging driving. Comprehensive integrated urban planning of transport infrastructure, land use development and service provision is required to create neighbourhoods that support active and sustainable living that allow for a flexible mix of land uses and transport options.

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1. Introduction

1.1. Background

Many cities around the world are growing at an accelerating pace: in 2014, the urban population accounted for 54% of the world population, by 2050, this number is predicted to rise to 66% (United Nations et al., 2015). Urbanisation represents a major challenge as it places increasing demands on infrastructure, services, and the environment (World Health Organization, 2010). Unplanned and poorly managed urban growth can give rise to a range of social and environmental issues including impacts on public health, social inequity, road trauma and traffic congestion and environmental pollution (World Health Organization, 2010).

Urban and transport planning affords significant opportunities to enable cities to act as powerful and inclusive development tools (Floater et al., 2014) that can mitigate these growing urban problems (Giles-Corti et al., 2016) and meet the challenge of achieving the United Nations' Sustainable Development Goals (Sachs, 2012). The United Nations has identified cities as key settings for developing sustainable practices (Development Goal 11) and for promoting health and well-being (Development Goal 3) (Sachs, 2012). Indeed, a growing body of research finds that built environments promoting active forms of transport, such as walking or cycling and public transport use, are associated with a range of short-term and long-term benefits including: increased capacity and reduced congestion in the general transport network; reduced environmental impacts (i.e., lower greenhouse gas emissions; improved public health; and community wellbeing and social cohesion (Koohsari et al., 2013). Frequent and comprehensive public transport services including trains, tramways, buses or ferries play a significant role in reducing traffic congestion, improving access to services such as education, health and employment and helping cities achieve significant energy savings and reduce greenhouse gas emissions (Woodcock et al., 2009). For those living in cities, a number of studies suggest that public transport users get more daily physical activity due to walking or cycling trips to and from transit stops (Rissel et al., 2012; Villanueva et al., 2008).

Conversely, high reliance on motor vehicles for transport has many negative outcomes including increased traffic congestion, sedentary behaviour, health impacts and social isolation (Frank et al., 2007; Handy, 2014). It is now apparent that the use of private vehicles endangers the environment and leads to many urban stressors including noise and air pollution, as well as accident and traffic congestion(Stevenson et al., 2016). For these reasons, across cities globally efforts are spreading to reduce car dependency and create liveable neighbourhoods where walking, cycling and public transport services are the primary transport choices (Watts et al., 2015).

The context for this study is Melbourne the second largest city in Australia. Melbourne was founded on the Yarra River in 1835 and the first suburbs developed between 1880 and 1920 (Lewis, 1995). Their original design of detached houses built along public transport corridors and near walkable retail high streets is still visible today in the inner suburbs. The surrounding suburbs developed rapidly after the introduction of the car in the 1950s (Fuller and Crawford, 2011). These middle and outer suburbs are less dense than the inner suburbs, they are served by freeways and typically include large enclosed shopping malls surrounded by car parks (Fuller and Crawford, 2011). Today, Melbourne is known as a sprawling city with suburbs extending up to 50 km from the centre of the city. Melbourne retains a large concentration of high density employment activity in and around its Central Business District (CBD)(Horan et al., 2014). Like many global cities, Melbourne is rapidly growing with the population predicted to double to approximately 8 million by 2050 (State Government Victoria, 2014) and consequently faces numerous planning challenges including: transport congestion; employment, public transport and services accessibility; housing affordability; and environmental sustainability. To meet these challenges and achieve a healthy and more sustainable future, the Victorian Planning Authority[2] developed Plan Melbourne, a planning strategy to guide the city's growth to 2050 (Department of Transport, Metropolitan Planning Authority, 2014). Plan Melbourne aspires to create a '20 minute city'. The 20 minute city concept broadly views access to everyday needs (i.e., social, recreation or retail services) within a 20 minute time limit by walking, cycling or public transport (Stanley and Stanley, 2014). Plan Melbourne refers to a 20 minute walk area catchment (Metropolitan Planning Authority, 2015) between 1 and 1.5 square kilometres in size. This aspiration (i.e., allowing people to live close to the local services they need) is consistent with the UN's Sustainable Development Goal 11 (Sachs, 2012) which relates to creating more inclusive, resilient and sustainable cities. However, shifting from a car-oriented city to a sustainable city is a major challenge as it requires the built environment to be supportive of walking, cycling and public transport in facilitating the delivery of the '20 minute city'. Furthermore, it requires that cities be flexible in adapting to population growth, which is a pre-requisite for attracting businesses and services to town centres and ultimately becoming destinations that people walk to (Cerin et al., 2007; State Government Victoria, 2014).

For this aspiration to be successfully achieved, research evidence is required to identify the characteristics of the built environment that influence individual travel behaviour including walking, cycling, public transport and private motor vehicle use when undertaking everyday activities.

1.2. Aim and objective

The aim of this study was to investigate which urban design attributes in residential neighbourhoods are associated with different transport mode choices (e.g., transport walking, transport cycling, public transport use and private motor vehicle use) in metropolitan Melbourne, Australia in order to help policy-makers and urban planners design interventions that deliver more healthy and

[2] A State Government statutory authority responsible for coordinating land use and infrastructure planning across local councils, government agencies and the planning and development industry.

sustainable cities.

2. Methods

2.1. Individual-level data

Individual level data from the Victorian Integrated Survey of Travel Activity 2009–2010 (VISTA09) were used. VISTA09 was developed by the Victorian Department of Transport, Planning and Local Infrastructure (formerly Victorian Department of Transport) (The Urban Transport Institute, 2011), it is an on-going self-report one-day survey of travel and activity, conducted across Greater Melbourne and selected regional centres of Victoria, Australia. Residents of the CBD and adjacent areas were excluded from the VISTA09 survey[3] (The Urban Transport Institute, 2011). VISTA09 sampling methods used a multi-stage, variable-proportion, clustered sampling of household addresses within Census Collection Districts (CCDs, a geographical unit comprising about 250 households). Thus, individuals were selected from households that were nested within CCDs. The final response rate was 47% (The Urban Transport Institute, 2011).

VISTA09 captured all trips made by individuals (n = 42,002) on a survey day, including trips, mode of travel, distance travelled, and trip origins and destinations. It also recorded socio-demographic information about participants and their household.

Eligibility for inclusion in the study were participants aged > 18 years, residing in urban metropolitan Melbourne who had engaged in any transport activities in their residential neighbourhood on the day they completed the survey (n = 16,890).

