Can the built environment reduce health inequalities? A study of neighbourhood socioeconomic disadvantage and walking for transport

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1 **Abstract**

2 Residents of socioeconomically disadvantaged neighbourhoods are more likely to walk for
3 transport than their counterparts in advantaged neighbourhoods; however, the reasons for
4 higher rates of transport walking in poorer neighbourhoods remain unclear. We investigated
5 this issue using data from the HABITAT study of physical activity among 11,037 mid-aged
6 residents of 200 neighbourhoods in Brisbane, Australia. Using a five-step mediation analysis
7 and multilevel regression, we found that higher levels of walking for transport in
8 disadvantaged neighbourhoods was associated with living in a built environment more
9 conducive to walking (i.e. greater street connectivity and land use mix) and residents of these
10 neighbourhoods having more limited access to a motor vehicle. The health benefits that
11 accrue to residents of disadvantaged neighbourhoods as a result of their higher levels of
12 walking for transport might help offset the negative effects of less healthy behaviours (e.g.
13 smoking, poor diet), thus serving to contain or reduce neighbourhood inequalities in chronic
14 disease.

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18 **Keywords:** health inequalities; walking; built environment; neighborhood; transport

1. Background

A large number of studies have examined the association between neighbourhood socioeconomic disadvantage and health (Pickett and Pearl, 2001; Kawachi and Berkman, 2003; Riva et al., 2007). Some of this work shows that residents of disadvantaged neighbourhoods experience higher rates of chronic disease (Diez Roux et al., 2001; Dragano et al., 2007; Chaix, 2009) and associated risk factors such as obesity (van Lenthe and Mackenbach, 2002; King et al., 2006; Matheson et al, 2008) than their counterparts in advantaged neighbourhoods. A parallel literature has investigated the relationship between neighbourhood disadvantage and physical activity, and studies find that residents of disadvantaged neighbourhoods are less likely to walk for leisure, recreation, or exercise, but more likely to walk for transport-related purposes such as accessing local shops and services, or utilizing public transport (Miles et al., 2008). Given that active transport (i.e. walking and cycling) confers health benefits to individuals who regularly undertake these activities (Hamer and Chida, 2008; Pucher et al., 2010; De Nazelle et al., 2011), higher levels of utilitarian walking among residents of disadvantaged neighbourhoods may provide some protection against chronic disease in those who walk. This may contain the disease rate for the neighbourhood as a whole and serve to reduce chronic disease inequalities between advantaged and disadvantaged neighbourhoods.

There are a number of plausible explanations why residents of disadvantaged neighbourhoods walk more for transport. First, the built environments of disadvantaged neighbourhoods may be more conducive to, and supportive of, active transport. A large public health and transport literature has examined features of the built environment that facilitate walking for transport (Handy et al, 2002; Owen et al, 2007; McCormack et al, 2008), and reviews of this work (Saelens et al 2003; Sallis et al, 2004; Leslie et al, 2007; Saelens et al, 2008; McCormack and Shiell 2011) have identified street connectivity, land-use mix, and residential density as being critical. Neighbourhoods with good street connectivity

1 have a well-connected street network with numerous intersections, few cul-de-sacs, and small
 2 block-sizes: these features result in shorter and more direct travel routes between origins and
 3 destinations. Land-use reflects the mix of commercial, institutional, office, and residential
 4 zones available in the neighbourhood. Walking for transport is more likely in neighbourhoods
 5 with diverse land uses, and a variety of centralised facilities and services that are closer
 6 together, with shorter travel distances between them. Residential density refers to the spatial
 7 concentration of people or dwellings within a given land area. In higher density
 8 neighbourhoods, destinations such as shops, services, and workplaces are more likely to be
 9 close to people's homes, facilitating pedestrian activity.

10 Second, residents of disadvantaged neighbourhoods may have limited or no access to
 11 a private motor vehicle (Badland and Schofield, 2006). Motor vehicle access is often found to
 12 be associated with lower levels of walking for transport (Giles-Corti and Donovan, 2002;
 13 Cerin et al, 2009; Frank et al, 2010), and respondents from disadvantaged backgrounds are
 14 less likely to own or have access to a motor vehicle (Sharma et al, 2010). Hence higher levels
 15 of transport walking among residents of disadvantaged neighbourhoods might simply reflect
 16 their more limited access to a private motor vehicle, and not to any differences in the design
 17 of the neighbourhoods in which they live (Ross, 2000; Besser and Dannenberg, 2005; Cerin
 18 et al 2009).

19 Third, access to and use of a motor vehicle has been shown to be lower in
 20 neighbourhoods that are characterised as highly walkable (i.e. they are residentially dense,
 21 with well connected street networks, and a variety of proximal land uses) (Cervero, 1996;
 22 Rodriguez et al, 2006; Frank et al, 2006; Frank et al, 2010). If socioeconomically
 23 disadvantaged neighbourhoods are more walkable, resulting in their residents having less
 24 need for a motor vehicle to undertake short trips to local amenities and services, then
 25 transport-related walking is likely to be higher in these neighbourhoods.

To date, none of these explanations has been extensively investigated, hence our understanding of the relationships between neighbourhood disadvantage, the built environment, motor vehicle access, and walking for transport is at a nascent stage. As a result there is little supporting evidence to guide interventions to promote active transport as a possible means of containing (and ideally reducing) neighbourhood inequalities in chronic disease and obesity.

