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Street connectivity and walking for transport: role of neighborhood destinations

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Abstract

Objective. Built environment attributes may be important determinants of physical activity. Greater street connectivity has been shown in several studies to be associated with adults' walking for transport (WFT). We examined the extent to which this association can be explained by the availability of utilitarian destinations.

Methods. Adults (n=2544) participating in the Physical Activity in Localities and Community Environments (PLACE) study in Adelaide, Australia during 2003-2004, reported their WFT and perceived distances to 16 utilitarian destinations. Connectivity was calculated as the ratio of the number of intersections to Census Collection District land area. Marginal models via generalized estimating equations were used and the product-of-coefficients test was used to test mediation effects.

Results. Connectivity was significantly associated with destination availability and with WFT frequency. The connectivity-WFT relationship was attenuated after taking availability of destinations into account, but remained significant. Availability of destinations accounted for 16% of the total effect of connectivity on WFT.

Conclusions. Higher connectivity can be associated with more frequent WFT, partly because more utilitarian destinations are available in areas with well-connected street networks. Further clarification of these relationships and other pathways through which connectivity influences residents' walking can inform urban design initiatives to promote physical activity.

Keywords: walking, street network, destinations, built environment, urban form, urban design

Introduction

Regular walking including – leisure and transport walking – has substantial preventive-health benefits (Lee and Buchner, 2008; Pucher et al., 2010). However, population estimates show participation in walking for leisure or transport that is sufficient to obtain health benefits has a low prevalence (Ham et al., 2005; Kruger et al., 2008; Pucher et al., 2011). For example, in 2011 the population prevalences among US adults of ‘any walking’ and ‘walking 30 min per day’ were 18% and 8% respectively (Pucher et al., 2011). To bring about sustainable increases in walking, environmental and policy initiatives at the neighborhood level are required (Heath et al., 2012). Ecological models of physical activity behavior and previous research identifying environmental correlates have highlighted aspects of the neighborhood built environment as potentially-significant determinants of different types of walking (Owen et al., 2004; Saelens and Handy, 2008; Sugiyama et al., 2012). A particular built environment attribute associated specifically with walking for transport (WFT) is street connectivity (Badland et al., 2008; Cervero et al., 2009; Li et al., 2008; Saelens et al., 2012). Although some studies have found no or negative associations of street connectivity with total walking or walking for leisure (Ball et al., 2007; Gómez et al., 2010; Lovasi et al., 2008; Oakes et al., 2007), a recent review reported street connectivity to be positively associated with WFT in about 60% of the studies identified (Sugiyama et al., 2012).

Street connectivity refers to the directness and availability of alternative routes between home and local destinations (Frank and Engelke, 2005; Handy et al., 2003), and is typically conceptualized as the number of intersections (3-way or more) per land-area unit (Dill, 2004; Handy et al., 2003; Wang et al., 2013). Low street connectivity is usually characterized by a low density of intersections, barriers preventing direct routes (e.g., cul-de-sacs) and few route

choices (Handy et al., 2003); high street connectivity is typically found in areas with a grid pattern street layout (Handy et al., 2003).

Well-connected street networks should act to facilitate residents' walking, through providing direct and short routes to destinations and permitting more route options (Berrigan et al., 2010; Handy et al., 2003; Handy et al., 2010; Saelens et al., 2003). However, it is also plausible that the relationship between higher levels of street connectivity and walking is partly mediated through other environmental attributes, particularly utilitarian destinations (such as local shops and services) that are found in well-connected areas. Studies have consistently shown that adults are more likely to walk for transport if they have destinations within walking distance (Owen et al., 2004; Saelens and Handy, 2008; Sugiyama et al., 2012). Street connectivity may be important for walking, provided that there are local destinations to walk to; however, the potential mediating role of destinations in the relationship between street connectivity and walking has not yet been examined. The hypothesis is that the association between street connectivity and WFT will be mediated in part by the availability of utilitarian destinations (Figure 1). Therefore, we examined to what extent the association between street connectivity and adults' WFT might be explained by the availability of utilitarian destinations.

INSERT FIGURE 1 ABOUT HERE

Methods

This study used cross-sectional survey data from the Physical Activity in Localities and Community Environments (PLACE) study conducted in Adelaide, Australia during 2003-

2004. Detailed methods of data collection have been described elsewhere (Owen et al., 2007). Briefly, residential addresses were randomly selected from 154 Census Collection Districts (CCDs) within the Adelaide Statistical Division. These CCDs were chosen from the neighborhoods in the top and bottom quartiles of walkability to have large variability in environmental characteristics related to physical activity. Walkability was calculated as a composite measure including objectively-determined residential density, street connectivity, land use mix, and net retail area ratio (Frank et al., 2005; Leslie et al., 2007). An invitation letter to participate in the study was sent to the addresses identified, and a self-administered survey was sent to those who were eligible (20–65 years) and agreed to participate. The total number of respondents was 2,650. The overall response rate, as a proportion of all the households initially identified, was 11.5%. After excluding those who did not provide data on frequency of WFT, the sample consisted of 2,544 participants. The Behavioural and Social Sciences Ethics Committee of the University of Queensland approved the study. All participants provided informed consent prior to being enrolled in the study.