Participants who did not undertake any travel (irrespective of travel mode) during the survey period were excluded (n = 4,659) since it is likely that their reasons for not traveling on the survey day were unrelated to the built environment (e.g., illness, injury). Participants who did not travel on their survey day within their residential neighbourhood were also excluded (n = 115). This was because the study focused on transport activity undertaken in the residential neighbourhood.

Ethics approval for the study was provided by the University of Melbourne (approval Number 1340998.4).

2.2. Spatial analysis

VISTA09 combined information about households, individuals and their travel activities including their residential addresses and the corresponding geographic coordinates. The trip distance provided with the VISTA09 dataset was based on the distance between an origin and destination. To preserve the confidentiality of the study participants, the home coordinates supplied by the data custodians with the VISTA09 dataset and used in all subsequent analyses were randomised by adding a random (positive or negative) amount to the longitude and latitude of the household, up to a maximum value of +/− 0.0005. Most household locations were shifted between 20 and 60 m (in a random direction), with a maximum shift of about 70 metres.

Residential neighbourhoods were defined as a 1600 m street sausage network buffer around participants' homes (Badland et al., 2016; Forsyth et al., 2012). The choice of 1600 m buffer was based on early public health guidance of the amount of moderate intensity walking required to benefit health and the speed at which moderate intensity walking was achieved (United States. Department of Health, Human Services, 1996); and previous research that found associations between urban design attributes and walking behaviours at that distance (Badland et al., 2016; United States. Department of Health, Human Services, 1996; Villanueva et al., 2014). Prior to creating buffers, all roads that could not be accessed by pedestrians (e.g. highways and on and off-ramps) were removed. All the spatial analysis were performed using ArcGIS version 10.3 (ESRI, 2011). The ArcGIS Network Analyst extension was used to generate the 1600 m street sausage network buffers around each of the geocoded residential address points.

2.3. Dependent variables

Four dependent variables were defined using VISTA09 transport data including: number of trips in the neighbourhood by: transport-walking, cycling; public transport[4]; and private motor vehicle.

VISTA09 categorises trips based on the destination and purpose. To exclude recreational trips, the origin, destination and trip purpose was examined. Trips that started and ended in "parks", "forests" or "lakes" were coded as recreational and excluded. However, trips that ended at recreational destinations were retained as a transport-walking trip. For each participant, a step-by-step approach was used to count the trips starting or ending within their residential neighbourhood. This approach was designed to reduce measurement error by ensuring specificity when examining the relationships between travel behaviours and the urban design attributes of residential neighbourhoods (Giles-Corti et al., 2005). First the residential addresses and the trip start and end points were imported into the GIS. Next a pedestrian network dataset was generated with the ArcGIS Network Analyst extension on a road network dataset where all freeways and intersections inaccessible to pedestrians were removed. The walkable road network distance from every residential address to every trip segment start and end points was calculated using the Origin-Destination function (also available in the ArcGIS Network Analyst extension). Custom R scripts were used on the Origin-Destination outputs to count by participant and by modes the number of trip segments that started and/or ended within 1600 m of the residential address.

[3] A separate Pilot Study was planned by the Victorian Department of Transport, Planning and Local Infrastructure to determine the best way of obtaining responses from residents of high-rise apartment towers living in the Central Melbourne area.

[4] Public transports included train, tram and bus.

Table 1
Urban design attributes.

Measure	Description	Data	GIS techniques	Policy requirement
Land use mix	The land use mix (LUM) measure was calculated using the following entropy formula, which is adapted from Frank et al. (Frank et al., 2005) and is the same as the one used by Christian and colleagues (Christian et al., 2011) where *pi* is the proportion of the area covered by land use *i* and *n* is number of land use classes of interest. Five land use categories: residential, retail, commercial, industrial and "other" were used in the calculation. $LUM = -1(\sum_{i=1}^{n} pi* \ln(pi))/\ln(n)$	A customised land use layer was created where parcel boundaries (Department of Sustainability and Environment, State Government of Victoria, 2012b), zoning data (Department of Sustainability and Environment, State Government of Victoria, 2012a), and geocoded business point data (Pitney Bowes Ltd, 2014) were combined. The parcel boundaries data and zoning data were readily available nationally while the business points were available on a fee-for-service basis.	The methodology for developing the LUM layer was adapted from Leslie and colleagues (Leslie et al., 2005). The *intersect* command was used to calculate the area of each land use type within each 1600 m buffer.	Town centres have a variety of land uses and a range of business sizes that have main street frontage. This includes a mix of retail, office (including home-office and other administration uses), housing, recreation and entertainment, community services and civic uses (Growth Areas Authority, 2009).
Intersection density	The intersection density measure was calculated using the following formula $\frac{Count\ of\ 3\ or\ more\ ways\ intersections}{Buffer\ area\ (in sq.km)}$	Intersection data were derived from the VicMap Transport road centrelines (Department of Sustainability and Environment, State Government of Victoria, 2012c).	The *join* command was used to count the number of intersection points in each buffer.	Arterial roads spaced at approximately 1600 m intervals and connector streets spaced at approximately 800 m intervals, having regard for existing and proposed land uses, public transport and property access requirements (Growth Areas Authority, 2009). Note that intersection density measure was used as a proxy for street spacing.
Dwellings density	The dwellings density measure was calculated using the following formula (gross dwelling density) $\frac{Sum\ of\ all\ dwellings}{Buffer\ area\ (in sq.km)}$	Dwelling count data were sourced from the meshblock-level census data (Australian Bureau of Statistics, 2011).	The *join* command was used to sum the number of dwellings in each buffer.	Housing should achieve an average density of at least 15 dwellings per net residential hectare, which will be achieved by providing a range of lot sizes (Growth Areas Authority, 2009).
Housing diversity score	The housing diversity score was calculated as a score based on as the sum of the presence/absence of each of the following eight housing types in a buffer. 1. Standalone house 2. 1 storey terrace 3. 2 or more storey terrace 4. 0–2 storey flat/unit/apartment 5. 3 storey flat/unit/apartment 6. 4 or more storey flat/unit/apartment 7. Flat attached to a house 8. Other	Dwelling typology data were sourced from the meshblock-level census data (Australian Bureau of Statistics, 2011).	The *intersect* command was used to sum the number of each dwelling type in each buffer.	A range of densities that enable a mix of housing types and sizes are provided across the precinct.
Local living score	The local living score was calculated as a score based on the sum of the presence/absence of each of the following 12 destination categories in a buffer (Badland et al., 2016). 1. Convenience destination (i.e. convenience store, newsagent, or petrol station) 2. Supermarket 3. Public transport stop (i.e. bus, tram, or train) 4. Speciality food destination (i.e. fruit and vegetable, meat, fish, or poultry store) 5. Post office 6. Bank 7. Pharmacy	Destinations data were sourced from geocoded business point data (Pitney Bowes Ltd, 2014).	The *join* command was used to retrieve the destination points within the boundaries of each buffer. Summary statistics were used to compute the number of destinations in each buffer.	Areas with a variety of land uses and a range of business sizes that have main street frontage. This includes a mix of retail, office (including home-office and other administration uses), housing, recreation and entertainment, community services and civic uses (Growth Areas Authority, 2009).

