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A Longitudinal Analysis of the Influence of the Neighborhood Environment on Recreational Walking within the Neighborhood: Results from RESIDE

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Background: There is limited longitudinal evidence confirming the role of neighborhood environment attributes in encouraging people to walk more or if active people simply choose to live in activity-friendly neighborhoods. Natural experiments of policy changes to create more walkable communities provide stronger evidence for a causal effect of neighborhood environments on residents' walking.

Objectives: We aimed to investigate longitudinal associations between objective and perceived neighborhood environment measures and neighborhood recreational walking.

Methods: We analyzed longitudinal data collected over 8 yr (four surveys) from the RESIDential Environments (RESIDE) Study (Perth, Australia, 2003–2012). At each time point, participants reported the frequency and total minutes of recreational walking/week within their neighborhood and neighborhood environment perceptions. Objective measures of the neighborhood environment were generated using a Geographic Information System (GIS).

Results: Local recreational walking was influenced by objectively measured access to a medium-/large-size park, beach access, and higher street connectivity, which was reduced when adjusted for neighborhood perceptions. In adjusted models, positive perceptions of access to a park and beach, higher street connectivity, neighborhood esthetics, and safety from crime were independent determinants of increased neighborhood recreational walking. Local recreational walking increased by 9 min/wk (12% increase in frequency) for each additional perceived neighborhood attribute present.

Conclusions: Our findings provide urban planners and policy makers with stronger causal evidence of the positive impact of well-connected neighborhoods and access to local parks of varying sizes on local residents' recreational walking and health. https://doi.org/10.1289/EHP823

Introduction

Increasingly, there are calls to "rethink" approaches to the prevention of disease in the face of global rises in noncommunicable diseases and obesity (Das and Horton 2012; Giles-Corti et al. 2016; Kleinert and Horton 2015). Working with sectors outside of health to create more supportive and sustainable built environments is recognized as an important strategy with a range of cobenefits, such as improving health and the environment, reducing traffic congestion and heat island effects, and mitigating the negative impacts of climate change (Cheng and Berry 2013; Sallis et al. 2016; Watts et al. 2015).

Designing cities that promote health is now a multisector global priority, building on the World Health Organization (WHO) decade-old Healthy Cities agenda (Duhl 1996). For example, the 2015 United Nations Sustainable Development Goals 2030 targets both making cities more inclusive, safe, resilient, and sustainable, and ensuring healthy lives and promoting well-being (United Nations 2015). The 2016 United Nations Conference on Housing and Sustainable Urban Development (HABITAT III) set the stage for the New Urban Agenda, including standards for achieving sustainable urban development worldwide (United Nations 2016). Moreover, in late 2016, the WHO Shanghai Declaration reaffirmed its commitment to planning cities to promote health (World Health Organization 2016). Effective translation of findings from transdisciplinary international built environment and health research to urban planning policy and practice will help guide implementation of the sustainable urban development agenda while also promoting health and well-being (Giles-Corti et al. 2016; Sallis et al. 2016; Stevenson et al. 2016).

There is a growing body of evidence showing associations between neighborhood attributes and physical activity, particularly transport walking (Ding and Gebel 2012; McCormack and Shiell 2012; Saelens and Handy 2008; Sallis et al. 2009, 2016). However, to date, much of this evidence is cross-sectional, which limits causal inferences being drawn. Only a handful of recent cohort studies with longitudinal data (Hirsch et al. 2014; Panter et al. 2013) and natural experiments of changes to the built environment (Goodman et al. 2013) provide evidence supporting a causal effect of the built environment on residents' physical activity (Giles-Corti et al. 2013; Halonen et al. 2015; Knuiman et al. 2014; Ranchod et al. 2014; Turrell et al. 2014).

Residential preferences (i.e., self-selection factors) are an important consideration when examining causal relationships between the neighborhood environment and local walking (Boone-Heinonen et al. 2010; Giles-Corti et al. 2008). Longitudinal studies collect repeated measures over time on built environment attributes, walking, and potential confounders. There are now modeling approaches available that utilize all available data on each individual, adjust for measured confounders, and which isolate and compare the between-person (cross-sectional) and within-person (longitudinal) effects of built environment attributes on walking (Allison 2005; Fitzmaurice et al. 2012; Knuiman et al. 2014). This is important because, unlike the between-person effect, the within-person effect is not subject to confounding by unmeasured

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(time constant) self-selection factors and other confounders (Allison 2005; Fitzmaurice et al. 2012; Knuiman et al. 2014).

Another important consideration in studies of the effect of the neighborhood environment on local walking is the effect of different neighborhood environment attributes on different types of behavior. We have previously argued (Giles-Corti et al. 2013) and shown that transport and recreational walking are distinct behaviors and impacted by different neighborhood features. Transport walking involves walking specifically to get to or from somewhere, such as walking to a shop, work, or public transport, while recreational walking is undertaken for recreation, health, or fitness purposes (Giles-Corti et al. 2006). As such, they should be examined using different models using context-specific measures of the behavior (e.g., recreational walking in neighborhood) and behavior-specific determinants (e.g., access to park). To date, relatively few studies have examined the impact of the built environment on recreation-based walking using a longitudinal design (Giles-Corti et al. 2013; Halonen et al. 2015; Ranchod et al. 2014). After a 3-yr follow-up of adults ($n = 6{,}814$) in the U.S. Multi-Ethnic Study of Atherosclerosis, an increase in access to objectively measured neighborhood recreational facility density over time was associated with a smaller decline in recreational physical activity, particularly in older adults (Ranchod et al. 2014). This study was limited because recreational physical activity undertaken in the local neighborhood environment was not measured, and hence the behavioral measure was not matched to the exposure variable, which assessed neighborhood recreational facility density. Moreover, other neighborhood attributes (e.g., parks) previously associated with recreational physical activity, particularly walking (Bancroft et al. 2015), were not investigated.