Based on the limited research available, we developed a conceptual model that postulates the interrelationships between neighbourhood disadvantage, the built environment, motor vehicle access, and walking for transport (Figure 1). In this paper we use an ecological mediation analysis to investigate the contribution of the built environment and motor vehicle access to differences in walking for transport between advantaged and disadvantaged neighbourhoods. In examining this model, we successively test a number of hypotheses implicit in each of the Figure 1 pathways. Specifically, we hypothesise that:

1. Residents of socioeconomically disadvantaged neighbourhoods will report higher levels of walking for transport than residents of more advantaged neighbourhoods (pathway 1),
2. Socioeconomically disadvantaged neighbourhoods will have greater street connectivity and land use mix and be more residentially dense (pathway 2).
3. Individuals of low socioeconomic position, and residents of disadvantaged neighbourhoods will have more limited access to a motor vehicle than those in more advantaged areas (pathway 3),
4. Motor vehicle access will be lower in neighbourhoods with greater street connectivity, land use mix and density (pathway 4),
5. Levels of walking for transport will be higher among residents with limited access to a motor vehicle (pathway 5),
6. Residents of neighbourhoods with greater street connectivity, land use mix, and residential density will walk more for transport-related purposes (pathway 6),

7. Differences between advantaged and disadvantaged neighbourhoods in walking for transport will be due to concomitant differences in their built environments; however this will be at least partially mediated by inequalities in access to a motor vehicle (all pathways modelled simultaneously).

FIGURE 1 ABOUT HERE

This investigation uses data from the HABITAT (**H**ow **A**reas in **B**risbane **I**nfluence **H**eal**T**h and **A**c**T**ivity) study. HABITAT is a multilevel longitudinal (2007-2011) study of physical activity among mid-aged (40 – 65 years) adults living in Brisbane, Australia (Turrell et al, 2010). The primary aim of HABITAT is to examine patterns of change in physical activity over the period 2007 – 2011 and to assess the relative contributions of environmental, social, psychological and socio-demographic factors to these changes. In this paper, we present findings from the HABITAT baseline survey data which were collected in May 2007.

2. Methods

The HABITAT study received ethical clearance from the Queensland University of Technology Human Research Ethics Committee (Ref. No. 3967H).

Sample Design

Details about HABITAT's sampling design have been published elsewhere (Burton et al, 2009). Briefly, a multi-stage probability sampling design was used to select a stratified random sample (n=200) of Census Collector's Districts (CCD), and from within each CCD, a random sample of people aged 40-65 years (n=17,000).

Neighbourhood-level unit of analysis, data sources, and measures

The primary area-level unit-of-analysis for the HABITAT study is the CCD: these are the smallest administrative units used by the Australian Bureau of Statistics (ABS) to collect

census data. In urban areas such as Brisbane, a CCD contains an average of 200 private dwellings which are deemed to be relatively homogeneous in terms of their socioeconomic characteristics. CCDs are embedded within a larger suburb, hence the area corresponding to, and immediately surrounding, a CCD is likely to have meaning and significance for their residents: for this reason, we hereafter use the term ‘neighbourhood’ to refer to CCDs.

Neighbourhood disadvantage: Each of the 200 CCDs was assigned a socioeconomic score using the ABS’ Index of Relative Socioeconomic Disadvantage (IRSD) (Australian Bureau of Statistics, 2006). The IRSD scores were calculated using 2006 census data and derived by the ABS using Principal Components Analysis. A CCD’s IRSD score reflects each area’s overall level of disadvantage measured on the basis of 17 variables that capture a wide range of socioeconomic attributes, including; education, occupation, income, unemployment, household structure, and household tenure (plus others). For analysis, the 200 CCDs were grouped into quintiles based on their IRSD scores with Q1 denoting the 20% (n=40) most disadvantaged areas in Brisbane and Q5 the least disadvantaged 20% (n=40).

Built environment measures: The neighbourhood-level data used to derive the measures of street connectivity, density, and land use mix, were provided by the Brisbane City Council (the local government authority responsible for the jurisdiction covered by the HABITAT study) and Pitney Bowes MapInfo (Pitney Bowes Software). Street connectivity was measured as a count of the number of four-way or more intersections within each CCD. The number of intersections across the 200 CCDs ranged from 0-12, with a median and mean of 2.0 and 2.5 (SD 2.3) per CCD respectively. For analysis, neighbourhoods were grouped into categories containing no 4-way or more intersections (n=40), those containing 1-2 intersections (n=79), 3-4 intersections (n=44), and 5 or more intersections (n=37).

Land use mix was derived from data that quantified the proportion of land area within a CCD that was zoned residential, commercial, industrial, recreational, and other. Using an entropy equation described by Leslie et al (2007) the five types of land use were combined to form a measure that ranged from 0-1, with 0 representing complete homogeneity of land use within the CCD, and 1 representing an even distribution of the five types of land use. Across the 200 CCDs, entropy scores ranged from 0.0002-0.942, with a median of 0.315 and mean of 0.340 (SD 0.264). For analysis, the neighbourhoods were grouped into quintiles, with quintile 1 containing 40 neighbourhoods with the lowest entropy scores (i.e. the most homogenous land use mix).

Residential density was measured by calculating the average block-size in square metres of all residential zoned land within each CCD. Smaller values indicate greater residential density: values ranged from 135.0-110,549m² across the 200 CCDs, with a median of 656 m² and a mean of 1757 m² (SD 8935). Given the distributional characteristics of this variable (i.e. highly skewed with some extreme outliers), the neighbourhoods were grouped into quintiles, with quintile 1 containing 40 neighbourhoods with the lowest levels of residential density.