(continued on next page)

Table 1 *(continued)*

Measure	Description	Data	GIS techniques	Policy requirement
	8. General practice/medical centre 9. Dentist 10. Community centre or hall 11. Child care facility 12. Library			
Closest supermarket	The closest supermarket measure was calculated as the distance to the closest supermarket along the road network.	Supermarket data were sourced from geocoded business points data (Pitney Bowes Ltd, 2014). Street network data were derived from the VicMap Transport road centrelines (Department of Sustainability and Environment, State Government of Victoria, 2012c).	The *origin-destination cost matrix* command (ArcGIS Network Analyst) was used.	80–90% of households should be within 1,000 m of a town centre of sufficient size to allow for provision of a supermarket (Growth Areas Authority, 2009).
Closest train station	The closest train station measure was calculated as the distance to the closest train station along the road network.	Train station data were sourced from Public Transport Victoria. Street network data were derived from the VicMap Transport road centrelines (Department of Sustainability and Environment, State Government of Victoria, 2012c).	The *origin-destination cost matrix* command (ArcGIS Network Analyst) was used.	95% of dwellings are located within 400 m street walking distance from the nearest existing or proposed bus stop (Growth Areas Authority, 2009).
Closest bus stop	The closest bus stop measure was calculated as the distance to the closest bus stop along the road network.	Bus stops data were sourced from Public Transport Victoria. Street network data were derived from the VicMap Transport road centrelines (Department of Sustainability and Environment, State Government of Victoria, 2012c).	The *origin-destination cost matrix* command (ArcGIS Network Analyst) was used.	

Count measures for each mode (transport-walking; cycling; public transport; and, private motor vehicle) were found to be highly right skewed with a high proportion of zero counts. For this reason the four dependent variables were dichotomised into binary measures (at least one trip versus no trips in the residential neighbourhood) (Streiner, 2002).

2.4. Independent variables

2.4.1. Urban design attributes

Urban design attributes including intersection density, distance to closest supermarket, and gross dwelling density among others were calculated in each residential neighbourhood using GIS techniques (see Table 1).

To maximise the policy-relevance of the study (Allender et al., 2009; Durand et al., 2011), the built environment measures were aligned with the Victorian planning policies including the Victorian State Planning Policy Framework (Department of Environment Land Water and Planning, 2016) Plan Melbourne (State Government Victoria, 2014) and the Precinct Planning Guidelines (Growth Areas Authority, 2009) as presented in Table 1.

2.4.2. Cofounders

Confounders likely to affect transport mode choices were identified from the literature including: age, sex, working (yes, no), household type (no children in household, children in household, other household structure), motor vehicle ownership (at least one motor vehicle, no motor vehicle in household) and survey day (weekday, weekend).

2.4.3. Statistical analysis

Prior to statistical modelling, Chi-square tests were used to compare differences in the demographic characteristics and urban design attributes with respect to mode choice. Next, the association between urban design attributes and transport mode choices were assessed using unadjusted univariate logistic regression models. Urban design attributes found to be significant at the 10% level were entered into the multilevel multivariate models with each of the transport modes as dependent variables adjusted for socio-demographic characteristics. More specifically, multivariate multilevel binary logistic regression (odds ratios and 95% confidence intervals) were used to regress transport mode choices[5] on the urban design attributes (e.g., land use mix, dwellings density, housing diversity score, local living score, distance to closest supermarket, number of public transport modes, distance to closest train station and distance to closest bus stop), adjusting for the covariates age, sex, household structure, employment status, motor vehicle ownership and survey day. The multilevel nature of the data necessitated a three-level nested structure: the neighbourhood trip counts were observations of individuals nested within households within CCDs. In these models, multicollinearity was tested for predictors by calculating the variance inflation factor (VIF) and tolerance values (1/VIF). VIF and tolerance values did not indicate any multicollinearity concern (VIF < 10 and tolerance $> .10$ for all variables) (Tabachnick et al., 2001).

All statistical analyses were performed using Stata IC v.13.0 (StataCorp LP, Texas, USA).

3. Results

3.1. Descriptive statistics

The study subset sample included 16,890 adults from 9490 households sampled across 631 CCDs (see Table 2). The final sample was evenly split between the sexes. Most study participants were under 49 years of age and a higher proportion lived in a household with children (51.6%). A large majority were employed (74.0%) and most had access to a motor vehicle (96.4%). A higher proportion completed the travel survey on a weekday (75.0%) than on the weekend.

Overall, 62.0% lived in areas where the population density was under 15 dwellings per hectare and a small proportion (4.3%) lived in areas where the population density was over 30 dwellings per hectares (see Table 3). However, the majority (85.0%) of study participants lived in neighbourhoods where there were less than 20 dwellings per hectare. Most participants lived within 1000 m of a supermarket (65.5%), 800 m of train station (75.5%) and 400 m of a bus stop (62.8%).

3.1.1. Transport-walking

As presented in Table 2, only 21% of study participants walked for transport in their residential neighbourhood on the survey day. There were several socio-demographic differences between those who walked and those who did not walk. Compared with those who did not walk for transport in their neighbourhoods, transport walkers were younger and more likely to be employed, lived in a household with no children and did not have access to a motor vehicle.

As reported in Table 3, there were significant differences in terms of urban design attributes of residential neighbourhoods between those who did and did not walk for transport: those who participated in some transport-walking in their residential neighbourhood lived in areas with significantly higher (i.e., $p < 0.01$): intersection density; mix of land uses; local living and housing diversity scores and population densities over 30 dwellings per hectare.

[5] Model 1. At least one transport-walking trip versus no transport-walking trips in the residential neighbourhood; Model 2. At least one cycling trip versus no cycling trips in the residential neighbourhood; Model 3. At least one public transport trip versus no public transport trips in the residential neighbourhood; Model 4. At least one private motor vehicle trip versus private motor vehicle trips in the residential neighbourhood.