To date, it appears that only one study, the RESIDential Environments Project (RESIDE), has examined the influence of the neighborhood environment on local recreational walking using a longitudinal design and context-specific measures of both exposure and behavior (Giles-Corti et al. 2013). RESIDE was a natural experiment of an urban policy intervention, and our previous analysis investigated the effect of gaining access to neighborhood destinations on local walking 1 yr after relocating to a new home (Giles-Corti et al. 2006, 2008). Among participants who gained access to recreational destinations (i.e., the beach, a park, or sports fields), their recreational walking increased by almost 18 min/wk for each type (range: 0–3) of recreational destination gained after relocation (Giles-Corti et al. 2013). However, notably, participants had only lived in their new neighborhood for about a year. Additionally, while key infrastructure, such as public parks, are typically delivered early in the land development process, there are often delays in the on-ground delivery of other community infrastructure until there are sufficient people in place to support shops, service, and public transport.

Longer-term follow-up is required to account for the evolving nature of new neighborhoods and the impact of these changes on residents' recreational walking levels over time (Giles-Corti et al. 2013). Hence, this paper advances our previous RESIDE analyses by using data collected over 8 yr (four surveys) to investigate longitudinal associations between objective and perceived neighborhood environment measures and neighborhood recreational walking.

Methods

Sample and Data Collection

RESIDE commenced in 2003 and is a longitudinal natural experiment of 1,813 people building homes in 73 new housing developments across metropolitan Perth, Western Australia. Details of participant recruitment procedures have been reported elsewhere (Giles-Corti et al. 2008). Briefly, participants moving to each development were invited to participate by the state water authority following the land transfer transaction. The following eligibility criteria were applied: English proficiency, ≥ 18 yr, intention to relocate by December 2005, and willingness to complete surveys four times over 8 yr. Participants were recruited by telephone and one person from each household randomly selected. Participants were surveyed four times: baseline (T1: $n = 1{,}813$), then approximately 1 (T2: $n = 1{,}467$), 3 (T3: $n = 1{,}230$), and 7 yr (T4: $n = 565$) later. Almost all participants (99%) relocated between T1 and T2, and 10% moved again after T2.

Sociodemographic Factors

Gender, age, marital status (married/de facto, separated/divorced/widowed/single), education (secondary or less, trade/apprenticeship/certificate, bachelor degree or higher), occupation (manager/administrator, blue collar, clerical/sales/service/other, not in workforce), hours of work per week (≤ 19, 20–38, 39–59, ≥ 60; not in workforce), minutes/day of work travel (work from home/≤ 30, 31–60, ≥ 60; work multiple locations; not in workforce), level of physical activity at work (physically inactive, regular walking, moderately active, vigorously active, not in workforce), children at home, and dog ownership status was collected.

Local Recreational Walking

Participants reported the frequency and total minutes of recreational walking within their neighborhood (defined as a 15-min walk from their home) over a usual week using the Neighborhood Physical Activity Questionnaire (Giles-Corti et al. 2006). The neighborhood was defined as a 1600-m road network buffer around each participant's home (Giles-Corti et al. 2008).

Objective Measures of the Neighborhood Environment

At each time point, temporally relevant objective measures of the neighborhood environment were generated using a Geographic Information System (GIS), and included street connectivity and residential density (Christian et al. 2011; Frank et al. 2005). The presence of pocket/small (≤ 0.5 ha) and medium/large (neighborhood) size (>0.5 to ≤ 5 ha) parks within a 400-m neighborhood service area and the presence of a district- or regional-size (district >5 to ≥ 15 ha, regional >15 ha) park and beach access within 1,600-m network-based neighborhood service area of each participant's home were calculated (Bull et al. 2013; Christian et al. 2015; Western Australian Department of Sport and Recreation 2012). Neighborhood service areas were selected to maximize variation between and within participants over time. An overall "objective" neighborhood environment index (range: 0 to 6) was calculated and included the presence or absence (yes = 1, no = 0) of pocket/small park, medium/large park, district/regional park, beach access, as well as street connectivity and residential density. Street connectivity and residential density values were converted to z-scores using the mean and standard deviation at baseline (T1). Dichotomized scores (yes = 1, no = 0) were based on the median split in z-score where an above median z-score = 1 and a below median z-score = 0.