Two spatial covariates were also used in the modelling to adjust for possible spatial confounding (see Statistical analysis): CCD size, which measured the area of each CCD in square kilometres (range 0.02-70.8, median 0.270, mean 0.881, SD 5.5), and the road network distance (km) between the Brisbane Central Business District (CBD) and the geographic centroid of each CCD (range 0.80-33.6km, median 11.4, mean 12.1, SD 5.5). The latter was conceptualized as capturing the urban-suburban distribution of Brisbane neighbourhoods, with neighbourhoods located further away from the CBD exhibiting built environment characteristics less conducive to walking for transport (e.g. greater distances between residents' homes and destinations such as shops and public transport). For analysis,

both measures were grouped into quintiles, with quintile 1 containing 40 neighbourhoods that were smallest in size, and closest to the CBD.

Individual-level data, response rates, and measures

A structured self-administered questionnaire was developed that asked respondents about their neighbourhood, participation in PA, correlates of activity, and socio-demographic characteristics. The questionnaire was administered using a mail-survey method developed by Dillman (2007), and after excluding out-of-scope respondents (i.e. deceased, no longer at the address, unable to participate for health-related reasons) a total of 11,037 usable surveys were returned (response rate 68.5%).

Controls:

The IRSD is an ecologic exposure derived by aggregating individual responses to questions asked on the national census form. When testing for an ecologic effect with an aggregated exposure it is necessary to simultaneously model individual-level variables (e.g. income) and their neighbourhood-level analogues (e.g. % low income households)(Subramanian et al, 2007). To this end, we included three individual-level socioeconomic controls in the multilevel analyses – education, occupation, and household income – each of which has an area-level analogue represented in the IRSD. Sex, age, and self-rated health were also included as controls. The latter was included as exploratory analyses suggested that part of the association between neighbourhood disadvantage, individual-level SEP, and walking for transport was due to the unmeasured correlation of these factors with respondents' health status (i.e. respondents from disadvantaged neighbourhoods and those of low SEP reported poorer self-rated health, and those with poorer health were less likely to walk for transport).

Motor vehicle access: this was measured with a single question which asked “Do you have a motor vehicle available for your personal use?” The response options were ‘Yes, always’, ‘Yes, sometimes’, ‘No’, and ‘Do not drive’: for analysis, the latter two options were combined.

Walking for transport: this was measured using a single question that asked participants to report how much time they had spent walking for transport (i.e., travel to and from work, to do errands, or to go from place to place) in the past week. Data were categorized into four levels of walking: none, $\geq 1 < 60$ minutes, $\geq 60 < 150$ minutes, and ≥ 150 minutes. Those in the highest category met current physical activity recommendations by walking for transport exclusively (Haskell et al, 2007).

Analysis

The baseline HABITAT sample (n=11,037) is broadly representative of the wider Brisbane population, although residents from disadvantaged areas, blue-collar employees, and persons who did not attain a post-school educational qualification are underrepresented (Turrell et al, 2010). For the present analysis, respondents who had missing data for education, motor vehicle access, self-rated health or walking for transport were excluded (n=326), which reduced the sample to n=10,711 (Table 1).

TABLE 1 ABOUT HERE

Exploratory analysis, which included inspecting maps and testing associations using a range of bivariate and multi-variable techniques, identified a complex spatial patterning between neighbourhood disadvantage, neighbourhood size, road distance of each neighbourhood from the Brisbane CBD, street connectivity, land use mix, residential density, and walking for transport. Based on this exploratory work, it was evident that neighbourhood-size and distance of the neighbourhood to the CBD spatially confounded associations between

neighbourhood disadvantage, street connectivity, land use mix, residential density, and walking for transport. To account for this confounding the models, where deemed appropriate, were adjusted for neighbourhood-size and/or distance to the CBD, with the decision being determined on the basis of the findings of the exploratory research (all tables include footnotes indicating which of the two spatial confounders were adjusted for).

When examining the contribution of the built environment and motor vehicle access to the association between neighbourhood disadvantage and walking for transport we used a five-step mediation-based approach that was broadly consistent with that initially proposed by Baron and Kenny (1986) and further developed and extended by others (MacKinnon 2008; Hayes, 2009; Fairchild and Mackinnon, 2009).

Step 1: Walking for transport (the dependent variable) was regressed on neighbourhood disadvantage (the independent variable)

Step 2(a): Neighbourhood disadvantaged was separately correlated with street connectivity, land use mix, and residential density (the built environment mediators). Our examination of these associations was examined with a neighbourhood-only (n=200) dataset in which the categories of street connectivity and the quintiles of residential density and land use mix were correlated with the quintiles of neighbourhood disadvantage using Spearman's Rank correlation (ρ). This analysis was undertaken using *Stata/SE for Windows* (StatCorp, 2007).

Step 2(b): Neighbourhood disadvantage, education, occupation, and household income were separately regressed on motor vehicle access (the individual-level mediator).

Step 3: Each of the built environment variables was separately regressed on motor vehicle access

Step 4: Each of the built environment variables and motor vehicle access were separately regressed on walking for transport. In keeping with Baron and Kenny (1986) these analyses were adjusted for neighbourhood disadvantage: in the absence of

this adjustment, the built environment measures and motor vehicle access (the mediators) might be spuriously associated with walking for transport (the dependent variable) because both are correlated with neighbourhood disadvantage (the independent variable).

Step 5: Neighbourhood disadvantage was regressed on walking for transport with adjustment for the built environment measures, and then with further adjustment for motor vehicle access. For this final step we assessed the contribution of the mediators to neighbourhood socioeconomic differences in walking for transport using a proportional difference in odds ratio measure (Droomers et al, 1999).