Table 2
Socio-demographic characteristics of study participants by transport mode choices.

	Transport-walking			Cycling			Public transport			Private motor vehicle			Total
	No trips	At least one trip		No trips	At least one trip		No trips	At least one trip		No trips	At least one trip		
N	13,385	3,505	*p*[*]	16,449	441	*p*	15,318	1,572	*p*	2,213	14,677	*p*	16,890
Age groups (%)			*0.000*			*0.000*			*0.000*			*0.000*	
18 to 29 years	17.1	22.1		18.1	20.2		16.7	32.7		25.7	17.0		18.2
30 to 49 years	43.3	39.8		42.2	56.2		42.7	40.8		37.3	43.3		42.5
50 to 64 years	27.1	21.7		26.2	18.6		26.9	16.5		19.8	26.9		26.0
65 years and over	12.5	16.4		13.6	5.0		13.7	9.9		17.2	12.8		13.3
Sex (%)			*0.000*			*0.000*			*0.000*			*0.000*	
Male	49.4	42.9		47.5	67.1		48.3	45.3		47.4	48.1		48.0
Female	50.6	57.1		52.5	32.9		51.7	54.7		52.6	51.9		52
Household composition (%)			*0.000*			*0. 000*			*0.000*			*0.000*	
No children in household	36.7	46.2		38.6	42.0		38.0	44.8		47.8	37.3		38.7
Children in household	54.4	41.2		51.8	43.8		52.8	40.6		36.3	53.9		51.6
Other household structure	8.9	12.6		9.6	14.3		9.2	14.5		15.9	8.7		9.7
Employment (%)			*0.000*			*0.000*			*0.000*			*0.000*	
Not working	23.7	34.5		26.2	15.4		26.1	24.3		37.4	24.2		26.0
Working	76.3	65.5		73.8	84.6		73.9	75.7		62.6	75.8		74.0
Motor vehicle (%)			*0.000*			*0.000*			*0.000*			*0.000*	
At least one vehicle	99.2	85.6		96.5	91.8		98.1	79.5		77.8	99.2		96.4
No vehicle	0.8	14.4		3.5	8.2		1.9	20.5		22.2	0.8		3.6
Survey day (%)			*0.008*			*0.023*			*0.000*			*0.000*	
Weekend	25.6	22.8		25.2	20.4		26.3	13.2		19.0	26.0		25.0
Weekday	74.4	77.2		74.8	79.6		73.7	86.8		81.0	74.0		75.0

* Statistically significance between clusters assessed using chi-squared tests for categorical variables and ANOVA for continuous variables: $p < 0.05$. Key: sd = Standard Deviation; dph = dwellings per hectares.

3.1.2. Cycling

As reported in Table 2, the clear majority of study participants did not cycle in their residential neighbourhood (97.0%) on the survey day. Of the 3.0% who cycled in their residential neighbourhood, 76.4% were under 50 years old and 67.1% were men. Most study participants who cycled were employed (84.6%).

From Table 3, there were significant differences in the urban design attributes of the residential neighbourhoods between the cyclists and non-cyclists: those who cycled lived in areas with significantly higher (i.e., $p < 0.01$): intersection density; mix of land uses; local living and housing diversity scores. They were also more likely (i.e., $p < 0.01$) to live within 500 m of a supermarket and in areas where the gross dwelling density was over 30 dwellings per hectare.

3.1.3. Public transport

As presented in Table 2, only 9.3% of study participants did at least one trip on public transport in their residential neighbourhood on the survey day. There were no noticeable socio-demographic differences between those who used public transport and those who did not.

From Table 3, compared with those who did not use public transport, public transport users lived in areas where the intersection density and mix of land uses were significantly (i.e., $p < 0.01$) higher and where there were significantly higher local living scores and housing diversity scores. Those who used public transport were also more likely to live in areas where the gross dwelling density was over 30 dwellings per hectare, compared with those who did not use public transport.

3.1.4. Private motor vehicle

From Table 2, much of study participants used a private motor vehicle to travel in their residential neighbourhood (87%) on the survey day. Drivers were older and more likely to live in a household with children (53.9%) compared with those who did not use a private motor vehicle to travel in their neighbourhoods (36.3%).

As reported in Table 3, those who used a private motor vehicle in their residential neighbourhood were more likely to live in areas where the population density was less than 15 dwellings per hectare. They were also significantly more likely (i.e., $p < 0.01$) to live

Table 3
Summary statistics of the urban design attributes of neighbourhoods by transport mode choices.