Perceptions of the Neighborhood Environment

Subscales from the Neighborhood Environment and Walking Scale (NEWS) questionnaire (Cerin et al. 2006) were used to measure participants' neighborhood environment perceptions. Scales included street connectivity, infrastructure and safety for walking, neighborhood esthetics, traffic safety, and crime safety (Cerin et al. 2006). To complement our objective measures, the

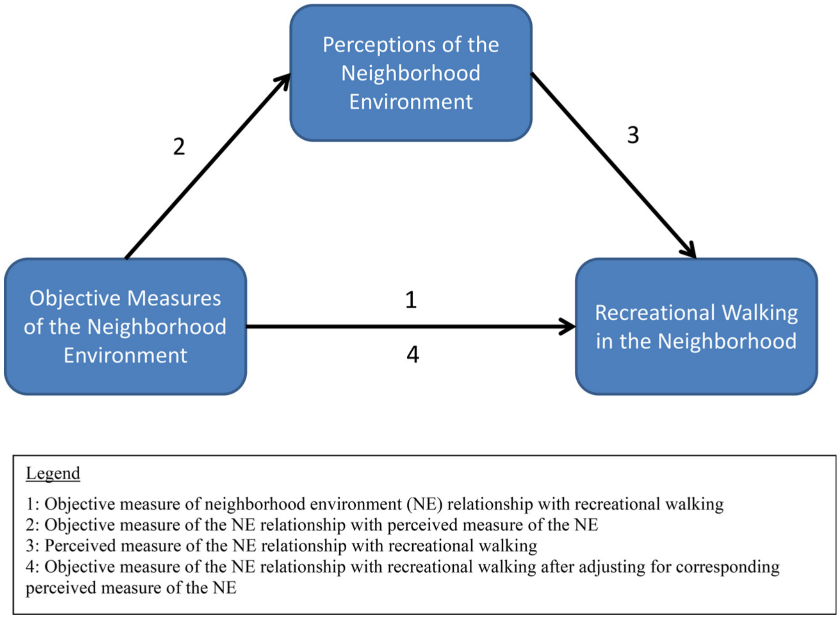

Figure 1. Mediation relationship between objective and perceived measures of the neighborhood environment and recreational walking.

presence of a park within 5 min perceived walking distance from home and the presence of a sports field and beach within 15 min were calculated from responses to the NEWS destinations subscale (Cerin et al. 2006). A perceived neighborhood environment index (range: 0 to 8) was calculated and included the perceived presence (yes = 1, no = 0) of a park, sports field, or beach, and perceived street connectivity, infrastructure and safety for walking, neighborhood aesthetics, traffic safety, and crime safety (*z*-scores above baseline median score = 1, *z*-scores below baseline median score = 0).

Statistical Analysis

Associations between neighborhood environment measures and frequency of recreational walking were assessed using negative binomial log-linear repeated measures regression models with generalized estimating equations (GEE) estimation and robust standard errors (Fitzmaurice et al. 2012). Associations with total minutes of recreational walking were assessed using a marginal linear repeated measures (unrestricted covariance) regression model. Three multivariate models were fitted. Model 1 included the objectively measured neighborhood environment variables. Model 2 included comparable perceived neighborhood environment variables. Model 3 included both the objectively measured and perceived neighborhood environment variables. All models adjusted for sociodemographic factors (age, gender, marital status, education level, occupation, weekly hours of work, daily minutes of work travel, physical activity level at work, children at home, and dog ownership) as time-varying covariates. For the log-linear models, the exponentiated coefficient estimates are reported [with 95% confidence intervals (CI)] and represent the relative change in frequency of recreational walking for a 1-unit change in the neighborhood environment measure. For the linear models, the coefficient estimates are reported and represent the absolute change in minutes/week of recreational walking in the neighborhood.

In addition to estimating the overall effect of each neighborhood environment measure, we fitted additional models that simultaneously included both the mean of the measure (averaged over time) and the mean-centered deviation in order to separately estimate and compare the between-person (cross-sectional) and within-person (longitudinal) effects of the measure (Allison 2005). The between-person and within-person effects were found to be similar for all measures; thus, only the overall combined between-person and within-person effect estimates have been reported.

Furthermore, we conducted a mediation analysis to determine whether a particular objectively measured neighborhood environment attribute (e.g., GIS-derived street connectivity *z*-score) was mediated by the corresponding perceived neighborhood environment measure (e.g., NEWS street connectivity scale) (Figure 1). We tested whether: *a*) the objective measure was related to recreational walking without adjustment for the perceived measure (Model 1); *b*) the objective measure was related to the perceived measure (Table S1); *c*) the perceived measure was related to recreational walking without adjustment for the objective measure (Model 2); and *d*) the objective measure has a smaller effect and the perceived measure a significant effect on recreational walking when both are included together in a model (Model 3).

Results

Baseline Sociodemographic Characteristics and Recreational Walking in Cohort

Table 1 shows the baseline sociodemographic characteristics of the study cohort ($n = 1{,}771$). The mean age of participants was 40 yr, 59% were female, 82% were married or in a de facto relationship, 23% had a bachelor degree or higher level of education, 49% had children at home, and 44% had a dog.

At baseline, participants walked for recreation in the neighborhood an average of twice per week for an average duration of 69 min. Local recreational walking increased following relocation and then stabilized, with the average frequency/duration per week at 1-, 3-, and 8-yr follow-up being: 2.6/89 min, 2.4/91 min, and 2.4/87 min, respectively (Table 2). There was considerable (cross-sectional) between-person variation, with the standard deviation in frequency of walking/week being 2.6 to 3.0 at each time point. There was also considerable (longitudinal) within-person variation with the standard deviation in the frequency of walking/week for the baseline to 1-yr follow-up change being 2.6, and for 1- to 3-yr follow-up and 3- to 8-yr follow-up being 2.7 and 3.0, respectively.

