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Title:

The influence of urban design on neighbourhood walking following residential relocation: Longitudinal results from the RESIDE study

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Abstract

The design of urban environments has the potential enhance the health and wellbeing of residents by impacting social determinants of health including access to public transport, green space and local amenities. Commencing in 2003, RESIDE is a longitudinal natural experiment examining the impact of urban planning on active living in metropolitan Perth, Western Australia. Participants building homes in new housing developments were surveyed before relocation (n=1813; 34·6% recruitment rate); and approximately 12 months later (n=1437). Changes in perceived and objective neighbourhood characteristics associated with walking following relocation were examined, adjusted for changes in demographic, intrapersonal, interpersonal and baseline reasons for residential location choice. Self-reported walking was measured using the Neighbourhood Physical Activity Questionnaire. Following relocation, transport-related walking declined overall ($p<0.001$) and recreational-walking increased ($p<0.001$): access to transport- and recreational destinations changed in similar directions. However, in those with increased access to destinations, transport-related walking increased by 5.8 minutes/week for each type of transport-related destination that increased ($p=0.045$); and recreational walking by 17.6 minutes/week for each type of recreational destination that increased ($p=0.070$). The association between the built environment and recreational walking was partially mediated by changes in perceived neighbourhood attractiveness: when changes in 'enjoyment' and 'attitude' towards local walking were removed from the multivariate model, recreational walking returned to 20.1 minutes/week ($p=0.040$) for each type of recreational destination that increased. This study provides longitudinal evidence that both transport and recreational-walking behaviours respond to changes in the availability and diversity of local transport- and recreational-destinations, and increases the potential of local infrastructure to support health-enhancing behaviours. As neighbourhoods evolve, longer-term follow-up is required to fully capture changes that occur, and the impact on residents. The potential for using policies, incentives and infrastructure

levies to enable the early introduction of recreational and transport-related facilities into new housing developments warrants further investigation.

Keywords: Australia, social determinants, natural experiment, built environment, walking, quasi experimental, longitudinal, physical environment

Background

Recognition that city design impacts public health was first established in the 19th century in efforts to control the outbreak of communicable disease (Corburn, 2007). With communicable disease control, the links between urban planning and public health attenuated, and only recently have there been calls for the two disciplines to reconnect (Corburn, 2007): this time in an effort to create healthy and sustainable cities that facilitate health behaviors that reduce the risk of non-communicable diseases.

For over two decades the World Health Organisation's Healthy City Movement (Duhl, 1996) has promoted urban design features required to create health enhancing cities (Rydin et al., 2012). Healthy and sustainable communities create the conditions that optimize physical and mental health and well being (Marmott, 2011) by impacting social determinants of health including access to public transport, public open space, local amenities and other social infrastructure. Nevertheless, relatively little systematic research has examined the influence of contextual factors on health outcomes (Macintyre & Ellaway, 2003). As a consequence, there is little understanding of the potential of urban environments to deliver and equitably distribute health benefits (Rydin et al., 2012).

Planning, transport and urban design policies and regulations directly influence the location and proximity of activities required for daily living (e.g. shops, workplaces and school, facilities places to socialize and recreate) and the ease with which places can be reached using active forms of transport (i.e., walking, cycling and public transport). Physical inactivity is a common risk factor for major non-communicable diseases, yet less than one half of adults in many developed countries are sufficiently active to protect their health (WHO, 2010). This poses a substantial public health risk and an economic burden to national health care budgets in both the developed (Department of Health, 2009) and the developing world (Rydin et al., 2012). Increasing levels of physical activity through popular activities such as walking and cycling is a practical means of improving health (Department of Health, 2009), as well as producing co-benefits across other sectors by reducing car use, traffic congestion and air pollution (Giles-Corti et al., 2010; Haines et al., 2009).

To support policy-reform, recently there has been a plethora of reviews on the impact of the built environment on various health outcomes, including physical activity and obesity (CDC, 2007; Kopelman et al., 2007; National Institute for Health and Clinical Excellence, 2008; National Preventative Health Taskforce, 2009). The evidence suggests that community design affects travel mode choices,(National Institute for Health and Clinical Excellence, 2008; Transportation Research Board, 2005) and levels of walking and/or cycling (Durand et al., 2011; McCormack et al., 2004; Ogilvie et al., 2007; Owen et al., 2004b; Panter et al., 2008; Saelens & Handy, 2008; Transportation Research Board, 2005) with mixed evidence on its impact on obesity (Dunton et al., 2009; Feng et al., 2010; Papas et al., 2007; Robertson-Wilson & Giles-Corti, 2010; Van Cauwenberg et al., 2011). Specifically, walking for transport appears to be associated with increased residential density, high street connectivity, mixed land-use and proximity to destinations. Recreational walking on the other hand is associated with access to public open space, neighbourhood attractiveness and the accessibility and functionality of local facilities. Thus, creating pedestrian-friendly neighbourhoods with access to local amenities and well designed public open space has the potential to be benefit health (Marmott, 2011).