Measures

Walking for transport (WFT). Participants reported their frequency of WFT (days) in the past week, by responding to the following question: “During the last 7 days, on how many days did you walk for at least 10 minutes at a time to go from place to place?”. This is an item in the International Physical Activity Questionnaire-Long Form (IPAQ) (Craig et al., 2003). Adequate reliability and validity of this instrument have been previously reported (Craig et al., 2003).

Built environment measures. Using Geographic Information Systems (GIS), objectively-measured street connectivity was calculated as the ratio of the number of intersections (3-way

or more) to the land area of a CCD. Street connectivity was log-transformed to adjust for positive skew. Participants' self-reported perceived closest distance (defined as minutes of walking: '1-5 min'; '6-10 min'; '11-20 min'; '20-30 min'; '30+ min'; 'don't know') to each of the following 16 utilitarian destinations: 1) local shops; 2) supermarket; 3) hardware store; 4) greengrocer; 5) laundry/dry cleaner; 6) post office; 7) library; 8) primary school; 9) other schools; 10) bookstore; 11) video store; 12) pharmacy; 13) bus or train stop; 14) professional offices; 15) appliance store; and 16) restaurant/cafe. The availability of utilitarian destinations was operationalized as the total number of destination types within a 10-minute walk. In the absence of a specific walking distance to use for research purposes, our choice of a 10-min walking distance corresponds reasonably closely to the 1km walking distance that has been used in previous studies on relationships of built environment attributes with walking (Kaczynski et al., 2009; Koohsari et al., 2013; Lovasi et al., 2008; Sugiyama et al., 2014).

Socio-demographic variables. Participants reported their age, gender, educational attainment, work status, marital status, having children in the household, annual household income, car ownership, and neighborhood socioeconomic status (median household income).

Statistical Analysis

Linear marginal models were fitted to examine the association between log-transformed street connectivity and the availability of utilitarian destinations, adjusting for socio-demographic variables. Marginal models using generalized estimating equations with exchangeable correlation structure and robust standard errors were used to adjust for clustering of participants within CCDs.

To test the mediation effect of the availability of utilitarian destinations on the association between street connectivity and WFT, a product-of-coefficients test was used as this has greater power than other commonly used mediation analyses (MacKinnon et al., 2002). Although the Baron and Kenny approach (Baron and Kenny, 1986) has recognized limitations (Hayes, 2009; MacKinnon et al., 2002), we present results from the steps of this process, for comparability with existing studies that address the relationship of street connectivity on WFT, without examining mediation. Marginal models were fitted to the frequency of WFT using log-transformed street connectivity as the exposure variable, adjusting for socio-demographic variables, with and without the inclusion of the availability of utilitarian destinations. Negative binomial regression was used to model WFT frequency due to the presence of over-dispersion.

Results

Table 1 shows the characteristics of this sample. Participants had a mean age of 44 years (SD=12), and the majority were women (64%), employed (64%), in a relationship (55%), had completed a tertiary or higher degree (46%), had children in their household (31%), had an annual income between AU\$41,600-77999 (28%), and had access to two or more cars in their household (52%). Participants reported a mean of 3.2 days of WFT in the past week (SD=2.5), and a mean of 8.3 utilitarian destinations accessible within 10-minute walk (SD=4.7). Street connectivity (number of intersections per square kilometer) ranged from 12 to 907 (mean: 245; SD: 156).

INSERT TABLE 1 ABOUT HERE

There was evidence of an association between street connectivity (log-transformed) and the availability of utilitarian destinations ($\beta = 3.20$, 95% CI=1.293-5.117), after adjusting for clustering and socio-demographic variables.

Table 2 shows the results of the negative binomial regression models, examining associations between street connectivity and frequency of WFT, with and without availability of utilitarian destinations. There was strong evidence of an association between street connectivity and frequency of WFT ($\beta = 0.27$, 95% CI=0.145-0.399). This association was slightly attenuated, but remained significant after taking availability of utilitarian destinations into account ($\beta = 0.22$, 95% CI=0.111-0.338). The product-of-coefficients test provided evidence to support a mediation effect ($p=0.011$). The number of utilitarian destination types partially mediated the association, accounting for approximately 16% of the total effect of street connectivity on WFT.