Table 1. Baseline sociodemographic characteristics of cohort ($n = 1{,}771$).

Variable	%
Female	59.3
Mean age (SD)	40.0 (11.9)
Marital status	
Married/de facto	81.6
Separated/divorced/widowed/single	18.4
Education level	
Secondary or less	39.7
Trade/apprenticeship/certificate	37.5
Bachelor degree or higher	22.8
Occupation	
Manager/administrator	15.1
Professional	27.4
Blue collar	17.1
Clerical/sales/service/other	23.2
Not in workforce	17.2
Hours of work per week	
≤19	10.5
20–38	26.7
39–59	41.1
≥60	4.5
Not in workforce	17.2
Minutes of work travel per day	
Work from home/ ≤ 30	20.7
31–60	23.0
≥61	17.8
Work multiple locations	21.2
Not in workforce	17.2
Level of physical activity at work	
Physically inactive	32.1
Regular walking	27.7
Moderately active	15.6
Vigorously active	7.3
Not in workforce	17.2
Children at home	49.0
Dog owner	44.1

Perceived and Objectively Measured Neighborhood Environment Attributes over Time

Three objectively measured neighborhood environment attributes (street connectivity, presence of pocket/small park, and presence of medium/large park within 400 m from home) improved after relocation and remained higher than baseline throughout follow-up (Table 2). Values for all other neighborhood environment attributes (e.g., shops and services, larger public open spaces) reduced immediately after relocation, but by 8-yr follow-up, had almost returned to, although did not exceed, baseline levels.

Participant's perceptions of street connectivity, infrastructure and safety for walking, traffic safety, neighborhood esthetics, crime safety, and perceived access to a park within a 5-min walk from home all increased after relocation and, in most instances, continued to improve with each follow-up (Table 2). Perceived access to a sports field and the beach within a 15-min walk from home reduced after relocation, but had also almost returned to baseline levels at 8-yr follow-up.

Associations between Frequency of Recreational Walking and Objective and Perceived Measures of the Neighborhood Environment

Objective neighborhood environment measures. Objectively measured neighborhood environment determinants of increased frequency of neighborhood recreational walking included access to a medium-/large-size park within 400 m from home and beach access within 1,600 m from home (both $p < 0.05$; Table 3, Model 1). On average, participants with a medium-/large-size park within 400 m from home had a 10% higher frequency of recreational walking than participants who did not have a medium-/large-size park within 400 m from home (relative change: 1.10, 95% CI $= 1.03 - 1.18$). Participants with a beach access point within 1,600 m from home had 11% higher frequency of recreational walking than participants without a beach access point within the same distance (relative change: 1.11, 95% CI $= 1.00 - 1.24$). However, inexplicably, the presence of a district-/regional-size park within 1,600 m from home appeared to reduce the frequency of recreational walking (relative change: 0.92; 95% CI: 0.86, 0.99), compared with not having a district/regional park at all. Notably, the presence of a pocket/small park within 400 m was not a significant independent determinant of local recreational walking (all $p > 0.05$), nor were street connectivity or residential density.

Neighborhood perceptions. The frequency of recreational walking was 12% higher in participants who perceived they had a park within a 5-min walk from home compared with participants who did not (relative change: 1.12; 95% CI: 1.05, 1.20) (Table 3, Model 2). Higher frequencies of recreational walking were also reported by participants who perceived they had beach access within a 15-min walk from home and higher levels street connectivity, neighborhood esthetics, and safety from crime (all $p < 0.05$; relative change: 1.08 to 1.20). Perceived infrastructure and safety for walking, traffic safety, and presence of a sports field within a 15-min walk from home were not significant independent determinants of local recreational walking.

Objective and perceived neighborhood environments. In models combining both objective and perceived neighborhood environment measures (Table 3, Model 3), all significant perceived measures from Model 2 remained significant, but associations with objective neighborhood measures were no longer significant. The frequency of local recreational walking increased by 12% for each additional neighborhood environment attribute perceived to be present ($p < 0.01$; relative change $= 1.12$). In contrast, after adjustment for neighborhood perceptions, no individual objective neighborhood environment measures, nor the cumulative index of exposures, remained significant determinants of local walking frequency in the fully adjusted model. None of the significant neighborhood environment variables in the three models had significantly different between-person (cross-sectional) and within-person (longitudinal) effect estimates (results not shown), suggesting that there was little confounding by uncontrolled time-constant factors, including time-constant self-selection factors.

Associations between Minutes of Recreational Walking and Objective and Perceived Measures of the Neighborhood Environment

The results for minutes of local recreational walking were generally similar to those for the frequency of local recreational walking with one exception; objectively measured connectivity remained statistically significant even after full adjustment (Tables 3 and 4, Model 1). Consistent with the frequency analyses, in Model 3 (adjusted for both objective and perceived measures), all perceived measures from Model 2 remained significant, while all but one objective measure (i.e., the presence of pocket/small parks within 400 m of home) remained significant determinants of the minutes of local recreational walking (Table 4, Model 3). Notably, participants with small/pocket parks within 400 m of their home undertook 6 min less recreational walking weekly compared with others. Conversely, participants who perceived they had access to a local park and access to the beach, and higher levels of street connectivity, neighborhood esthetics, and safety from crime reported significantly higher total minutes/week of recreational walking (absolute increases between 7 and 22 min; all $p < 0.05$). Minutes of local recreational walking increased by

Table 2. Neighborhood recreational walking and attributes of the objectively measured and perceived neighborhood environment at each time point [mean ± SD or n (%)].