N	Transport-walking			Cycling			Public transport			Private motor vehicle			Total
	No trips	At least one trip		No trips	At least one trip		No trips	At least one trip		No trips	At least one trip		
	13,385	3505		16,449	441		15,318	1572		2213	14,677		16,890
Mean (sd)			*p*[*]			*p*			*p*			*p*	
Intersection density[a]	66.1 (21.1)	80.4 (31.4)	*0.000*	68.6 (23.9)	85.0 (30.0)	*0.000*	67.5 (22.9)	83.4 (31.3)	*0.000*	83.9 (32.8)	66.8 (21.9)	*0.000*	69.0 (24.3)
Land Use Mix[b]	0.2 (0.2)	0.3 (0.2)	*0.000*	0.2 (0.2)	0.3 (0.2)	*0.000*	0.2 (0.2)	0.3 (0.2)	*0.000*	0.3 (0.2)	0.2 (0.2)	*0.000*	0.3 (0.2)
Local living score[c]	7.1 (3.2)	9.2 (2.7)	*0.000*	7.5 (3.2)	9.6 (2.5)	*0.000*	7.3 (3.2)	9.7 (2.4)	*0.000*	9.4 (2.6)	7.3 (3.2)	*0.000*	7.5 (3.2)
Housing diversity score[d]	6.1 (1.7)	7.0 (1.4)	*0.000*	6.2 (1.6)	7.3 (1.2)	*0.000*	6.2 (1.7)	7.2 (1.1)	*0.000*	7.1 (1.2)	6.1 (1.7)	*0.000*	6.3 (1.7)
Dwellings density (gross)	14.2 (5.8)	19.0 (8.6)	*0.000*	15.0 (6.7)	20.4 (7.4)	*0.000*	14.7 (6.3)	20.0 (8.4)	*0.000*	19.9 (8.8)	14.4 (6.1)	*0.000*	15.1 (6.7)
(%)													
≤ 10 dph	16.4	8.1		15	3.9		15.7	5.2		6.4	16.0		14.7
10 – 15 dph	51.2	33.3		48.2	22.4		49.4	29.3		30.7	50.1		47.5
15 – 20 dph	22.3	24.6		22.7	25.4		22.6	24.8		24.5	22.5		22.8
20 – 30 dph	7.7	22.2		10.0	38.1		9	27.5		24.4	8.6		10.7
30 – 40 dph	1.7	8.5		3.0	7.9		2.4	9.8		9.9	2.1		3.1
> 40 dph	0.6	3.3		1.1	2.3		1	3.4		4.2	0.7		1.2
Distance to closest supermarket	847.7 (410.0)	653.2 (375.2)	*0.000*	810.1 (411.2)	660.0 (362.8)	*0.000*	825.3 (411.2)	636.3 (369.5)	*0.000*	636.3 (369.5)	832.6 (410.4)	*0.000*	806.0 (410.6)
(%)													
> **1000 m**	70.3	54.2		67.6	42.2		68.9	48.5		51.5	69.3		67.0
500 – 1000 m	19.1	22.9		19.6	29.3		19.3	24.7		23.8	19.2		19.8
< **500 m**	10.7	22.9		12.8	28.6		11.8	26.8		24.7	11.5		13.2
Distance to nearest train station	998.6 (347.4)	883.0 (354.6)	*0.000*	965.3 (353.7)	902.9 (349.7)		978.0 (352.4)	883.4 (350.0)	*0.000*	878.6 (351.2)	984.5 (351.1)	*0.000*	962.5 (353.7)
(%)													
> 800 m	37.2	26.1		35.1	27.9		35.9	25.8		25.7	36.3		34.9
≤ 800 m	62.8	73.9		64.9	72.1		64.1	74.2		74.3	63.7		65.1
Distance to nearest bus stop	397.4 (292.6)	335.3 (235.8)	*0.000*	385.7 (284.0)	338.0 (229.6)	*0.000*	390.8 (287.8)	322.9 (219.2)	*0.000*	333.4 (234.6)	392.2 (288.6)	*0.000*	384.4 (282.7)
(%)													
> 400 m	6.9	3.2		6.2	2.7		6.5	2.9		3.0	6.6		6.1
≤ 400 m	93.1	96.8		93.8	97.3		93.5	97.1		97.0	93.4		93.9

* Statistically significance between clusters assessed using chi-squared tests for categorical variables and ANOVA for continuous variables: $p < 0.05$. Key: sd = Standard Deviation; dph = dwellings per hectares.
[a] Number of intersections per square kilometres;
[b] Land Use Mix ranges from 0 to 1;
[c] Local living score ranges from 0 to 12;
[d] Housing diversity score ranges from 0 to 8.

further than 1000 m from a supermarket compared with those who did not use a private motor vehicle. Compared with those who did not use a private motor vehicle, those who did lived in areas where the intersection density; mix of land uses; local living scores and housing diversity scores were significantly lower (i.e., $p < 0.01$).

3.2. Adjusted associations between urban design attributes and transport behaviours

As presented in Table 4, for transport-walking, cycling and public transport use, the odds of undertaking at least one trip within the residential neighbourhood were consistently significantly higher when the gross dwelling densities were above 20 dwellings per hectare. The housing diversity score was also positively associated with transport-walking, cycling and public transport use within the residential neighbourhood. When fully adjusted, the local living score was positively associated with public transport use and transport-walking, however there was no significant association between land use mix or the local living score and cycling.

The odds of transport-walking increased when the closest supermarket was within 500 m, the closest bus stop was within 400 m (OR = 1.3, 95%CI = 1.2–1.5) and the closest train station was within 800 m (OR = 1.2, 95%CI = 1.1–1.5). The odds of public transport use also increased when the closest supermarket was within 500 m (OR = 1.5, 95%CI = 1.2–1.8). However, there was no significant association between cycling and proximity to bus stop or train station and no significant association between public transport use and proximity to bus stop or train station.

The odds of undertaking at least one private motor vehicle trip within the residential neighbourhood almost halved when

Table 4
Odd ratios for associations between transport modes and urban design attributes.

	Model 1 Transport-walking OR [CI]	Model 2 Cycling OR [CI]	Model 3 Public transport OR [CI]	Model 4 Private motor vehicle OR [CI]
Age groups				
18 to 29 years	Ref.	Ref.	Ref.	Ref.
30 to 49 years	0.65*** [0.55,0.76]	1.32 [0.93,1.89]	0.34*** [0.28,0.43]	1.98*** [1.63,2.41]
50 to 64 years	0.57*** [0.47,0.68]	0.68 [0.45,1.02]	0.21*** [0.16,0.27]	2.33*** [1.88,2.87]
65 years and over	0.62*** [0.48,0.79]	0.33** [0.17,0.66]	0.20*** [0.14,0.29]	2.19*** [1.63,2.96]
Sex				
Male	Ref.	Ref.	Ref.	Ref.
Female	1.24*** [1.12,1.38]	0.29*** [0.22,0.39]	1.02 [0.88,1.18]	1.25*** [1.10,1.42]
Household composition				
No children in household	Ref.	Ref.	Ref.	Ref.
Children in household	0.90 [0.78,1.05]	0.84 [0.59,1.19]	0.88 [0.72,1.07]	1.18 [0.99,1.41]
Other household structure	1.10 [0.89,1.36]	1.16 [0.72,1.89]	1.07 [0.81,1.40]	0.62*** [0.49,0.78]
Employment				
Not working	Ref.	Ref.	Ref.	Ref.
Working	0.45*** [0.38,0.53]	1.13 [0.76,1.67]	1.11 [0.89,1.37]	2.54*** [2.09,3.07]
Motor vehicle				
At least one vehicle	Ref.	Ref.	Ref.	Ref.
No vehicle	29.84*** [20.94,42.53]	1.62 [0.90,2.93]	22.47*** [15.17,33.28]	0.01*** [0.01,0.02]
Survey day				
Weekend	Ref.	Ref.	Ref.	Ref.
Weekday	1.18* [1.01,1.39]	1.43 [0.97,2.09]	4.12*** [3.23,5.26]	0.57*** [0.46,0.70]
Street connectivity	1.00 [1.00,1.01]	1.00 [0.99,1.01]	1.00 [0.99,1.00]	0.99* [0.99,1.00]
Land Use Mix	1.42 [0.86,2.33]	0.99 [0.33,3.01]	1.29 [0.70,2.37]	0.46** [0.27,0.80]
Local living score	1.19*** [1.15,1.23]	1.06 [0.97,1.15]	1.22*** [1.16,1.28]	0.87*** [0.83,0.91]
Housing diversity score	1.10** [1.03,1.18]	1.30** [1.09,1.55]	1.30*** [1.18,1.43]	0.88** [0.81,0.95]
Dwelling density (gross)				
< 10.0 dph	Ref.	Ref.	Ref.	Ref.
10.0 – 14.9 dph	0.71* [0.53,0.94]	0.93 [0.47,1.87]	0.84 [0.55,1.31]	1.34 [0.97,1.86]
15.0 – 19.9 dph	0.91 [0.64,1.29]	1.98 [0.89,4.39]	1.18 [0.72,1.91]	0.91 [0.61,1.34]
20.0 – 29.9 dph	1.70* [1.11,2.61]	5.58*** [2.16,14.44]	2.31** [1.33,4.02]	0.55* [0.34,0.87]
30.0 – 39.9 dph	2.52** [1.39,4.57]	3.57* [1.08,11.83]	2.99** [1.37,6.55]	0.42** [0.23,0.78]
≥ 40 dph	2.07* [1.02,4.20]	1.85 [0.51,6.78]	1.22 [0.49,3.07]	0.45* [0.21,0.98]
Distance to closest supermarket				
Over 1000 m	Ref.	Ref.	Ref.	Ref.
500 m to 1000 m	1.11 [0.90,1.36]	1.46 [0.93,2.27]	1.12 [0.86,1.47]	0.89 [0.70,1.12]
Within 500 m	1.45** [1.16,1.82]	1.50 [0.93,2.44]	1.38* [1.02,1.86]	0.72* [0.56,0.93]
Distance to closest train station				
Over 800 m	Ref.	Ref.	Ref.	Ref.
Within 800 m	1.25**1.06,1.47]	0.79 [0.53,1.17]	0.84 [0.65,1.09]	1.00 [0.81,1.25]
Distance to closest bus stop				
Over 400 m	Ref.	Ref.	Ref.	Ref.
Within 400 m	1.35***1.16,1.55]	1.75 [0.78,3.94]	1.08 [0.69,1.69]	0.89 [0.60,1.30]