All analyses, except Step 2(a), were conducted using multilevel multinomial logistic regression in *MLwiN* (Rasbash et al, 2003). As recommended (Browne, 2009), the multilevel logistic model parameters were estimated using Markov chain Monte Carlo (MCMC) simulation. All multilevel results are reported as odds ratios (OR) and their 95% credible intervals (CrI).

3. Results

Step 1: Neighbourhood disadvantage and walking for transport

There was a strong, graded association between neighbourhood disadvantage and walking for transport (Figure 2). Residents of disadvantaged neighbourhoods were significantly more likely to walk at low, medium, and high levels than their counterparts in more advantaged neighbourhoods.

FIGURE 2 ABOUT HERE

Step 2(a): Neighbourhood disadvantage and the built environment

The correlation analyses between neighbourhood disadvantage and the built environment measures showed a weak but significant association (*rho*) between neighbourhood disadvantage and street connectivity ($r=-0.17$, $p=0.011$) and land use mix ($r=-0.13$, $p=0.066$);

however there was no evidence of a bivariate association between neighbourhood disadvantage and residential density ($r=0.07$, $p=0.307$). Substantively, the significant associations indicate that more advantaged neighbourhoods have fewer four-way intersections and lower entropy scores (i.e. more likely to have single land uses).

Step 2(b): Neighbourhood disadvantage, individual-level SEP and motor vehicle access

Table 2 shows graded associations between neighbourhood disadvantage, individual-level SEP, and motor vehicle access. Residents of disadvantaged neighbourhoods, and respondents with school-only educational qualifications, blue collar workers, and those in low income households, were more likely than their higher status counterparts to have restricted or no access to a motor vehicle.

TABLE 2 ABOUT HERE

Step 3: Built environment and motor vehicle access

Table 3 shows the association between features of the built environment and motor vehicle access. In neighbourhoods characterised by greater street connectivity, land use mix, and density, residents were more likely to report that they ‘sometimes’ or ‘never’ had access to a motor vehicle (or didn’t drive). For example, residents were 45% (OR 1.45, 95% CrI 1.00-2.14) more likely to report that they never had access to a motor vehicle if they lived in a neighbourhood with 5 or more 4-way intersections, 102% (OR 2.02, 95% CrI 1.28-3.24) more likely if they lived in highly mixed-use neighbourhoods, and 233% (OR 3.33, 95% CrI 2.24-5.00) more likely if they lived in the most residentially dense neighbourhoods.

TABLE 3 ABOUT HERE

Step 4: Built environment, motor vehicle access, and walking for transport

Residents of neighbourhoods with good street connectivity, diverse land use mix, and greater residential density were more likely to have reported walking for transport in the previous week (Table 4). Strong and linear associations were also observed between motor vehicle

access and walking for transport: those without access to a motor vehicle (including those who didn't drive) were much more likely to walk for transport than respondents who always had access.

TABLE 4 ABOUT HERE

Step 5: Neighbourhood disadvantage and walking for transport, adjusted for the built environment and motor vehicle access

Table 5 presents the association between neighbourhood disadvantage and walking for transport before (Model 1) and after adjustment for the built environment (Model 2) and after further adjustment for motor vehicle access (Model 3). There was a strong association between neighbourhood disadvantage and the likelihood of walking for transport in the last week, with residents' of disadvantaged neighbourhoods being more likely to walk at low, medium, and high levels (Model 1). Indeed, the magnitude of the association between the least and most disadvantaged neighbourhoods and walking for transport increased linearly across the low (OR 1.54), medium (OR 1.80), and high (OR 2.26) levels of walking. After adjustment for the built environment (Model 2) the association between neighbourhood disadvantage and walking for transport was attenuated for all levels, although residents of disadvantaged neighbourhoods were still more likely to have reported doing transport-related walking in the previous week. Additional adjustment for motor vehicle access (Model 3) produced a further attenuation of the association between neighbourhood disadvantage and walking for transport: however, in this fully adjusted model residents of disadvantaged neighbourhoods were still more likely to walk for transport at low, medium, and high levels.

TABLE 5 ABOUT HERE

4. Discussion

Residents of socioeconomically disadvantaged neighbourhoods were significantly more likely to have reported walking for transport than residents of advantaged neighbourhoods, which is consistent with the findings of previous research (Miles et al, 2008; Cerin et al 2009; Berrigan et al, 2006; van Lenthe et al, 2005). However, in an attempt to understand this association we developed a mediation model based on studies from the transport, urban planning, and public health literatures: this model posited that differences between advantaged and disadvantaged neighbourhoods in walking for transport would be due to concomitant differences in their built environments and access to a motor vehicle. When testing the separate pathways in this model we observed associations that concurred with our hypotheses and the findings of earlier work. Specifically, the built environments of disadvantaged neighbourhoods tended to be characterized by a greater number of 4-way intersections and a more diverse land use mix (Lee and Mouden, 2006; Neckerman et al, 2009), respondents from low SES backgrounds and residents of disadvantaged neighbourhoods were less likely to have access to a motor vehicle (Sharma et al, 2010), living in a well connected, residentially dense neighbourhood with a variety of land uses was associated with more limited access to a motor vehicle (Cervero, 1996; Rodriguez et al, 2006; Frank et al, 2006; Frank et al, 2010), and each of these factors was associated with higher levels of walking for transport. The key outcome of this study however, and its most important contribution to the literature, emerged from the fully adjusted mediation analysis which showed that higher levels of walking for transport in disadvantaged neighbourhoods was partly due to both living in a built environment more conducive to walking and residents having more limited access to a motor vehicle. Hence both neighbourhood- and individual-level factors explain neighbourhood variation in walking for transport, a finding that is consistent with the central tenets social-ecological theory (Sallis et al, 2006) and one that

further underscores the use of a multilevel perspective in advancing our understanding of how neighbourhoods influence health (Diez Roux, 2001).