	T1	T2	T3	T4
	$n = 1,771$	$n = 1,383$	$n = 1,176$	$n = 541$
Neighborhood recreational walking				
Frequency per week	2.04 (2.64)	2.57 (2.82)	2.35 (2.87)	2.40 (3.03)
Minutes per week	69.0 (98.4)	89.3 (113.5)	90.7 (128.2)	86.7 (121.2)
Objectively measured				
Connectivity z-score	0.00 (1.00)	0.68 (1.42)	0.95 (1.44)	1.15 (1.52)
Residential density z-score	−0.00 (0.99)	−0.30 (0.69)	−0.09 (0.66)	−0.10 (0.51)
Presence of a pocket/small park within 400 m (%)[a]	767 (43.3)	810 (58.6)	656 (55.8)	356 (65.8)
Presence of a medium/large park within 400 m (%)[b]	781 (44.1)	725 (52.4)	618 (52.6)	294 (54.3)
Presence of a district/regional park within 1,600 m (%)[c]	1,307 (73.8)	604 (43.7)	557 (47.4)	337 (62.3)
Presence of a beach access point within 1,600 m (%)	197 (11.1)	90 (6.5)	75 (6.4)	54 (10.0)
Perceived measures				
Street connectivity[d]	3.40 (0.65)	3.54 (0.63)	3.56 (0.60)	3.62 (0.60)
Infrastructure and safety for walking[d]	3.09 (0.57)	3.14 (0.53)	3.12 (0.52)	3.17 (0.54)
Traffic safety[d]	3.61 (0.76)	3.90 (0.64)	3.81 (0.59)	3.85 (0.60)
Neighborhood aesthetics[d]	3.48 (0.76)	3.83 (0.69)	3.61 (0.67)	3.59 (0.71)
Crime safety[d]	3.52 (0.78)	3.98 (0.60)	3.84 (0.61)	3.80 (0.67)
Presence of a park within 5-min walk (%)	890 (50.3)	978 (70.7)	802 (68.2)	368 (68.0)
Presence of a sports field within 15-min walk (%)	990 (55.9)	570 (41.2)	599 (50.9)	294 (54.3)
Presence of a beach within 15-min walk (%)	211 (11.9)	116 (8.4)	94 (8.0)	51 (9.4)

Note: T1 = baseline; T2 = 1-yr follow-up; T3 = 3-yr follow-up; T4 = 8-y follow-up.
[a]Pocket/small park = ≤ 0.5 ha.
[b]Medium/large park = ≤ 5 ha.
[c]District/regional park = ≤ 15 ha.
[d]NEWS 5-point scale: Strongly disagree to Strongly agree.

almost 9 min/wk for each additional perceived neighborhood environment present ($p < 0.01$).

Mediation Relationship between Objective and Perceived Measures of the Neighborhood Environment and Recreational Walking

As the effects of objectively measured neighborhood environment exposures decreased when adjusted for perceptions, it was plausible that neighborhood perceptions mediated the relationship between objective measures and recreational walking. With the exception of small/pocket park access at time point 2, all objective measures were significantly (although mostly modestly) correlated with their corresponding perceived neighborhood environment measure (Table S1). Correlations between perceived and objectively measured beach access were substantially higher (range: 0.58–0.73) than for any other neighborhood attribute. The mediation analyses showed that the relationship between objective measures of the neighborhood environment and recreational walking was mediated by the perceived measures. Almost all estimates of objective measures of the neighborhood environment decreased and became nonsignificant in Model 3 when adjusted for neighborhood perceptions. Finally, objective measures of the neighborhood environment were associated with recreational walking when not adjusting for the perceived measure (Model 1), and perceived measures were related to recreational walking when not adjusted for the objective measure (Model 2), thus confirming that the perceived neighborhood environment mediates the relationship between the objectively measured neighborhood environment and local recreational walking.

Discussion

Consistent with numerous previous cross-sectional studies conducted in Australia and North America, we found that the frequency and duration of recreational walking was determined by objectively measured access to a medium-/large-size park (but not small pocket parks), beach access, and street connectivity (duration but not frequency of walking). However, these effects attenuated when adjusted for neighborhood perceptions. In fully adjusted models, positive perceptions of access to a park and beach and street connectivity, neighborhood esthetics, and safety from crime remained independent determinants of increased neighborhood recreational walking. Notably, local recreational walking increased by 9 min/wk (12% increase in frequency) for each additional perceived neighborhood attribute present. These latter findings are consistent with the International Physical Activity and the Environment Network 11 country study, which showed a linear gradient in the association between neighborhood environment perceptions and achieving recommended levels of physical activity (Sallis et al. 2009). With adjustment for unmeasured time-constant self-selection factors, we found between-person cross-sectional and within-person longitudinal effect estimates to be similar. This suggests that the longitudinal estimates observed of changes in the neighborhood environment on change in recreational walking can be interpreted in the same way as cross-sectional between-person effects.