Despite the complexities associated with implementation (Rydin et al., 2012), urban planning that promotes walking, cycling and transit use is now being recommended by multiple sectors including public health (CDC, 2007; Kopelman et al., 2007; National Institute for Health and Clinical Excellence, 2008; National Preventative Health Taskforce, 2009), transport (Transportation Research Board, 2005) and planning authorities (Planning Institute of Australia & Heart Foundation, 2008). Nevertheless, most of the evidence to date is cross-sectional, and most evidence reviews conclude that stronger longitudinal evidence is required to better inform urban planning and practice. A limitation of cross-sectional evidence is self-selection: i.e., people may choose to live in neighbourhoods that reflect their active-living preferences, rather than neighbourhood design changing their behaviour. To address this limitation, some cross-sectional studies control for participants' reasons for moving into their current neighbourhood (Cao et al., 2009; Frank et al., 2007; Handy et al., 2005; G. R. McCormack & Shiell, 2011; Owen et al., 2007). However recall bias cannot be ruled out when asking retrospectively about factors influencing decisions to relocate. Longitudinal evidence is therefore required to examine the influence of changes in urban form on health outcomes and individual lifestyle behaviors (Rydin et al., 2012).

Studies examining the impacts of changes to neighbourhood design and transport infrastructure are difficult to design and implement, and randomised controlled trials (RCTs) are rarely possible. Consequently, there are now a number of large established cohort studies examining the impact of neighbourhood design on health outcomes by identifying participants who relocate during follow-up (Berry et al., 2010; Boone-Heinonen et al., 2009; Boone-Heinonen et al., 2010; Hou et al., 2010; Krizek, 2000; Lee et al., 2009; Ludwig et al., 2011). To date, mixed results have been reported, and frequently authors highlight methodological flaws that may contribute to their findings including: a small sample of 'movers'; an inability to account for length of exposure to residential environments; and the use of behavioural and built environment measures that lack specificity or were chosen for another purpose. In addition, few of these studies have been grounded within a broader ecological framework. Ecological frameworks consider multilevel factors that influence behavior including intrapersonal, interpersonal, and physical environment factors (Sallis et al., 2006; Stokols, 1996), allowing both contextual and compositional variables to be captured (Macintyre & Ellaway, 2003). Use of this framework enables consideration and adjustment for changes in demographic, intrapersonal (e.g., attitudes), and interpersonal, (e.g., social support) factors, as well as changes in built environmental factors following relocation.

Importantly, very few studies (Wells & Yang, 2008) have been specifically designed to study residential relocation within the context of a natural experiment, although this has been identified as a gap in the literature (Ogilvie et al., 2007). Such an opportunity arose in Australia, where capital cities are experiencing average annual growth of around 1.6% (ABS, 2012), and providing sufficient affordable housing is a major policy challenge for government (Department of Infrastructure and Transport, 2011). The current study was conducted in the west coast city of Perth, which is one of Australia's fastest growing capital cities (2.5% annually) (ABS, 2012). Nevertheless, outer suburban metropolitan regions of other Australian capital cities are also experiencing even more rapid growth (e.g., some areas in the North-West metropolitan region of Melbourne grew almost 8% in the 12 months to June 2011) (ABS, 2012). Thus, the findings in this study are relevant to other greenfield outer suburban areas in Australia and elsewhere.

This paper uses data from the RESIDential Environment Project (RESIDE), a longitudinal natural experiment of people building houses and relocating to new neighbourhoods, to examine the impact of the built environment on walking for transport and recreation following relocation. We hypothesized that people relocating to neighbourhoods with infrastructure supportive of transport or recreational walking, would walk more. To understand the independent effects of the built environment, the study adopted an ecological framework (Giles-Corti et al., 2008), which allowed for adjustment for changes in demographic, intrapersonal and interpersonal characteristics as well as the changes in the built environment. In addition, measures of residential location preference were collected to adjust for one aspect of self-selection.

Methods

The University of Western Australia's Human Research Ethics Committee (#RA/4/1/479) provided ethics approval. RESIDE involved participants who moved into 73 new housing developments across metropolitan Perth. Intrapersonal, interpersonal and perceived built environmental data were collected using questionnaires completed by participants, while objective built environmental data were derived from a Geographic Information System (GIS).

Selection of housing developments

Housing developments were selected to include developments planned according to the state government's new sub-division design code, the 'Liveable Neighbourhoods Guidelines' (Western Australian Planning Commission, 2004), a local interpretation of new urbanism. RESIDE included 18 housing developments classified by the Department of Planning as 'Liveable' (i.e., complying with most of the LN Guidelines), 11 as 'hybrid' (i.e., complying with some but not all of the LN guidelines) and 44 'Conventional' (i.e., conventional development that did not comply with the LN Guidelines) (Giles-Corti et al., 2008).

Selection of participants

People building new homes in the study areas were identified and invited to participate by the state water authority (n=10,193), which is notified routinely of land transfer transactions. Eligibility criteria included English proficiency, ≥18 years, intention to relocate by December 2005, and willingness to complete surveys and wear a pedometer for a week on three separate occasions over four years. Those ineligible or not interested opted-out by returning a reply-paid card. Remaining home builders were contacted by phone or letter by the study team (n=9,148). One person from each household was randomly selected, of whom 5,238 were eligible for inclusion.

Data collection and response rates

The design includes participants being surveyed four times, each in the same season: before they moved into their new home (T1); then approximately 12 (T2), 36 (T3) and 48 (T4) months later. This paper reports changes from T1 to T2 only. Of those eligible to participate, 1813 provided written consent and returned completed T1 questionnaires (34.6% response rate), 1437 (83.3% of those still eligible) also completed T2 questionnaires, and 1420 provided current address data.

Variables

Table 1 provides details of the variables used in the analyses (dependent, independent and covariates), their source and how they were handled in models. Table 2 presents the factor analyses of items measuring factors influencing choice of new neighbourhood i.e., variables used to adjust for self-selection.