To date, studies investigating the association between neighbourhood disadvantage and physical activity have typically operationalised activity using either broad categories of physical activity (e.g. none/some), frequency-based indicators (e.g. days per week) or dichotomous measures (e.g. meeting recommended levels or not). In this present study, the use of these types of measures would have obscured a fuller understanding of neighbourhood disadvantage and walking for transport as the measures provide little information about the quantity of activity, hence detailed analyses of activity patterns or dose-response relationships are not possible. Moreover, the qualitative nature of many extant measures of activity (e.g. none/some) does not allow the data to be examined with reference to the current physical activity recommendations. In this study we redressed these limitations by using a quantitative measure of walking for transport that was based on time (minutes per week) and operationalised using four specific categories that allowed us to assess whether the magnitude of the association between neighbourhood disadvantage and walking for transport was the same or different at varying levels of the activity spectrum. Moreover, the walking for transport categories were calibrated so that they could be interpreted in relation to the latest physical activity recommendations (Haskell et al, 2007). Using multilevel multinomial logistic regression we observed that the magnitude of the association between neighbourhood disadvantage and walking for transport was not constant across low ($>0<60$ mins/week), medium ($\geq 60<150$ min/week) and high (≥ 150 min/week) levels of walking: the association was weakest (but still statistically significant) at low levels, intermediate at medium levels, and strongest at high levels. The reasons for this patterning are unclear: possibly, advantaged and disadvantaged neighbourhoods in Brisbane do not differ greatly on the built environment characteristics that facilitate low levels of walking for transport, whereas neighbourhood differences might be much greater for those environmental factors that influence high levels

of walking. Future research could explore this issue by examining associations between different ‘thresholds’ of the built environment and walking for transport. For example, what level of residential density or street connectivity is required to bring about a meaningful change in the proportion of the population who walk for transport at low, medium, and high levels, and to what extent do advantaged and disadvantaged neighbourhoods differ in meeting these thresholds? Answers to these and related questions would usefully inform the development of policies relating to urban design and planning.

Approximately 15% of the HABITAT sample spent between 60 and 150 minutes walking for transport in the week prior to receiving the survey; however, the odds of spending this amount of time walking was 79% higher in residents of the most disadvantaged neighbourhoods (quintile 5) than residents of the least disadvantaged neighbourhoods. Similarly, whilst just under 7% of the sample accumulated 150 minutes or more of transport walking during the reference period, the odds of walking at this level were 220% higher in residents of the most disadvantaged neighbourhoods than their least disadvantaged counterparts. Taken together, these results indicate that residents of disadvantaged neighbourhoods were more likely to be meeting (or close to meeting) the current (2007) American College of Sports Medicine and American Heart Association physical activity recommendations exclusively by active transport (Haskell et al, 2007). Given that walking for transport confers health benefits to individuals who regularly undertake this activity (Sallis et al, 2004; Hamer and Chida, 2008; Pucher et al., 2010; De Nazelle et al., 2011), higher levels of transport walking among residents of disadvantaged neighbourhoods may protect against the onset and progression of chronic disease in residents who walk. By extension, these higher levels of walking for transport might serve to reduce the chronic disease rates in disadvantaged walkable neighbourhoods as a whole, and hence reduce chronic disease inequalities between advantaged and disadvantaged neighbourhoods. Importantly, despite residents of disadvantaged neighbourhoods being more likely to walk for transport, they also

walk less for recreation or exercise (Giles-Corti and Donovan, 2002; Leslie et al, 2010) than residents of advantaged neighbourhoods, and they are more likely to smoke (Turrell et al, 2012; Shohaimi et al, 2003; Diez Roux et al, 2003) and possibly have poorer diets (Lovasi et al, 2009) and consume alcohol to harmful levels (Mulia and Karriker-Jaffe, 2012). In principle at least, the negative health consequences of these types of behaviours might be partially offset by the higher levels of walking for transport in disadvantaged neighbourhoods, particularly if this walking is done at moderate or high intensity.

Higher levels of walking for transport in disadvantaged neighbourhoods were due in part to features of their built environments hence the challenge for urban and transport planners, developers, and policy makers is to ensure that disadvantaged neighbourhoods are designed to be walkable, thus increasing opportunities for local walking and reducing the need to drive. Such investments are also likely to have positive implications for the population more broadly, as active transport produces numerous co-benefits in addition to improved health, such as increased social capital, and reduced traffic congestion, fossil fuel dependency, and greenhouse gas emissions (Giles-Corti et al, 2010; Woodcock et al, 2009). However, investments directed at initiating and supporting walking for transport in disadvantaged neighbourhoods need to be paralleled by similar efforts to increase leisure-time walking in these areas: the greatest gains to health within disadvantaged neighbourhoods, and hence reductions in health inequalities between advantaged and disadvantaged neighbourhoods, are likely to result from increasing both the levels of walking for transport and walking for recreation or exercise (and total physical activity more generally).