INSERT TABLE 2 ABOUT HERE

Discussion

Street connectivity was positively associated with the availability of utilitarian destinations. Availability of utilitarian destinations partially mediated the association between street connectivity and WFT. These findings suggest that high street connectivity facilitates adult residents' WFT, not simply due to street configuration but also partly due to the presence of destinations to which residents can walk.

The associations between street connectivity and destinations may be explained by using the concept of space syntax. Space syntax is a topological concept and method developed

primarily in the fields of urban design and architecture to explore the role of network configuration on locomotion behavior (Hillier, 1996; Hillier and Hanson, 1984). Space syntax measures how a street segment is “integrated” within a larger street network. Highly integrated street segments are easily accessible from other areas, and considered to have higher pedestrian activities. Hillier, who developed space syntax, argued that movement is drawn to more integrated streets within a street network, and consequently such integrated streets attract more commercial destinations (Hillier, 1999). For example, a study in Korea (Kim and Sohn, 2002) found that more integrated areas had higher land-use density. Another recent study (Tsou and Cheng, 2013) also reported significant association of street configuration on retail patterns in Taiwan. While street connectivity itself is a spatial construct, it may have implications on functional aspects of urban form (i.e., how spaces are used within a street network). Indeed, street configuration is considered the “primary generator of pedestrian movement” in space syntax (Hillier et al., 1993). Although research has frequently examined associations of street connectivity with walking, only a few studies have investigated the role of space syntax in walking behaviors (Baran et al., 2008; Koohsari et al., 2013). Future research involving space syntax measures has the potential to contribute new insights into the relationship between urban form and residents’ walking behaviors.

Our findings indicated that 16% of the total effect of street connectivity on WFT was mediated through availability of utilitarian destinations. This indicates that there might be other pathways through which street connectivity influences WFT. Grid-pattern street layouts may increase “legibility”, an individual’s ability to better perceive the spatial arrangement of their built environment (Long and Baran, 2012; Lynch, 1960), and legible urban space has been related to increased motivation for walking (Ewing and Handy, 2009). Other potential pathways between street connectivity and WFT include pedestrian infrastructure

(availability/quality of sidewalks), attractiveness, better public transport service (not simply access to transit stops), car ownership, and difficulties in car parking. However, some studies have shown high street connectivity to be associated with objective and perceived crime and traffic safety (Johnson and Bowers, 2010; Rifaat et al., 2010), which may deter residents from walking. Future research can disentangle the relationship between connectivity and WFT by examining the role of these attributes.

Although our findings suggest a partial mediation effect, as our study is cross-sectional it is not possible to draw conclusions regarding the causality of the associations. It may be that those who commonly walk for transport chose to live in highly connected areas, or areas with a greater number of available destinations within walking distance. Furthermore, it is possible that our analysis may be subject to possible sources of confounding, such as mediator-outcome confounding affected by the exposure (Richiardi et al., 2013), which prevents us from reaching stronger conclusions. Our findings are thus less conclusive than they are hypothesis-generating and further evidence from studies with prospective designs is needed. In addition, research findings on the associations of neighborhood environmental attributes with adults' WFT have identified some age-related differences. For example, the impact of more proximal neighborhood destinations can be stronger among those in older age categories. (King et al., 2011; Shigematsu et al., 2009) Future studies, particularly using prospective designs to overcome some of the limitations that are inherent to our cross-sectional study design, might examine the role and destinations specifically for young adults of working age and for older adults who may no longer be in full-time work.

Another limitation of our findings is that the walking and destination measures used were self-reported, which may be subject to recall error. Perceived distance can have poor

agreement with objectively-measured distance (Ball et al., 2008; Lackey and Kaczynski, 2009). However, perceived measures of the built environment may be more important than the objective measures, depending on the outcome behavior (e.g., Caspi et al., 2012; Gebel et al., 2009; Prins et al., 2009). Future studies with both objective and perceived measures of distance to destinations are needed to confirm the results of this study. In addition, this study examined the presence of the closest destination for each of the 16 different destination types, but not the total number of the each destinations, which may be also relevant to walking for transportation. For example, it is likely that there would be more than one local shop within a 10 min-walk from a participant's location. Furthermore, this study used data collected from the city of Adelaide, which has relatively low intersection density, compared to European and Asian cities. Whether the findings observed in this study apply to other cities or to other populations remains to be determined.

Although street connectivity is a key urban design element that is associated with residents' walking, it is an attribute that may be difficult to modify in existing neighborhoods.