Multivariate models adjusted for clustering at the census area and household levels.
Key: CI = Confidence Interval; dph = dwellings per hectares; OR = Odd Ratio; Ref. = reference.
* for p < .05,
** for p < .01, and
*** for p < .001.

dwelling densities were above 20 dwellings per hectare (OR: 0.55, 95%CI = 0.34–0.87). The odds of private motor vehicle use significantly reduced when there was greater mix of land uses (OR: 0.46, 95%CI = 0.27–0.80) and with higher local living score (OR: 0.87, 95%CI = 0.83–0.91). Housing diversity score was also associated with reduced odds of driving (OR: 0.88, 95%CI = 0.81–0.95). The odds of private motor vehicle use decreased by more than 25% when the closest supermarket was within 500 m (OR: 0.72, 95%CI = 0.56–0.93). However, there was no significant association between proximity to bus stop or train station and private motor vehicle use.

4. Discussion

The results showed significantly increased odds of transport-walking within the neighbourhood when households were located within 800 m of a train station and within 400 m of a bus stop. These findings are consistent with other studies conducted in Australian cities (Badland et al., 2014) and internationally which specify that in urban areas, walking distances to a bus stop should not exceed 400 m and 800 m for a train station (Cervero and Kockelman, 1997). The results also indicated that each additional local living destination present in the neighbourhood increased the odds of transport-walking within the neighbourhood and the odds of public transport use within the neighbourhood. The findings on the association between participation in transport-walking and the local living score were consistent with a recent Australian study (2015), which found that having access to a range of destinations had a positive impact on walking frequency by providing incentives to walk (King et al., 2015).

The results show that urban design guidelines may need to be strengthened to ensure that liveable and healthy neighbourhoods are created. For example, in Melbourne planning policy stipulates a recommended density aim of 15 dwellings per hectare for new urban growth. Our results show that this level of density is too low, and will continue to encourage driving and discourage active transport modes. Moreover, our results indicate that multiple design elements are critical in creating the conditions for active and sustainable form of living. This includes the level of street connectivity; the mixture of land uses as well as the distribution of shops and services across urban environments. Moreover, we found that the impact of these interventions increases with increasing implementation of these urban design features.

Participation in cycling was found to be only associated with housing diversity score and residential density. As proposed by Foryth and colleagues (2011), the evidence we found suggest that the specific urban design features associated with cycling need to be further considered (Forsyth and Krizek, 2011).

Nonetheless, overall the results indicate that an urban environment that encourages walking, cycling and public transport use may also discourage private motor vehicle use. Specifically, an environment that encourages active modes is defined by high intersection density (i.e., ≥ 67 intersections per square kilometres), high gross dwelling density (i.e., ≥ 20 dwellings per hectares), diversity of local living destinations (i.e., ≥ 9 types), as well as proximity of key destinations required for daily living including supermarkets, train stations and bus stops.

Although causality cannot be conferred by cross-sectional data, these results provide some evidence that a shift from private motor vehicle use to active and public transport use has potential to be achieved through careful integrated urban and transport planning that prioritises pedestrians, cyclists, and public transport users. The effectiveness of approach has been demonstrated in a number of north American cities including Portland, San Francisco, Minneapolis, Chicago, Washington, New York, Vancouver and Toronto (Pucher et al., 2011) highlighting how with appropriate policy and political commitment, it is possible to shift behaviour even in car dependent cities (Pucher and Buehler, 2008). In the past two decades these cities have invested in a range of infrastructure and programs designed to improve the conditions for active and public transports and consequently have seen a surge in walking and cycling (Bassett et al., 2008; Pucher et al., 2011). From these case studies it is apparent that integrated urban and transport planning has a pivotal role to play in reducing unnecessary private motor vehicle use where more sustainable options could be used (Gotschi, 2011; Pucher et al., 2011). Policies and planning strategies that encourage active urban travel and discourage private motor vehicle use afford significant opportunities to help achieve the United Nation's Sustainable Development Goals (Sachs, 2012) as a shift toward active and public transport would facilitate health, climate change, environmental and social benefits (Koohsari et al., 2013).

However, as this study shows, the scale of the task ahead is significant. In metropolitan Melbourne, most people live in suburbs that are not designed to encourage them to use active transport modes as an alternative to driving. Indeed, whilst the results here suggest that to encourage transport-walking 20 dwellings per hectare is the minimum requirement instead we find that 62% of the study participants lived in areas where the population density was under 15 dwellings per hectare which is too low to support active or public transport. Furthermore, greater investments toward active transport may be needed. The 2016-17 Victorian Budget invests over $10.4 billion in public transport and road projects across Victoria, compared with only $9.3 million (0.09%) to support cycling and $1.9 billion (18%) to support Melbourne's public transport network (State Government of Victoria, 2016).