Study limitations

A number of methodological and analytic issues need to be considered when interpreting and understanding this study's findings. First, survey non-response in the HABITAT baseline

1 study was 31.5%, and non-response tended to be higher among the low SES and residents of
2 disadvantaged neighbourhoods. If these non-responding low SES residents were more likely
3 to have walked for transport, then the neighbourhood socioeconomic differences reported in
4 this paper are likely to be an underestimate of the ‘true’ magnitude of socioeconomic
5 differences in the Brisbane population (Rothman et al, 2008). Second, we assessed cross-
6 sectional associations between neighbourhood disadvantage, the built environment and motor
7 vehicle access, and walking for transport, hence no claims about causality can be made.
8 Third, our finding of an association between neighbourhood disadvantage and walking for
9 transport might be confounded by individual-level socioeconomic factors not included in the
10 models. However, we adjusted our analyses for the three most commonly used individual-
11 level measures of SES in health research (i.e. education, occupation and income) (Galobardes
12 et al, 2007; Turrell et al 2003) thus it is likely they captured the unmeasured influence of
13 other socioeconomic factors not included in the models. Fourth, via the use of the
14 proportional reduction in odds ratio measure we were able to demonstrate that together the
15 built environment and motor vehicle access explained one-half to two-thirds of the relative
16 inequality in walking for transport between the least and most disadvantaged
17 neighbourhoods. However, we were unable to quantify the unique contribution of the built
18 environment and motor vehicle access due to the correlation between these factors and their
19 complex interrelationships with neighbourhood disadvantage and walking for transport
20 (Blakely and Woodward, 2000). Fifth, residents of disadvantaged neighbourhoods were
21 significantly more likely to walk for transport even after adjustment for the built environment
22 and motor vehicle access, which suggests that other (unmeasured) factors contribute to
23 neighbourhood socioeconomic differences in transport-related walking. This warrants further
24 investigation, as these remaining factors may be important in informing future interventions.

25

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1 Conclusion

2 Residents of socioeconomically disadvantaged neighbourhoods are more likely than others to
3 walk for transport: this is partly because they live in more walkable neighbourhoods and are
4 less likely to have access to a motor vehicle. It is plausible that increased transport walking
5 may serve to contain or reduce health inequalities between advantaged and disadvantaged
6 neighbourhoods, by protecting residents of the latter against even higher levels of chronic
7 disease. Given trends to house lower income households in fringe developments on the
8 outskirts of cities (Baum and Gleeson 2010) there is clearly a need to ensure these are
9 designed to be walkable. This could help decrease health inequality by increasing
10 opportunities for local walking and reducing the need to drive. A comprehensive approach
11 that involves designing neighbourhoods with connected street networks, and access to local
12 and regional public transport and employment, and local shops and services is important.
13 This would not only produce better health outcomes, but would also have co-benefits across a
14 range of sectors including: reducing traffic congestion and improving air quality, reducing
15 green house emissions, and increasing social capital and sense of community. To inform
16 future interventions designed to increase and maintain participation in active transportation,
17 further research is required to understand other factors associated with neighbourhood
18 differences in walking for transport.

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Figure 1: Conceptual model of the association between neighbourhood socioeconomic disadvantage, built environment, motor vehicle access and walking for transport

Table 1: Neighbourhood disadvantage, socio-demographic characteristics, access to a motor vehicle, self-rated health, and walking for transport: persons aged 40-65 years in the HABITAT analytic sample (n=10,711)

Neighborhood disadvantage (quintiles)	n	%
Q5 (Least disadvantaged) ^a	2521	23.5
Q4	2645	24.7
Q3	2209	20.6
Q2	1775	16.6
Q1 (Most disadvantaged)	1561	14.6
Sex		
Males	4742	44.3
Females	5969	55.7
Age		
40 – 44	2186	20.4
45 – 49	2367	22.1
50 - 54	2210	20.6
55 - 59	2032	19.0
60 - 65	1916	17.9
Highest attained education level		
Bachelor's degree or higher	3378	31.5
Diploma/Associate diploma	1253	11.7
Certificate (trade/business)	1892	17.7
School	4188	39.1
Occupation		
Managers & Professionals	3606	33.7
White collar	2362	22.1
Blue Collar	1498	14.0
Not Easily Classified ^b	3245	30.3
Household income		
\$130,000 pa or more	1855	17.3
\$72,800 - \$129,999	2789	26.0
\$41,600 - \$72,799	2387	22.3
\$26,000 - \$41,599	1151	10.8
\$0 - \$25,999	992	9.3
Missing	1537	14.4
Motor vehicle access		
Always	9598	89.6
Sometimes	554	5.2
Never/Don't drive	559	5.2
Self-rated health		
Excellent/Very Good/Good	8816	82.3
Fair/Poor	1895	17.7
Walking for transport (minutes last week)		
None	6972	65.1
Low ($\geq 1 < 60$)	1470	13.7
Moderate ($\geq 60 < 150$)	1566	14.6
High (≥ 150)	703	6.6

^a Q5 contains the 40 least disadvantaged neighborhoods in the HABITAT sample and Q1 the 40 most disadvantaged

^b Comprises groups outside of the labour market: retired, home duties, disabled, student, and unemployed.