Identifying the pathways through which street connectivity influences walking may provide insights into alternative ways of enhancing walking in this context.

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Conflict of interest

The authors declare there is no conflict of interest.

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Tables

Table 1. Characteristics of study participants (N=2544) (Adelaide, Australia, 2003-2004)

Variable	Mean (SD) or N (%)
Age (years)	44.4 (12.3)
<i>Missing</i>	12 (0.5%)
Gender	
<i>Women</i>	1624 (63.8%)
<i>Missing</i>	4 (0.2%)
Employed	
<i>Yes</i>	1632 (64.2%)
Education	
<i>Tertiary or higher</i>	1174 (46.1%)
Children in household	
<i>Yes</i>	782 (30.7%)
Marital status	
<i>Single</i>	1068 (42.0%)
<i>Couple</i>	1409 (55.4%)
<i>Other</i>	67 (2.6%)
Household income (AUD\$ per annum)	
<i><\$20800</i>	582 (22.9%)
<i>\$20800-41599</i>	641 (25.2%)
<i>\$41600-77999</i>	722 (28.4%)
<i>≥\$78000</i>	500 (19.7%)
<i>Missing</i>	99 (3.9%)
Car ownership	
<i>No car</i>	199 (7.8%)
<i>One car</i>	1030 (40.5%)
<i>Two or more cars</i>	1315 (51.7%)
Neighborhood socioeconomic status	
<i>Higher</i>	1340 (52.7%)
Days of walking for transport in the past week	3.2 (2.5)
Number of utilitarian destination types within 10-minute walk (range: 0 to 16)	8.3 (4.7)

Table 2. Associations of frequency of WFT (days) with street connectivity: negative binomial regression models testing mediation by availability of utilitarian destinations (Adelaide, Australia, 2003-2004)

	Model 1 (without utilitarian destinations) †	Model 2 (with utilitarian destinations) †
	Coefficient (95% CI)	Coefficient (95% CI)
Street connectivity (log-transformed; range: 1.07 to 2.96)	0.27 (0.145, 0.399) *	0.22 (0.111, 0.338) *
Perceived number of utilitarian destination types within 10-min walk (range: 0 to 16)£	-	0.01 (0.005, 0.022) *

† Models adjusted for clustering at the CCD level and for age, gender, education, marital status, children in household, income, employment status, car ownership, and neighborhood socioeconomic status.

* *p*-value for street connectivity prior to inclusion of the potential mediator is <0.001; after including the mediator, the *p*-value is <0.001; CI: Confidence Interval.

£ The model shows associations between availability of utilitarian destinations and frequency of WFT

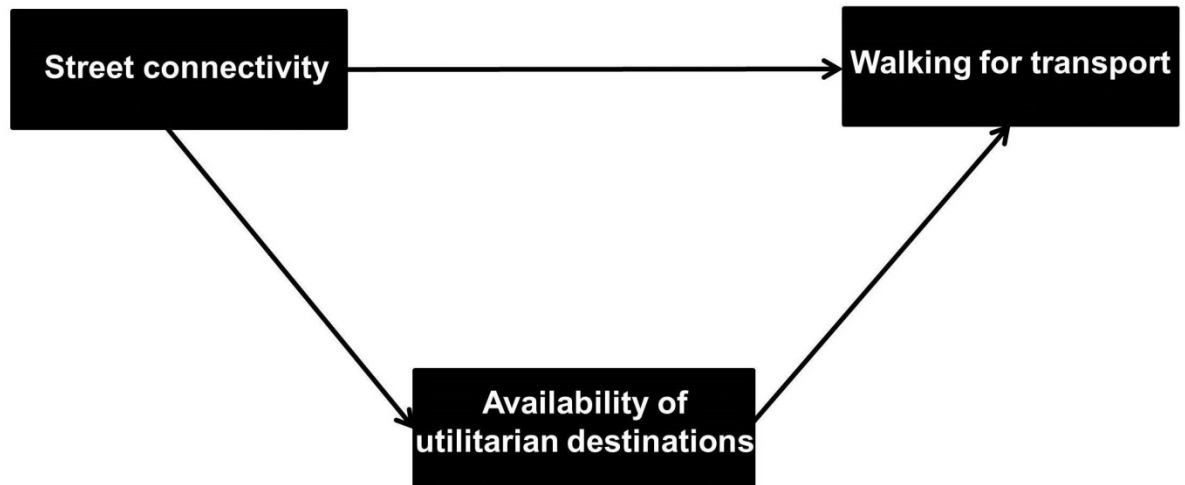


Figure 1. Conceptual diagram to examine if availability of utilitarian destinations is a mediator in the association between street connectivity and walking for transport