Additionally, in this study, we found that on average metropolitan Melbourne, residents have access to only 7.5 types of local living destinations. This level of access appears insufficient for promoting active and public transport: residents with access to at least nine types of local living destinations within their residential neighbourhood had significantly higher odds of walking, cycling or using public transport; and were less likely to drive.

Depending on the circumstances, retrofitting the existing neighbourhoods for greater walking, cycling and public transport use may be extremely difficult and expensive. As an example, Gunn and colleagues found that the cost of retrofitting sidewalks was 50% higher than the initial installation (Gunn et al., 2014). Moreover, politically it is often difficult to retrospectively create the look and feel of neighbourhoods once residents have moved in. Hence, designing housing developments that promote active forms of transport from the outset, is preferable to building housing developments that will require retrofitting.

Nevertheless, the authors of recent Urban design, transport, and health Lancet Series (2016), argued that good local urban design will only work in practice, if it is coupled with strong regional planning that ensures destination accessibility, increases the distribution of employment across regions making commute distances shorter; and reduces demand for driving through congestion charging and control of the availability and price of parking (Giles-Corti et al., 2016; Sallis et al., 2016; Stevenson et al., 2016). These authors argued that to encourage walking, cycling and public transport while discouraging driving, requires a comprehensive integrated approach with multiple interventions at both local and regional levels.

5. Limitations

The study had several limitations. It operationalized and tested a small selection of state-level policies (see Table 1) that were related to active transport and public transport. However, there are other policies related to the built environment that could impact travel behaviour, for example planning regulations for car parking, provisions of cycling infrastructure, or street lighting - but these were not tested here. The travel data were self-reported, and there may be errors and inaccuracies in the reporting of trips. Another limitation acknowledged by others (Brownson et al., 2009), is related to the temporal accuracy of GIS data with the timing of the outcome measurements. GIS data that temporally matched the data collection from the VISTA09 survey (2008–2009) could not be sourced and instead datasets that represented the study areas at the 2010, 2011 and 2012 time points were used. The mismatch between the timing of measuring urban design attributes and outcome behaviours, may introduce measurement error. Likewise, the shift of residential addresses to protect participant privacy is a source of error. However, this is unlikely to have had changed the results since the relative distance of the shift (maximum of 70 m) is small compared to the size of the neighbourhood (1600 m radius). Finally, since the study is cross-sectional, causality cannot be implied.

6. Conclusion

This study provides evidence that neighbourhoods with gross residential densities exceeding 20 dwellings per hectare, a well-connected street network, access to 9 or more local living destinations and short distances to public transport services (i.e., ≤ 400 m for bus and ≤ 800 m for train) encourage walking, cycling and public transport use, while discouraging driving. However, most Melbournians do not live in suburbs with these urban design features, highlighting the need for comprehensive integrated urban planning of transport infrastructure, land use development and service provision. Such integration appears critical for creating neighbourhoods that support active and sustainable ways of living that will achieve the UN Sustainable Development Goals.

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References

Allender, S., Cavill, N., Parker, M., Foster, C., 2009. Tell us something we don't already know or do!" The response of planning and transport professionals to public health guidance on the built environment and physical activity. J. Public Health Policy 30, 102–116.
Australian Bureau of Statistics, 2011. Census of Population and Housing: Mesh Block Counts.
Badland, H., Hickey, S., Bull, F., Giles-Corti, B., 2014. Public transport access and availability in the RESIDE study: is it taking us where we want to go? J. Transp. Health 1, 45–49.
Badland, H., Mavoa, S., Boulangé, C., Eagleson, S., Gunn, L., Stewart, J., David, S., Giles-Corti, B., 2016. Identifying, creating, and testing urban planning measures for transport walking: findings from the Australian national liveability study. J. Transp. Health.
Bassett, D.R., Pucher, J., Buehler, R., Thompson, D.L., Crouter, S.E., 2008. Walking, cycling, and obesity rates in Europe, North America, and Australia. J Phys. Act. Health 5.
Brownson, R.C., Hoehner, C.M., Day, K., Forsyth, A., Sallis, J.F., 2009. Measuring the built environment for physical activity: state of the science. Am. J. Prev. Med. 36, S99–S123 (e112).
Cerin, E., Leslie, E., Toit, Ld, Owen, N., Frank, L.D., 2007. Destinations that matter: associations with walking for transport. Health Place 13, 713–724.
Cervero, R., Kockelman, K., 1997. Travel demand and the 3Ds: density, diversity, and design. Transp. Res. Part D: Transp. Environ. 2, 199–219.
Christian, H., Bull, F., Middleton, N., Knuiman, M., Divitini, M., Hooper, P., Amarasinghe, A., Giles-Corti, B., 2011. How important is the land use mix measure in understanding walking behaviour? Results from the RESIDE study. Int. J. Behav. Nutr. Phys. Act. 8. http://dx.doi.org/10.1186/1479-5868-1188-1155.
Department of Environment Land Water and Planning, 2016. Victoria Planning Provisions. In: Department of Environment LandWater and Planning (Ed.), Melbourne.
Department of Sustainability and Environment, State Government of Victoria, 2012a. VicMap Planning.
Department of Sustainability and Environment, State Government of Victoria, 2012b. VicMap Property.
Department of Sustainability and Environment, State Government of Victoria, 2012c. VicMap Transport.
Department of Transport, Metropolitan Planning Authority, 2014. Plan Melbourne.
Durand, C.P., Andalib, M., Dunton, G.F., Wolch, J., Pentz, M.A., 2011. A systematic review of built environment factors related to physical activity and obesity risk: implications for smart growth urban planning. Obes. Rev. 12, e173–e182.
ESRI, 2011. ArcGIS Desktop: Release 10. Environmental Systems Research Institute, Redlands, CA.
Floater, G., Rode, P., Robert, A., Kennedy, C., Hoornweg, D., Slavcheva, R., Godfrey, N., 2014. Cities and the New Climate Economy: the Transformative Role of Global Urban Growth.
Forsyth, A., Krizek, K., 2011. Urban design: is there a distinctive view from the bicycle? J. Urban Des. 16, 531–549.
Forsyth, A., Van Riper, D., Larson, N., Wall, M., Neumark-Sztainer, D., 2012. Creating a replicable, valid cross-platform buffering technique: the sausage network buffer for measuring food and physical activity built environments. Int. J. Health Geogr. 11, 14.
Frank, L., Saelens, B., Powell, K., Chapman, J., 2007. Stepping towards causation: do built environments or neighborhood and travel preferences explain physical activity, driving and obesity? Soc. Sci. Med 65, 1898–1914.
Frank, L.D., Schmid, T.L., Sallis, J.F., Chapman, J., Saelens, B.E., 2005. Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. Am. J. Prev. Med. 28, 117–125.
Giles-Corti, B., Timperio, A., Bull, F., Pikora, T., 2005. Understanding physical activity environmental correlates: increased specificity for ecological models. Exerc. Sport Sci. Rev. 33, 175–181.
Giles-Corti, B., Vernez-Moudon, A., Reis, R., Turrell, G., Dannenberg, A.L., Badland, H., Foster, S., Lowe, M., Sallis, J.F., Stevenson, M., 2016. City planning and population health: a global challenge. Lancet.
Gotschi, T., 2011. Costs and benefits of bicycling investments in Portland, Oregon. J. Phys. Act. Health 8, S49–S58.
Growth Areas Authority, 2009. Precinct Structure Planning Guidelines – Part One. In: Growth Areas Authority (Ed.), Melbourne, Victoria.
Gunn, L.D., Lee, Y., Geelhoed, E., Shiell, A., Giles-Corti, B., 2014. The cost-effectiveness of installing sidewalks to increase levels of transport-walking and health. Prev.