Figure 2: Neighbourhood disadvantage and minutes of walking for transport in the last week ^{a, b, c}

- ^a The two reference groups are 'no' walking for transport in the previous seven days, and residents of the least disadvantaged neighbourhoods (quintile 5)
- ^b Adjusted for within-neighbourhood variation in sex, age, self-rated health, education, occupation and household income, and between-neighbourhood variation in road network distance to the Brisbane Central Business District, and neighbourhood size
n=10,711 individuals, n=200 neighbourhoods
- ^c Probability of walking for transport significantly different from the reference group (i.e. residents of the least disadvantaged neighbourhoods) at * $p \leq 0.05$, ** $p \leq 0.01$, † $p \leq 0.001$, ‡ Not statistically significant at $p \leq 0.05$

Table 2: Motor vehicle access by individual-level socioeconomic position and neighbourhood disadvantage (estimated odds ratios and 95% credible intervals, CrI)

n=10,711 individuals n=200 neighbourhoods		Motor Vehicle Access			
		OR, 95% CrI		OR, 95% CrI	
	Always	Sometimes		Never/Don't drive	
Neighborhood disadvantage (quintiles)^a					
Q5 (Least disadvantaged) ^b	1.00				
Q4	1.00	1.09	0.80, 1.48	1.26	0.81, 1.94
Q3	1.00	1.22	0.89, 1.66	1.67	1.08, 2.57
Q2	1.00	1.18	0.84, 1.63	2.08	1.35, 3.19
Q1 (Most disadvantaged)	1.00	1.37	0.97, 1.93	3.19	2.10, 4.85
<i>Highest attained education level^c</i>					
Bachelor's degree or higher	1.00				
Diploma/Associate diploma	1.00	0.89	0.66, 1.19	0.94	0.62, 1.38
Certificate (trade/business)	1.00	0.84	0.64, 1.09	1.51	1.10, 2.04
School	1.00	0.86	0.69, 1.05	2.25	1.72, 2.81
<i>Occupation^{c, d}</i>					
Managers & Professionals	1.00				
White collar	1.00	0.90	0.70, 1.17	2.02	1.46, 2.83
Blue Collar	1.00	1.00	0.74, 1.34	2.47	1.73, 3.55
<i>Household income^{c, e}</i>					
\$130,000 pa or more	1.00				
\$72,800 - \$129,999	1.00	1.38	1.04, 1.86	3.08	1.69, 5.91
\$41,600 - \$72,799	1.00	1.27	0.94, 1.73	4.25	2.34, 8.09
\$26,000 - \$41,599	1.00	1.29	0.89, 1.87	6.31	3.44, 12.10
\$0 - \$25,999	1.00	1.87	1.29, 2.74	16.73	9.29, 31.75

^a. Model adjusted for within-neighbourhood variation in sex, age, self-rated health, education, occupation, and household income

^b. Q5 contains the 40 least disadvantaged neighborhoods in the HABITAT sample and Q1 the 40 most disadvantaged

^c. Each socioeconomic indicator modelled separately, with adjustment for sex, age, self-rated health, and neighbourhood disadvantage

^d. The 'Not easily classified' category (see Table 1) was retained in the analysis but the results are not presented in the table.

^e. The 'Missing' income category (see Table 1) was retained in the analysis but the results are not presented in the table.

Table 3: Built environment and motor vehicle access (estimated odds ratios and 95% credible intervals, CrI)^a

n=10,711 individuals n=200 neighbourhoods	Motor vehicle access				
	Always	Sometimes		Never/don't drive	
		OR	95%CrI	OR	95%CrI
<i>Street connectivity</i>					
<i>(No. 4-way intersections)</i>					
None	1.00			1.00	
1 to 2	1.00	1.14	0.87, 1.49	1.13	0.81, 1.60
3 to 4	1.00	1.24	0.90, 1.73	1.48	1.01, 2.17
5 or more	1.00	1.38	1.00, 1.89	1.45	1.00, 2.14
<i>Land use mix</i>					
Q1(largely single use)	1.00			1.00	
Q2	1.00	0.99	0.69, 1.42	1.30	0.87, 1.97
Q3	1.00	1.30	0.93, 1.85	1.71	1.15, 2.55
Q4	1.00	1.26	0.86, 1.84	1.58	1.01, 2.50
Q5 (highly mixed use)	1.00	1.35	0.91, 2.03	2.02	1.28, 3.24
<i>Residential density</i>					
Q1(least dense)	1.00			1.00	
Q2	1.00	1.15	0.85, 1.58	1.45	0.98, 2.19
Q3	1.00	1.56	1.14, 2.13	1.84	1.25, 2.76
Q4	1.00	1.48	1.07, 2.04	2.18	1.50, 3.32
Q5 (most dense)	1.00	1.73	1.25, 2.39	3.33	2.24, 5.00

^a. All models adjusted for within-neighbourhood variation in sex, age, self-rated health, education, occupation, and household income, and between-neighbourhood variation in socioeconomic disadvantage and neighbourhood size

Table 4: Built environment, motor vehicle access, and walking for transport (estimated odds ratios and 95% credible intervals, CrI)^a