Longitudinal analysis of RESIDE data 12 mo after relocating to a new neighborhood found that participants who favorably changed their neighborhood environment perceptions reported 2 mins/wk of additional recreational walking for each (range: 0–14) positive neighborhood perception (Giles-Corti et al. 2013). The 8-yr follow-up findings further highlight how local recreational walking is determined by resident perceptions about access to recreational opportunities (parks and the beach), street connectivity, safety from crime, and esthetics. Furthermore, recreational walking may increase over time as these positive perceptions grow. A previous cross-sectional study of RESIDE participants highlighted the importance of the quality of neighborhood environments (Sugiyama et al. 2015). This study found that walking to local public open space was associated with public open spaces being attractive with gardens, grassed areas, walking paths, water features, wildlife, amenities, dog-related facilities, and off-leash areas for dogs (Sugiyama et al. 2015). Notably, in the current study, we found that lower levels of walking were determined by the presence of smaller pocket parks, which is important, given that many subdivision design codes encourage the creational of

Table 3. Associations between frequency of walking for recreation per week and perceived and objective measures of the neighborhood environment.

	Model 1[ab]	Model 2[ac]	Model 3[ad]
	Relative change (95% CI)	Relative change (95% CI)	Relative change (95% CI)
Objectively measured			
Connectivity *z*-score	1.01 (0.99, 1.04)		0.98 (0.95, 1.01)
Residential density *z*-score	1.00 (0.96, 1.04)		1.02 (0.98, 1.06)
Presence of a pocket/small park within 400 m[e]	1.00 (0.93, 1.07)		0.97 (0.91, 1.04)
Presence of a medium/large park within 400 m[f]	1.10 (1.03, 1.18)		1.03 (0.96, 1.11)
Presence of a district/regional park within 1,600 m[g]	0.92 (0.86, 0.99)		0.96 (0.90, 1.04)
Presence of a beach access point within 1,600 m	1.11 (1.00, 1.24)		0.95 (0.84, 1.09)
Perceived measures			
Street connectivity[h]		1.12 (1.06, 1.19)	1.12 (1.06, 1.19)
Infrastructure and safety for walking[h]		1.02 (0.96, 1.09)	1.03 (0.96, 1.10)
Traffic safety[h]		1.03 (0.98, 1.08)	1.03 (0.98, 1.09)
Neighborhood aesthetics[h]		1.20 (1.14, 1.27)	1.20 (1.14, 1.26)
Crime safety[h]		1.08 (1.02, 1.14)	1.08 (1.02, 1.14)
Presence of a park within 5-min walk		1.12 (1.05, 1.20)	1.12 (1.05, 1.20)
Presence of a sports field within 15-min walk		1.04 (0.97, 1.11)	1.04 (0.97, 1.11)
Presence of a beach within 15-min walk		1.10 (1.00, 1.21)	1.14 (1.01, 1.28)
Objective neighborhood environment index[i]	1.01 (0.98, 1.03)		0.98 (0.95, 1.01)
Perceived neighborhood environment index[j]		1.12 (1.10, 1.14)	1.12 (1.10, 1.14)

Note: T1 = baseline; T2 = 1-yr follow-up; T3 = 3-yr follow-up; T4 = 8-yr follow-up.
[a]All models adjusted for baseline age, gender, marital status, level of education, occupation, hours of work/week, minutes/day of work travel, level of physical activity at work, children at home, and dog ownership.
[b]Model 1: Objective measures of the neighborhood environment only.
[c]Model 2: Perceived measures of the neighborhood environment only.
[d]Model 3: Objective and perceived measures of the neighborhood environment.
[e]Pocket/small park = ≤ 0.5 ha.
[f]Medium/large park = ≤ 5 ha.
[g]District/regional park = ≤ 15 ha.
[h]NEWS 5-point scale: Strongly disagree to Strongly agree.
[i]Presence or absence (yes = 1, no = 0) of pocket/small park, medium/large park, district/regional park, beach access, and street connectivity and residential density (*z*-scores above baseline median score = 1, *z*-scores below baseline median score = 0); range: 0–6.
[j]Perceived presence (yes = 1, no = 0) of park, sports field, or beach, and perceived street connectivity, infrastructure, and safety for walking, neighborhood esthetics, traffic safety, and crime safety (*z*-scores above baseline median score = 1, *z*-scores below baseline median score = 0); range: 0–8.

smaller local public open spaces. Hence, providing residents with larger attractive public open space (Giles-Corti et al. 2005a; Sugiyama et al. 2010) and activating these spaces with social, cultural, and physical activity opportunities may positively impact on local recreational walking (de Blasio 2016). Nevertheless, the effects observed in this study are relatively modest, and greater efforts to encourage more residents to increase their physical activity are warranted. This is underscored by findings from Sugiyama and colleagues (Sugiyama et al. 2013), who found that while access to a park may assist active residents to maintain levels of walking, other strategies were required to encourage inactive participants to initiate physical activity. Encouraging local residents to initiate park use through park activation strategies (e.g., walking groups, permitting private service providers to use parks for physical activity programs, community music, or cultural events) may encourage residents to commence walking as well as increase their walking levels.