Insert Table 1 about here

Insert Table 2 about here

Statistical analysis

Generalized Linear Mixed Models (that included a random cluster effect to allow for clustering by (new) developments) in SAS v9.2 were used to examine associations with changes in neighbourhood recreational and transport-related walking. All models were adjusted for baseline age, gender, education level, marital status, having children < 18 years at home, and baseline total minutes of recreational or transport-related walking. Socio-demographic change variables ($p \leq 0.20$) were included in all multivariate models using forced entry. Thus, 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 change in education level.

The first (adjusted) multivariate model included variables representing changes (T2-T1) in objective environmental characteristics (Model 1), followed by progressive adjustment for changes in neighbourhood environment perceptions (Model 2), interpersonal variables (Model 3), and intrapersonal variables (Model 4). Given the importance of self-selection for studies of this type, the final models further adjusted for the self-selection scales ($p \leq 0.20$).

The variables representing changes in objective environmental characteristics and the variables representing changes in environmental perceptions are counts of the number of objective and subjective favourable changes. These variables are included as continuous variables in the regression models. We also included the square of these variables to assess curvature in the relationship but in no case was there any evidence of curvature (all $p > 0.2$).

The effect of a continuous variable is reported as the estimated additional minutes of walking for a unit increase in the continuous variable. For a categorical change variable, the estimated mean change in minutes of walking for each level of the categorical change variable is reported.

Results

Table 3 shows the socio-demographic characteristics of study participants who completed both surveys (n=1420) and those who completed T1 only. Those remaining in the study at T2 were significantly more likely to be female, slightly older, and more likely to be married or in a de facto relationship and to have children under 18 years at home ($p<0.05$). They were also significantly less likely to work and were engaged in significantly fewer hours of paid or unpaid work ($p<0.05$). Nevertheless, mean minutes of neighbourhood transport and recreational walking were similar ($p>0.05$).

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Insert Table 3 about here

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Following relocation, there was an overall decrease of 8.5 minutes/week in transport-related walking ($p<0.001$) and an overall increase of 15.5 minutes/week in recreational walking ($p<0.001$) (see Table 4).

Univariate associations between changes in mean minutes of transport and recreational walking following relocation and changes in objective and subjective measures of the built environment are shown in Table 4. Subjective measures with $p\leq0.20$ were included in the construction of the perceived neighbourhood environment indices.

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Insert Table 4 about here

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Table 5 shows univariate associations between changes in transport and recreational walking and baseline reasons for choice of housing development location (i.e., self-selection variables). Walking for transport was associated with the perceived importance of pedestrian and cycling friendly streets ($p=0.019$), and the proximity to parks and recreational facilities ($p=0.036$). However, none of the other self-selection scales nor the type of housing development to which respondents moved was significantly associated with changes in transport-related or recreational walking in the univariate models. However, using the $p\leq0.20$ cut-off, the importance of the accessibility of services required for daily living (e.g., shops, jobs, or place of study) (p=0.188), and neighbourhood safety, diversity and ease of living (p=0.182) were also adjusted for in the final transport-related walking multivariate model, while the perceived importance of pedestrian and cycling friendly streets (p=0.088) and a self-selection scale used in previous studies (p=0.190) were also adjusted for in the final recreational walking model.

Insert Table 5 about here

Table 6 shows the multivariate associations between changes in built environment and weekly minutes of transport-related walking, with progressive adjustment for changes in intrapersonal and interpersonal characteristics. After adjustment for changes in socio-demographic variables, neighbourhood perceptions, interpersonal and intrapersonal characteristics (model 4) walking for transport increased on average 6.1 minutes/week (p=0.035) for each transport-related destination type that increased, attenuating to 5.8 minutes/week after adjustment for self-selection variables (p=0.045). In the final model (model 5), for each additional neighbourhood feature that was perceived to change favourably, walking for transport also increased by 3.0 minutes/week (p=0.011). Notably, although not shown, 89% of RESIDE participants did not gain access to local transport-related destinations following relocation. Only 8% of participants gained access to one additional transport destination, while only 0.2% gained access to four or more.

Table 6 also shows the multivariate associations between changes in built environment and changes in minutes/week of recreational walking, progressively adjusted for changes in socio-demographic, intrapersonal and interpersonal characteristics. After adjustment for changes in socio-demographic and intrapersonal characteristics (Model 3) for each additional recreational destination type that increased, recreational walking increased by

21.1 minutes/week (p=0.034). This attenuated slightly and did not retain statistical significance after adjustment for interpersonal characteristics (Model 4; 17.2 minutes/week (*p*=0.078)). It remained constant with further adjustment for self selection variables (17.6 minutes/week (*p*=0.070) (Model 5).

Further modeling indicated that the association between changes in the built environment and recreational walking were mediated through changes in attitudes to walking and enjoyment of walking locally. When these variables were removed from the final, similar results were observed prior to adjustment for interpersonal characteristics (Model 3) i.e., for each additional recreational destination type that increased, recreational walking increased by 20.6 minutes/week (p=0.035).

Finally, we also found that after full adjustment (model 4), for each additional neighbourhood perception that changed favourably from T1 to T2, on average, recreational walking increased by 2.3 minutes/week (*p*=0.024), with little change in Model 5 after adjustment for self-selection i.e., 2.2 minutes/week (p=0.033).