n=10,711 individuals n=200 neighbourhoods		Minutes walking for transport in the last week					
	None	>0<60 Minutes (low)		≥60 <150 Minutes (medium)		≥150 Minutes (high)	
		OR	95%CrI	OR	95%CrI	OR	95%CrI
<i>Street connectivity^a</i> (No. 4-way intersections)							
None	1.00			1.00		1.00	
1 to 2	1.00	1.23	0.99, 1.53	1.10	0.87, 1.43	1.30	0.95, 1.76
3 to 4	1.00	1.36	1.07, 1.73	1.40	1.06, 1.85	1.83	1.29, 2.56
5 or more	1.00	1.38	1.06, 1.78	1.54	1.16, 2.08	2.03	1.39, 2.89
<i>Land use mix^a</i>							
Q1(largely single use)	1.00			1.00		1.00	
Q2	1.00	1.02	0.76, 1.35	1.18	0.86, 1.64	1.15	0.77, 1.74
Q3	1.00	1.07	0.82, 1.41	1.35	0.97, 1.84	1.16	0.78, 1.72
Q4	1.00	1.05	0.77, 1.42	1.39	0.97, 1.98	1.37	0.88, 2.17
Q5 (highly mixed use)	1.00	1.19	0.86, 1.63	1.81	1.25, 2.58	1.62	1.02, 2.58
<i>Residential density^b</i>							
Q1(least dense)	1.00			1.00		1.00	
Q2	1.00	1.15	0.90, 1.48	1.14	0.86, 1.52	1.09	0.75, 1.57
Q3	1.00	1.37	1.06, 1.79	1.28	0.95, 1.74	1.19	0.80, 1.77
Q4	1.00	1.40	1.07, 1.82	1.39	1.04, 1.87	1.40	0.94, 2.04
Q5 (most dense)	1.00	2.40	1.84, 3.13	1.96	1.46, 2.66	2.72	1.85, 3.99
<i>Motor vehicle access^a</i>							
Always	1.00						
Sometimes	1.00	3.35	2.63, 4.27	4.61	3.65, 5.78	4.50	3.31, 6.09
Never/Don't drive	1.00	5.17	4.00, 6.71	7.43	5.76, 9.53	11.21	8.17, 14.63

^a. Adjusted for within-neighbourhood variation in sex, age, self-rated health, education, occupation, and household income, and between-neighbourhood variation in socioeconomic disadvantage and neighbourhood size

^b. Adjusted for within-neighbourhood variation in sex, age, self-rated health, education, occupation, and household income, and between-neighbourhood variation in socioeconomic disadvantage

Table 5: Neighbourhood disadvantage and walking for transport (Model 1), with adjustment for the built environment (Model 2) and further adjustment for motor vehicle access (Model 3) (estimated odds ratios and 95% credible intervals, CrI)^a

Neighborhood disadvantage	None	>0<60 Min. (low)			≥60 <150 Min. (medium)			≥150 Min. (high)		
		OR	95%CrI	% difference	OR	95%CrI	% difference	OR	95%CrI	% difference
Model 1 ^b										
Q5 (Least Dis.)	1.00	1.00			1.00			1.00		
Q4	1.00	1.12	0.89, 1.40	--	1.16	0.89, 1.50	--	1.20	0.87, 1.64	--
Q3	1.00	1.27	1.00, 1.60	--	1.53	1.17, 1.90	--	1.33	0.95, 1.86	--
Q2	1.00	1.39	1.09, 1.78	--	1.83	1.40, 2.39	--	1.66	1.19, 2.34	--
Q1 (Most Dis.)	1.00	1.54	1.19, 1.99	--	1.80	1.33, 2.40	--	2.26	1.57, 3.25	--
Model 2 ^{c, d}										
Q5	1.00	1.00		--	1.00		--	1.00		--
Q4	1.00	1.09	0.87, 1.38	--	1.08	0.83, 1.41	--	1.11	0.80, 1.57	--
Q3	1.00	1.27	0.98, 1.65	0.0 ^f	1.38	1.04, 1.86	-28.3	1.22	0.84, 1.75	--
Q2	1.00	1.36	1.05, 1.77	-7.7	1.62	1.22, 2.17	-25.3	1.44	1.00, 2.09	-33.3
Q1	1.00	1.43	1.08, 1.90	-20.4	1.53	1.12, 2.10	-33.8	1.92	1.31, 2.84	-27.0
Model 3 ^e										
Q5	1.00	1.00		--	1.00		--	1.00		--
Q4	1.00	1.08	0.86, 1.36	--	1.08	0.83, 1.39	--	1.10	0.80, 1.54	--
Q3	1.00	1.24	0.92, 1.60	-11.1 ^g	1.35	1.01, 1.78	-34.0	1.17	0.81, 1.71	--
Q2	1.00	1.34	1.03, 1.74	-12.8	1.59	1.18, 2.11	-28.9	1.38	0.96, 2.01	-42.4
Q1	1.00	1.29	0.98, 1.72	-46.3	1.36	1.00, 1.84	-55.0	1.63	1.10, 2.44	-50.0

a. n=10,711 individuals, n=200 neighbourhoods

b. Model 1: adjusted for within-neighbourhood variation in sex, age, self-rated health, education, occupation, and household income, and between-neighbourhood variation in road network distance to the Brisbane Central Business district (CBD), and neighbourhood size.

c. Model 2: model 1 plus adjustment for, street connectivity, land use mix, and residential density (excluding motor vehicle access)

d. Although neighbourhood disadvantage and residential density were not significantly associated on the basis of the bivariate (correlation) analyses, the multi-variable modelling indicated that when in the presence of other built environment characteristics, density made a measurable (attenuating) contribution to the association between neighbourhood disadvantage and walking for transport: hence it was retained in the mediation analysis.

e. Model 3: model 1 plus simultaneous adjustment for motor vehicle access and street connectivity, land use mix, and residential density

f. Proportional difference in odds ratio (OR Model 1 – OR Model 2)/OR Model 1 – 1. Calculated only when Model 1 estimate (odds ratio) significantly different from the reference group (i.e. residents of the least disadvantaged neighbourhoods).

g. (OR Model 1 – OR Model 3)/OR Model 1 – 1

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- Disadvantaged neighbourhoods have greater street connectivity and a more diverse land use mix
- Residents of disadvantaged neighbourhoods are less likely to have access to a motor vehicle
- The built environment of disadvantaged neighbourhoods and limited motor vehicle access contribute to higher levels of walking for transport
- Built environment interventions that increase walking for transport in disadvantaged neighbourhoods may reduce inequalities in chronic disease

h.

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