Med. 67, 322–329.
Handy, S., 2014. Health and travel. In: Gärling, T., Ettema, D., Friman, M. (Eds.), Handbook of Sustainable Travel. Springer, Netherlands, Dordrecht, pp. 199–214.
King, T.L., Bentley, R.J., Thornton, L.E., Kavanagh, A.M., 2015. Does the presence and mix of destinations influence walking and physical activity? Int. J. Behav. Nutr. Phys. Act. 12, 115.
Koohsari, M.J., Badland, H., Giles-Corti, B., 2013. (Re) Designing the built environment to support physical activity: bringing public health back into urban design and planning. Cities 35, 294–298.
Leslie, E., Saelens, B., Frank, L., Owen, N., Bauman, A., Coffee, N., Hugo, G., 2005. Residents' perceptions of walkability attributes in objectively different neighbourhoods: a pilot study. Health Place 11, 227–236.
Metropolitan Planning Authority, 2015. About Plan Melbourne Refresh.
Pitney Bowes Ltd, 2014. Axiom Business Points.
Pucher, J., Buehler, R., 2008. Cycling for everyone: lessons from Europe. Transp. Res. Rec.: J. Transp. Res. Board 58–65.
Pucher, J., Buehler, R., Seinen, M., 2011. Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies. Transp. Res. part A: Policy Pract. 45, 451–475.
Rissel, C., Curac, N., Greenaway, M., Bauman, A., 2012. Physical activity associated with public transport use—a review and modelling of potential benefits. Int. J. Environ. Res. Public Health 9, 2454–2478.
Sachs, J.D., 2012. From millennium development goals to sustainable development goals. Lancet 379, 2206–2211.
Sallis, J.F., Bull, F., Burdett, R., Frank, L.D., Griffiths, P., Giles-Corti, B., Stevenson, M., 2016. Use of science to guide city planning policy and practice: how to achieve healthy and sustainable future cities. The Lancet.
Stanley, J., Stanley, J., 2014. Achieving the 20 min City for Melbourne: Turning Our City Upside Down.
State Government of Victoria, 2016. 2016-17 Victorian Budget Getting It Done.
State Government Victoria, 2014. Plan Melbourne. Metropolitan Planning Strategy 2014. State Government Victoria, Melbourne.
Stevenson, M., Thompson, J., de Sá, T.H., Ewing, R., Mohan, D., McClure, R., Roberts, I., Tiwari, G., Giles-Corti, B., Sun, X., 2016. Land use, transport, and population health: estimating the health benefits of compact cities. Lancet 388, 2925–2935.
Streiner, D.L., 2002. Breaking up is hard to do: the heartbreak of dichotomizing continuous data. Can. J. Psychiatry 47, 262–266.
Tabachnick, B.G., Fidell, L.S., Osterlind, S.J., 2001. Using Multivariate Statistics.
The Urban Transport Institute, 2011. Victorian Integrated Survey of Travel & Activity 2009–2010: Survey Procedures and Documentation. The Urban Transport Institute.
United Nations, Department of Economic and Social Affairs, Population Division, 2015. World Population Prospects: The 2015 Revision. Key Findings and Advance Tables.
United States. Department of Health, Human Services, 1996. Physical Activity and Health: A Report of the Surgeon General. Department of Health and Human Services. Centres for Disease Control and Prevention. National Center for Chronic Disease Prevention and Health Promotion, Atlanta, Georgia, U.S.
Villanueva, K., Giles-Corti, B., McCormack, G., 2008. Achieving 10,000 steps: a comparison of public transport users and drivers in a university setting. Prev. Med. 47, 338–341.
Villanueva, K., Knuiman, M., Nathan, A., Giles-Corti, B., Christian, H., Foster, S., Bull, F., 2014. The impact of neighborhood walkability on walking: does it differ across adult life stage and does neighborhood buffer size matter? Health Place 25, 43–46.
Watts, N., Adger, W.N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., Chaytor, S., Colbourn, T., Collins, M., Cooper, A., Cox, P.M., Depledge, J., Drummond, P., Ekins, P., Galaz, V., Grace, D., Graham, H., Grubb, M., Haines, A., Hamilton, I., Hunter, A., Jiang, X., Li, M., Kelman, I., Liang, L., Lott, M., Lowe, R., Luo, Y., Mace, G., Maslin, M., Nilsson, M., Oreszczyn, T., Pye, S., Quinn, T., Svensdotter, M., Venevsky, S., Warner, K., Xu, B., Yang, J., Yin, Y., Yu, C., Zhang, Q., Gong, P., Montgomery, H., Costello, A., 2015. Health and climate change: policy responses to protect public health. Lancet 386, 1861–1914.
Woodcock, J., Edwards, P., Tonne, C., Armstrong, B.G., Ashiru, O., Banister, D., Beevers, S., Chalabi, Z., Chowdhury, Z., Cohen, A., 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet 374, 1930–1943.
World Health Organization, 2010. Hidden Cities: Unmasking and Overcoming Health Inequities in Urban Settings. World Health Organization.