Insert Table 6 about here

Discussion

The physical characteristics of neighbourhoods can facilitate health enhancing behaviours, thus having the potential to reduce social inequalities (Marmott, 2011). Nevertheless, to date much of the evidence on the impact of the built environment on physical activity is cross sectional. There has been a small number of quasi-experimental studies (Berry et al., 2010; Boone-Heinonen et al., 2009; Boone-Heinonen et al., 2010; Hou et al., 2010; Krizek, 2000; Lee et al., 2009; Ludwig et al., 2011; Wells & Yang, 2008), but a dearth of purpose-designed longitudinal studies (Wells & Yang, 2008).

Our study extends this limited evidence-base using a longitudinal study design allowing estimation of changes in minutes of neighbourhood walking among adults following relocation to a new neighbourhood, after adjusting for a myriad of other variables that might also change with relocation. We found that following relocation overall transport-related walking significantly declined, while recreational walking significantly increased. This appeared to be because most participants relocated into housing developments with fewer local transport-related destinations, but more public open spaces. Nevertheless, consistent with previous cross-sectional evidence (McConville et al., 2011; McCormack et al., 2008), we also found that if residents did gain access to a mix of neighbourhood destinations, this was positively associated with changes in minutes of local walking, highlighting how responsive walking behavior is to the presence of local destinations. Similarly, in those whose perceptions of their local neighbourhood improved following relocation, minutes of transportation and recreational local walking increased modestly for each positive perception gained and this effect remained even after adjusting for objectively-measured changes in their environments. Thus positive changes in perceived and objective neighbourhood attributes are independently related to changes in walking and suggest that the impact on walking of an enhanced built environment will be greater if residents also perceive these to be favourable changes.

Given growing recognition of the importance of the mix and diversity of local destinations (McCormack et al., 2008; Sallis et al., 2009), the overall changes observed in walking behavior in this study were not surprising. Following relocation to their suburban fringe neighbourhoods, only 11% of study participants gained access to local transport-related destinations, yet 99% gained access to at least one type of public open space (data not shown). The public open space results are likely to reflect local planning requirements in Perth which, since the 1950s, have specified that 10% of the sub-dividable land in new developments must be allocated to public open space (Stephenson & Hepburn, 1955). Thus, all housing developments studied had access to at least one public open space. Moreover, in many housing developments studied (i.e., those developed according to the Western Australian government's Liveable Neighbourhood Guidelines (Western Australian Planning Commission, 2004)), the government also offered property developers an incentive to provide *high quality* public open space i.e., a 2% dispensation on the open space requirement if they developed and maintained the public open spaces during the establishment phase of these new developments. This is likely to have created more attractive neighbourhoods (Owen et al., 2004a) thereby increasing the enjoyment of, and amount of, local recreational walking. No comparable incentive strategy was offered to encourage the early establishment of local businesses or other social infrastructure. It clearly takes time to establish local businesses and services in urban fringe greenfield developments, which explains why few participants gained access to these destinations following relocation. Unless policies or strategies are in place to escalate their development, those relocating to urban fringe developments are likely to live for extended periods in communities with poor access to the facilities required for daily living – including public transport – thereby fostering greater car dependency and unsustainable living (Marmott, 2011). In Western Australia, it is clear that what constitutes a healthy, walkable neighbourhood is well known in urban planning circles, and this is reflected in state urban planning policies (Department of Infrastructure and Transport, 2011; Western Australian Planning Commission, 2000) aimed at creating more pedestrian-friendly environments. Nevertheless, while urban planners might plan for more mixed use development and the location of public transport, there appears to be a gap between policy and policy implementation: or at the very least, there will be a considerable delay in full implementation when new neighbourhoods are developed. This suggests that business development and regional transportation policy and delivery strategies are required to complement urban planning to ensure that plans for well designed communities are both fully implemented, and implemented in a timely manner. Critically, unless urban fringe developments are planned with sufficient population density, it may take decades (if ever) for the infrastructure required for daily living to be provided (Giles-Corti et al., 2012).

This study provides preliminary evidence of a dose-response relationship between transport and recreational walking, and access to a mix of local neighbourhood destinations. This was independent of changes in other known intrapersonal, interpersonal and socio-demographic determinants. For each additional transport-related destination type that increased following relocation, neighbourhood transport-related walking increased by 5.8 mean minutes/week, findings highly consistent with previous cross-sectional evidence conducted in Australia (McCormack et al., 2008) and elsewhere (McConville et al., 2011). McCormack and colleagues found that for each additional local (i.e., within 1500m) transport destination present, transport walking increased by an additional 11 minutes/fortnight (McCormack et al., 2008). Moreover, McConville et al. (McConville et al., 2011) found an increase in the likelihood of achieving sufficient levels of transport-related walking (i.e., ≥150 minutes/week) for each additional type of destination located within 800m of home.

This highlights the importance of both the presence and mix of local destinations to optimize walking outcomes.

However, contrary to previous research (e.g., (Rodriguez et al., 2006)) we also found preliminary longitudinal evidence that recreational walking also may be determined by increasing access to a mix of supportive, local recreational opportunities highlighting the importance of social infrastructure. In this study, for each additional recreational destination type that increased, recreational walking increased by 17.6 mean minutes/week ($p=0.078$). This increased to 21.0 mean minutes/week ($p<0.05$) when 'attitude towards', and 'enjoyment of local walking' were removed from the model, confirming cross sectional evidence (Owen et al., 2004a) that an attractive local environment encourages recreational walking. Our results suggest that access to well designed green space may partly influence recreational walking by making the experience of walking more pleasant and enjoyable. This finding is important given that questions have been raised about whether the built environment is indeed a determinant of recreational walking (Rodriguez et al., 2006). However, there is evidence that exposure to nature is restorative and beneficial to mental health (Francis, 2010), further supporting the importance of green space. Thus, RESIDE provides vital quasi-experimental evidence reinforcing the 19th century view (Giles-Corti et al., 2005) of the value and importance of public open space for the health and well-being of residents.