Participants who perceived they lived in an attractive neighborhood with recreational destinations, such as a park within a 5-min walk or a beach within a 15-min walk, did an additional 10 and 22 min/wk of local recreational walking, respectively (see Table 4). We observed similar unadjusted effect sizes for objectively measured park and beach access; however, these results were reduced when the perceptions were added to the model. These findings support the idea of the "coastal effect" reported by Bauman and colleagues, who found that those living in coastal suburbs were 27% more likely to meet recommended levels of physical activity (Bauman et al. 1999; White et al. 2014). The "coastal effect" might imply that those drawn to live by the coast may be those predisposed to be active; however, our longitudinal study suggests that the attractiveness of the ocean may also encourage those less predisposed to be more recreationally active. Although we did not investigate, similar findings may be found for access to walking paths along rivers and lakes, which would provide more residents with convivial recreational opportunities. From an equity perspective, there is a need for policies that facilitate access to pleasant recreational opportunities. This includes affordable housing located within close proximity to the beach, as well as developing walkways along other waterways, such as rivers and lakes. However, inequities in access to recreational destinations, such as the beach, could be reduced by ensuring people have access to high-quality larger parks. Although the effects were smaller, we found that access to a local medium-size park, but not smaller pocket parks, determines levels of recreational walking. Thus, in areas without proximate access to the beach or other waterways, additional resources are required for the design, management, and maintenance of higher-quality neighborhood parks. In disadvantaged areas, this may produce important cobenefits (de Blasio 2016). For example, a Scottish study found that increased access to green space decreased perceived and objectively measured stress levels in residents of disadvantaged areas (Roe et al. 2013). However, importantly, these parks must be well maintained, particularly in lower income areas. Another RESIDE cross-sectional study found that parks with disorder (e.g., graffiti, rubbish, and vandalism) discouraged recreational walking (Sugiyama et al. 2010), while an English study concluded that poorly maintained public open space may produce poorer mental health outcomes in lower income areas (Mitchell and Popham 2007). A number of pathways could explain these findings: areas with poorly maintained parks may become stigmatized, which may be internalized by residents, but may also increase levels of fear in residents. Both of these outcomes would be detrimental to the health and well-being of residents.

We have previously shown the potential walking benefits from gaining access to recreational destinations-and reported that

Table 4. Associations between minutes of walking for recreation per week and perceived and objective measures of the neighborhood environment.

	Model 1[ab]	Model 2[ac]	Model 3[ad]
	Estimate (95% CI)	Estimate (95% CI)	Estimate (95% CI)
Objectively measured			
Connectivity z-score	3.29 (0.76, 5.82)		0.44 (–2.16, 3.04)
Residential density z-score	0.48 (–3.38, 4.34)		1.59 (–2.28, 5.46)
Presence of a pocket/small park within 400 m[e]	−3.87 (−9.79, 2.05)		− 6.24 (− 12.11, − 0.37)
Presence of a medium/large park within 400 m[f]	7.50 (1.55, 13.45)		2.90 (−3.10, 8.91)
Presence of a district/regional park within 1,600 m[g]	− 8.38 (− 14.62, − 2.13)		−4.95 (−11.31, 1.42)
Presence of a beach access point within 1,600 m	15.10 (4.31, 25.89)		−4.43 (−18.20, 9.32)
Perceived measures			
Street connectivity[h]		8.57 (3.95, 13.18)	8.65 (3.99, 13.30)
Infrastructure and safety for walking[h]		4.75 (−0.78, 10.29)	4.70 (−0.98, 10.38)
Traffic safety[h]		−0.02 (−4.41, 4.37)	−0.23 (−4.64, 4.17)
Neighborhood esthetics[h]		10.43 (6.03, 14.83)	10.44 (6.00, 14.87)
Crime safety[h]		7.85 (3.35, 12.35)	7.49 (2.91, 12.08)
Presence of a park within 5-min walk		10.03 (4.07, 15.99)	9.52 (3.37, 15.67)
Presence of a sports field within 15-min walk		2.44 (−3.27, 8.15)	2.72 (−3.09, 8.53)
Presence of a beach within 15-min walk		19.37 (9.42, 29.33)	21.51 (8.59, 34.43)
Objective neighborhood environment index[i]	1.50 (−0.82, 3.82)		−0.40 (−2.72, 1.92)
Perceived neighborhood environment index[j]		8.76 (7.09, 10.44)	8.81 (7.12, 10.50)

Note: T1 = baseline; T2 = 1-yr follow-up; T3 = 3-yr follow-up; T4 = 8-yr follow-up.
[a]All models adjusted for baseline age, gender, marital status, level of education, occupation, hours of work/week, minutes/day of work travel, level of physical activity at work, children at home, and dog ownership.
[b]Model 1: Objective measures of the neighborhood environment only.
[c]Model 2: Perceived measures of the neighborhood environment only.
[d]Model 3: Objective and perceived measures of the neighborhood environment.
[e]Pocket/small park = ≤ 0.5 ha.
[f]Medium/large park = ≤ 5 ha.
[g]District/regional park = ≤ 15 ha.
[h]NEWS 5-point scale: Strongly disagree to Strongly agree.
[i]Presence or absence (yes = 1, no = 0) of pocket/small park, medium/large park, district/regional park, beach access, and street connectivity and residential density (z-scores above baseline median score = 1, z-scores below baseline median score = 0); range: 0–6.
[j]Perceived presence (yes = 1, no = 0) of park, sports field, or beach, and perceived street connectivity, infrastructure, and safety for walking, neighborhood esthetics, traffic safety, and crime safety (z-scores above baseline median score = 1, z-scores below baseline median score = 0); range: 0–8.