If the level of change observed in this relocation study (i.e., about 6 minutes of additional transport walking per additional transport destination-type present and 18 minutes of additional recreational walking per additional recreational destination-type present) were able to be achieved across entire population groups simply by increasing access to suitable destinations in all areas, the population health impacts could be significant. For example, more than a decade ago, it was estimated a five percentage point increase in the proportion of

Australians who were moderately physically activity could save as many as 600 lives per year and the health system $18 million annually (Stephenson & Bauman, 2000).

From a public health perspective, this study provides further longitudinal evidence that efforts to increase the mix and diversity of local transport- and recreational-related destinations are to be encouraged (McCormack et al., 2008; Sallis et al., 2009). It supports the notion that the physical characteristics of communities enable and promote health behaviours and thus have the potential to reduce social inequalities in health (Marmott, 2011). In new housing developments, it may therefore be warranted to consider providing incentives (e.g., to the private sector) and/or introducing infrastructure levies that would facilitate the early establishment of a mix of local businesses (e.g. shops, retail) and social infrastructure (e.g., public transport, government health and community services), as well as public open space. This might include levies also being paid by residents living in amenity-rich neighbourhoods to fund the social infrastructure required to support healthy and sustainable living in newly established areas. However, it is also important to explore how these tools could be used to facilitate the retrofitting of established neighbourhoods (Giles-Corti & Donovan, 2002b). Importantly, greater emphasis needs to be placed on the location and design of local infrastructure, with the aim of maximizing the number of people able to access these facilities using active modes of transport (i.e., walking, cycling and public transport).

Contrary to previous findings, we found no evidence that self-selection related to the choice of residential location was associated with changes in walking. Indeed, nearly 90 percent of RESIDE participants cited 'affordability' as the main reason for their choice of neighbourhood (Giles-Corti et al., 2008). Our findings contrast with earlier cross-sectional evidence (Owen et al., 2007), however in cross-sectional studies participants generally recall (often from the distant past) reasons for neighbourhood choice. Plausibly, their current responses reflect current preferences, rather than what influenced their original choice of neighbourhood.

Limitations

Our findings are limited to new home buyers moving into new housing developments, most of which were greenfield developments located on the urban fringe. This was unavoidable given RESIDE aimed to study the impact of the built environment on behavior, controlling for self selection. This required that participants be surveyed prior to relocation and new home buyers were more readily identified than other groups, for example, those who rent accommodation. This is a major limitation and future studies may attempt to replicate this study design with other population groups, particularly those more disadvantaged. Nevertheless, those living on the urban fringe as home owners or tenants, typically move to the outer suburbs in search of more affordable housing, and tend to be less advantaged those living closer to the city. Thus our findings are important because they highlight inequalities, in that (at least when they first relocate) these residents have very poor access to local amenities and public transport.

While RCTs are often seen as the gold-standard for intervention research, randomization is generally impossible when investigating the impact of the built environment on free living adults. In this study, a natural experiment was undertaken. These studies provide an alternative study design for complex interventions around the built environment (Ogilvie et al., 2007) and are increasingly being recognized as providing valuable policy-relevant evidence (Medical Research Council, 2011).

Another limitation was the response rate at T1. Although at T2 the response rate was high (83.3%), the recruitment response rate at T1 was only 34% and loss to follow-up was more likely in males, and those younger or employed. Nevertheless, we were limited by the study design and the need to recruit our study participants through an intermediary i.e., the

Water Authority. Our aim was therefore to maximize our retention levels, which were high at T2. Notably, the physical activity patterns of participants and non-participants at T2 were similar.

Conclusion

This study provides longitudinal evidence that both transport and recreational-walking behaviors change in response to changes to access and the diversity of local transport- and recreational-destinations, highlighting the importance of local facilities to enable and promote active living. Together these will help reduce social inequality by providing a supportive environment. However, longer-term follow-up is paramount to explore the full impact on behavior, as some of the features designed to encourage walking (e.g., access local shops and services, green leafy streets) take time to develop. Our results suggest that using policies, incentives and infrastructure levies to facilitate the early introduction of recreational and transport-related destinations into new housing developments are important to reduce inequalities in access, and warrant further investigation.

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Table 1: Variables used in analyses

Variable	Measures	Source	Handling for analyses
DEPENDENT	Self-reported walking for recreation and transport in a usual week within the neighbourhood	[1]Neighbourhood Physical Activity Questionnaire (NPAQ) (Giles-Corti et al., 2006)	Changes in total weekly minutes of neighbourhood recreational and transport-related walking calculated from T1 to T2
COVARIATES	Age, gender, marital status, having children <18 years at home, and level of education	[2]	Baseline (T1) variables adjusted for in all analyses
CHANGE VARIABLES		[1]	Adjustment was made for changes in all known correlates of walking from T1 to T2. Unless indicated variables coded as an increase, decrease or no change.
Socio-demographic change variables	Marital status, work status, level of education, having children <18 years at home, hours worked and minutes travelled to work	[1]	T1 to T2 changes in marital (coded as no change, couple to single, single to couple) and work status (coded as no change – still not in workforce, no change – still in workforce, now in workforce, no longer in workforce, level of education, having children <18 years at home (coded as no change, children now living at home, children no longer living at home), hours worked and minutes travelled to work.
Intrapersonal change variables[3]	Behaviour intention, enjoyment, attitudes towards trying to walk locally, self-efficacy, perceived behavioural control, and	[1](Cutt et al., 2008; Giles-Corti & Donovan, 2002a; Giles-Corti & Donovan, 2003;	T1 to T2 changes in all variables in the **recreation walking models** T1 to T2 changes in all variables except behavioural skills in **transport walking models**.

	behavioural skills	Giles-Corti et al., 2008)	
Social environmental change variables[3]	Frequency in last month of social support from family and friends who: (i) encouraged; (ii) offered to walk; or (iii) walked with; the study participant (5 point scale: never to very often) Dog ownership (Yes/No)	[1]Modified from (Sallis et al., 1987) (Cutt et al., 2008)	T1 to T2 changes in all variables included in the **recreation walking models** T1 to T2 changes in encouragement to walk (only) included in **transport walking models**
Objective built environment change variables[3]	Seven transport-related destinations (i.e., post offices, bus stops, delicatessens, supermarkets within 800m of study participant's home, and train stations, shopping centres or CD or DVD stores within 1.6km) Three recreation-related destinations (i.e., beaches within 800m, or parks or sports fields within 1.6km)	[4]Participant addresses were geocoded and destinations sourced from SENSIS Pty. Ltd. using a Geographic Information System (GIS). Choice of variables based on (GR McCormack et al., 2008)	Number out of seven of key transport-related walking destinations (range 0-7) that increased from T1 to T2. Number out of three of key recreation-related walking destinations (range 0-3) that increased from T1 to T2.
Perceived built environment change variables	Scales and individual items measuring perceived access to mixed use and services,[5] fewer cul de sacs, having footpaths on most streets; neighbourhood aesthetics,[5] shorter intersection distances, many alternative routes,	[1]Based on neighbourhood Environment and Walking Scale (Cerin et al., 2006)	Score constructed based on number of favourable changes in perceptions T1 to T2 associated with transport and recreational walking (p<0.20). **Recreation walking models** included the number out of fourteen key recreation-related neighbourhood perceptions that became more favourable: perceived access to mixed use and services,

	slower traffic speeds, traffic slowing devices, accessibility of local parks or nature reserve, traffic safety,[5] crime safety,[5] infrastructure and safety for walking and local footpaths, hilly streets, the presence of major barriers (five-point Likert scale)		neighbourhood aesthetics, fewer cul de sacs, 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, and a decrease in hilly streets and major barriers (Range=0-14). **Transport walking models** included the number out of four key transport-related neighbourhood perceptions that became more favourable: perceived access to mixed use services, fewer cul de sacs, having footpaths on most streets, and infrastructure and safety for walking (Range=0-4).
MEASURES OF SELF SELECTION	Importance of 21 reasons that may have influenced participants choice of new housing development (five-point Likert scale)	[2](Giles-Corti et al., 2008)	T1 items were factor analysed using principal axis factoring extraction and oblique rotation (see Table 2). Five factors accounted for 42% of the variables and were used as 'self selection scales' in subsequent analyses.

[1]Data derived from both the T1 and T2 RESIDE questionnaires; [2]Data derived from T1 RESIDE questionnaire only; [3]The choice of interpersonal, intrapersonal and environmental variables included in recreational and transport-walking models based on our previous research (Giles-Corti & Donovan, 2002a; Giles-Corti & Donovan, 2003; GR McCormack et al., 2008); and knowledge of the literature. [4] Data derived from both T1 and T2 Geographic Information System data; [5]This variable is a scale.

Table 2: Factor analysis of factors that influenced purchase of home in new housing development

Item	Pedestrian and cycling friendly streets	Accessible services for daily living	Child friendly	Proximate parks and recreation facilities	Safe, diverse and easy living community
Streets designed safer for pedestrians/cyclists	0.803[1]	0.017	-0.035	-0.029	0.153
Streets have footpaths	0.673[1]	0.118	0.056	-0.010	0.137
Ease of cycling	0.632[1]	0.045	-0.132	0.136	-0.138
Streets designed to minimize traffic	0.409[1]	0.012	-0.012	0.024	0.320
Ease of walking	0.329[1]	0.172	0.078	0.285	0.164
Closeness to public transport	0.120	0.589[2]	-0.026	0.048	-0.064
Desire nearby shops/services	0.063	0.526[2]	0.035	0.160	0.168
Access to freeway	0.109	0.395[2]	0.176	0.079	0.100
Closeness to place study	0.177	0.379[2]	-0.230	0.050	-0.090
Closeness to jobs	-0.030	0.309[2]	-0.184	-0.038	0.019
Affordability/value	-0.141	0.221[2]	-0.045	-0.018	0.188
Closeness to school	0.003	0.100	-0.727[3]	0.099	-0.048
Designed safe for children	0.171	-0.077	-0.530[3]	-0.007	0.432
Closeness to variety of parks	0.028	-0.144	-0.108	0.778[4]	0.143
Closeness to parks	0.090	-0.107	-0.147	0.544[4]	0.158
Closeness to recreational facilities	0.144	0.172	-0.072	0.422[4]	0.132
Closeness to beach	-0.050	0.083	0.057	0.421[4]	-0.085
Safety from crime	0.150	0.095	0.025	0.010	0.573[5]
Sense of community	0.165	0.014	-0.060	0.172	0.448[5]
Easy find way around neighbourhood	0.213	0.120	-0.139	0.026	0.427[5]

Choice lot sizes and housing types	0.019	0.013	0.005	0.104	0.347[5]
% Variance	28.2	4.2	3.7	3.4	2.7
Cronbach's alpha for scale[a]	0.82	0.63	0.67	0.68	0.67

[a] Scales[1-5] includes all items indicated with relevant superscript

Table 3: Socio-demographic and behavioural characteristics of study participants at T1 by whether they completed questionnaires at T2

Characteristic	Completed T1 only (n=388)	Completed T1 & T2 (n=1,420)	p-value
Gender (Male)	47.7	38.6	0.001
Mean age (years)	37.2 (11.8)	40.7 (11.8)	< 0.001
Marital status			
Married/defacto	76.3	83.0	< 0.001
Separated/divorced/widowed	6.7	8.1	
Single	17.0	8.9	
Education			
Secondary or less	40.6	39.4	0.732
Trade/apprentice/certificate	38.0	37.4	
Bachelor or higher	21.4	23.2	
Work status			
Work	88.4	81.4	0.005
No work	8.8	13.3	
Retired	2.8	5.3	
Mean hours paid or unpaid work (SD)	39.7 (14.8)	36.5 (14.3)	< 0.001
Mean minutes spent travelling to and from work daily[a] (SD)	55.5 (31.2)	56.1 (33.6)	0.798
Children under 18 years at home	54.9	70.4	< 0.001
Access to motor vehicle for personal use (Always)	90.7	93.2	0.103
Mean weekly minutes of transport-related walking within neighbourhood	26.0 (57.7)	26.5 (57.6)	0.877
Mean weekly minutes of recreational walking within neighbourhood	62.5 (92.4)	69.0 (99.5)	0.245

[a]Excludes those who work from home, in multiple locations or who were not in the workforce at T1

Table 4: Univariate associations between changes (**Δ**) in built environment, interpersonal and intrapersonal characteristics (T1 to T2) and **Δ** mean minutes of transport-related and recreational walking

Change in built environment characteristic	% (n=1420)	Δ Transport-related walking[a]	p-value	Δ Recreational walking[a]	p-value
		-8.5	<0.001	15.5	<0.001
Built environment items and scales					
Number of objectively measured transport-related destination types that increased[b]		7.0	0.014	-2.9	0.627
Number of objectively measured recreation-related destination types that increased[c]		-3.0	0.531	22.1	0.028
Perceived access mixed use and services			0.002		0.021
Decrease	61.9	-11.9		11.2	
No change	14.4	-4.8		12.5	
Increase	23.7	-2.0		28.5	
Perceived neighbourhood aesthetics			0.468		0.005
Decrease	30.5	-10.6		2.8	
No change	11.5	-5.8		21.6	
Increase	58.0	-7.9		21.3	
Perceive infrastructure and safety for walking			0.039		0.194
Decrease	40.0	-11.8		11.7	
No change	15.4	-10.0		10.2	
Increase	44.6	-5.1		20.7	
Perceived traffic safety			0.353		0.024
Decrease	22.5	-6.5		10.7	
No change	32.0	-11.1		7.9	
Increase	45.6	-7.9		23.2	
Perceived crime safety			0.955		0.081
Decrease	21.1	-8.2		4.8	
No change	16.0	-8.0		14.0	
Increase	63.0	-8.9		19.5	

Perceive streets in neighbourhood hilly making it difficult to walk			0.741		0.180
Decrease	19.6	-10.4		6.5	
No change	44.6	-7.8		15.7	
Increase	35.7	-8.5		20.1	
Perceive major barriers present			0.785		0.024
Decrease	28.6	-9.2		20.4	
No change	47.7	-7.7		18.9	
Increase	23.7	-9.6		2.8	
Perceive not many cul de sacs			0.050		0.004
Decrease	17.7	-8.7		2.1	
No change	33.9	-12.5		26.2	
Increase	48.5	-5.7		12.9	
Perceive intersection distance to be short			0.872		0.069
Decrease	22.9	-9.4		15.7	
No change	42.9	-8.8		9.3	
Increase	34.2	-7.7		23.1	
Perceive many alternative routes			0.232		<0.001
Decrease	18.5	-13.0		-3.4	
No change	53.7	-7.4		15.1	
Increase	27.8	-7.9		28.9	
Perceive traffic speeds slow			0.572		0.009
Decrease	17.4	-5.7		9.6	
No change	49.6	-9.2		10.0	
Increase	33.0	-9.2		26.9	
Perceive traffic slowing devices present			0.417		0.138
Decrease	26.1	-9.2		21.8	
No change	37.5	-10.2		9.1	
Increase	36.3	-6.5		17.6	

Perceive local park or nature reserve easily accessible			0.317		0.004
Decrease	14.9	-13.0		-4.1	
No change	54.3	-7.9		16.9	
Increase	30.8	-7.5		22.6	
Perceive footpaths on most streets in local area			0.159		0.016
Decrease	17.2	-12.8		3.8	
No change	51.4	-6.5		13.4	
Increase	31.4	-9.6		25.4	
Number of transport-related neighbourhood perceptions that changed favourably[d]		3.5	0.002	6.1	0.010
Number of recreation-related neighbourhood perceptions that changed favourably[e]		0.8	0.082	4.5	<0.001

[a] Adjusted for neighbourhood clustering, baseline age, gender, education level, marital status, having <18 children at home and minutes of recreational and transport-related walking; [b] Number of types of transport-related destinations that increased (post offices, bus stops, delicatessens and supermarkets within 800m; and train stations, shopping centres, CD/DVD stores within 1.6km) (range 0-7); [c] Number of types of recreation-related destinations that increased (beaches within 800m; and parks, sports fields within 1.6km) (range 0-4); [d] Number of transport-related neighbourhood perceptions with $p \leq 0.20$ that became more favourable (perceived access to mixed use services, fewer cul de sacs, having footpaths on most streets, infrastructure and safety for walking) (range 0-4); [e] Number of recreation-related neighbourhood perceptions with $p \leq 0.20$ that became more favourable (perceived access to mixed use 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 reserves, traffic safety, crime safety, infrastructure and safety for walking, presence of hilly streets, presence of major barriers) (range 0-14).

Table 5: Baseline self-selection factors (i.e., reasons for residential location choice, self-selection factors used in previous studies and housing development selected for relocation) by changes (**Δ**) in mean minutes of transport-related and recreational walking **(**T1 to T2)

	% (n=1420)	**Δ Transport-related walking[a]**	**p-value**	**Δ Recreational walking[a]**	**p-value**
Reason for residential location choice					
Streets are pedestrian and cycling friendly			0.019		0.088
Not important or not important at all	25.3	-14.6		14.5	
Somewhat important	7.8	-6.7		-3.6	
Important	66.9	-6.5		18.1	
Access to services/jobs/place study			0.188		0.279
Not important or not important at all	40.1	-10.7		20.6	
Somewhat important	11.7	-3.4		13.9	
Important	48.2	-8.0		11.7	
Access to school			0.429		0.346
Not important or not important at all	27.0	-11.3		19.5	
Somewhat important	13.0	-9.7		23.0	
Important	60.0	-7.1		12.1	
Close to parks and recreational facilities			0.036		0.460
Not important or not important at all	22.7	-12.1		9.5	
Somewhat important	11.4	-14.4		17.1	
Important	65.9	-6.3		17.3	
Safe, diverse, easy living community			0.182		0.957
Not important or not important at all	11.3	-14.3		13.5	
Somewhat important	6.4	-11.8		17.0	
Important	82.3	-7.5		15.7	

Self selection scale used in previous studies[11]			0.277		0.190
Not important or somewhat important	59.6	-9.7		18.4	
Important	40.4	-6.9		11.2	
Type of housing development selected[b]			0.988		0.928
Liveable	29.2	-8.5		14.9	
Hybrid	20.3	-9.0		14.0	
Conventional	50.5	-8.5		16.4	

[a] Adjusted for neighbourhood clustering and baseline age, gender, education level, marital status, having children at home, and minutes of walking; [b] The State Government assessed each of the housing development structure plans against the Liveable Neighbourhood Guidelines as one of the following: Liveable i.e., complying with most of the guidelines; Hybrid i.e., complying with many but not all of guidelines; Conventional i.e., a conventional development not consistent with guidelines.

Table 6: Adjusted associations between changes (**Δ**) in built environment characteristics (T1 to T2) and **Δ** in mean minutes of transport and recreational walking

Change in built environment characteristics	Un-adjusted	Model 1	Model 2	Model 3	Model 4	Model 4 + self selection
TRANSPORT-RELATED WALKING						
Number of objectively measured transport-related destination types that increased	7.0[1]	6.7[2]	5.8[3]	6.0[4]	6.1[5]	5.8[6]
	0.014	0.018	0.042	0.038	0.035	0.045
Number of transport-related neighbourhood perceptions that changed favourably	3.5[1]		3.1[3]	3.0[4]	3.1[5]	3.0[6]
	0.002		0.006	0.008	0.008	0.011
RECREATIONAL WALKING						
Number of objectively measured recreational destination types that increased	22.1[1]	21.7[7]	19.4[8]	21.1[9]	17.2[10]	17.6[11]
	0.028	0.031	0.053	0.034	0.078	0.070
Number of recreation-related neighbourhood perceptions that changed favourably	4.5[1]		4.4[8]	3.8[9]	2.3[10]	2.2[11]
	<0.001		<0.001	<0.001	0.024	0.033

[1]Adjusted for neighbourhood clustering, and baseline age, gender, education level, marital status, having children at home and minutes of walking
[2]Adjusted for neighbourhood clustering, and baseline age, gender, education level, marital status, having children at home, change in work status, change in the number of hours worked, change in time to travel to work and minutes of walking; [3]Model 1 plus further adjustment for increased number of favorable transport-related neighbourhood perceptions; [4]Model 2 plus further adjustment for encouragement to go walking; [5]Model 3 plus further adjustment for behavioural intention, enjoyment and attitude towards trying to walk and perceived behavioural control; [6]Model 4 plus further adjustment for self-selection factors; [7]Adjusted for neighbourhood clustering, and baseline age, gender, education level, marital status, having children at home, change in level of education and minutes of walking; [8]Model 1 plus further adjustment for increased number of favorable recreation-related neighbourhood perceptions; [9]Model 2 plus further adjustment for encouragement to go walking, offering to go walking, walking with study participant and dog ownership; [10]Model 3 plus further adjustment for behavioural intention, enjoyment and attitude towards trying to walk, perceived behavioural control and behavioural skills for walking; [11]Model 4 plus further adjustment for self-selection factors.

Research highlights:

- The built environment determined recreational (RW) and transport walking (TW).
- Following relocation, TW declined, as did access to transport-related destinations.
- Yet for each type of TW destination gained, TW increased 5.8 minutes/week.
- Following relocation, RW increased, as did access to recreational destinations.
- For each type of recreational destination gained, RW increased 17.6 minutes/week.