this relationship is partly mediated by its effect on residents' enjoyment of walking (Giles-Corti et al. 2013). Neighborhood esthetics are repeatedly associated with recreational walking: green, leafy suburbs with high-quality local open space provide attractive destinations and pleasant routes, and together can be powerful determinants of physical activity by encouraging more recreational walking (Sugiyama et al. 2012). There is already considerable evidence that park quality is a critical factor in encouraging more walking, while the presence of disorder (Foster et al. 2012) and high-speed traffic (Kaczynski et al. 2014) are deterrents (Sugiyama et al. 2010). Given the importance of a variety of public open spaces for increasing physical activity (Giles-Corti et al. 2009), a systems view is required to avoid any unintended consequences from only focusing on the needs of adults and ignoring the impact on the health and well-being of children and adolescents (Giles-Corti and King 2009).

This study appears to be one of the first longitudinal studies to show an association between street connectivity and local recreational walking. A 1-unit increase in the street connectivity z-score was associated with 3 additional min/wk of local recreational walking. This also supports cross-sectional findings showing that living in neighborhoods with high levels of street connectivity encourages more park-based activity (Kaczynski et al. 2014). Although we found access to smaller parks decreased recreational walking, others have found an interaction between park presence (even small parks) and connected street networks (Hooper et al. 2015b). People who reside in neighborhoods with more connected streets are able to access local destinations such as parks more easily because more connected street networks offer a more direct route to local destinations (Hooper et al. 2015b).

Our findings are important for achieving the UN's Sustainable Development Goals particularly related to increasing access to green space to create resilient cities that will promote health. Our longitudinal analysis suggested that the presence of smaller parks was negatively associated with duration (but not frequency) of local recreational walking. This is not surprising, given that larger parks with more amenities are more interesting and offer users more opportunities and variety. Compared with smaller parks, larger parks may attract residents to walk further to visit them and to visit for longer once at the park, and they will have more amenities present that encourage users to be more active while there. It is possible that very small parks do not attract local residents to be physically active, although they may be important for some population subgroups (e.g., young children with parents, older adults, inner city residents). However, in established areas where there are only smaller local parks, particularly in areas with connected street networks that foster a range of alternative routes, it may be possible to generate a network of smaller local parks to create attractive recreational walking routes. Such a network may foster positive neighborhood perceptions, which our study shows determine recreational walking. Interventions of this type, particularly in lower socioeconomic areas where residents tend to undertake less recreational walking, are worth exploring, given the challenge of retrofitting established neighborhoods. However, more evidence is required to explore what role small parks play (if any) and for whom, and how the quality of smaller parks affects both physical activity and mental health outcomes (Francis et al. 2012). In the meantime, given the exponential growth of cities around the globe and global targets to increase access to public open space, both our longitudinal and cross-sectional findings suggest that fewer larger open spaces may be preferable than providing many small public open spaces (Sugiyama et al. 2010, 2015).

Our findings highlight that each individual attribute of the objectively measured neighborhood environment is associated with a relatively small increase in recreational walking per week. However, they are potentially more significant when their combined effects are considered. We found that local recreational walking increased by 9 min/wk (12% increase in frequency) for each additional perceived neighborhood attribute present. This suggests that improving just one attribute of the neighborhood environment may have little effect on residents' overall walking levels (Hooper et al. 2015a, 2015b). Rather, it is likely that recreational walking is determined by a combination of factors, that is, having access to safe attractive neighborhoods with highly connected street networks and good access to larger local public open space. In addition, individual attitudes and abilities and the social environment cannot be ignored. Previously, we have found that individual, social, and built environment factors are equally important (Giles-Corti and Donovan 2003). Hence, a combination of intervention strategies are required to maximize local walking levels, and simply having one attractive park alone may be insufficient to change the behavior of residents (Sugiyama et al. 2013). It may be that interventions designed to encourage more park use and encourage inactive residents to use local facilities are warranted. Future natural experiments might investigate both the individual and combined effects of changes to the neighborhood environment on recreational walking and the added benefit of implementing strategies to encourage residents to make better use of their local recreational destinations. Moreover, examining the effect of changes to the neighborhood environment for other domains of physical activity is warranted to better understand the potential tradeoff (if any) of neighborhood environment features for recreational compared with transport-related physical activities and whether local neighborhood attributes encourage other types of physical activity in adults, children, and adolescents.

Our mediation analysis results show that participants' perceptions of the neighborhood environment mediate the relationship between objectively measured attributes of the neighborhood environment and local recreational walking. However, in this study, not all neighborhood environment perceptions (e.g., neighborhood esthetics and safety from crime) had a corresponding objectively measured neighborhood environment variable. Thus, future longitudinal studies should consider including both perceived and objective measures of crime and neighborhood attractiveness to fully explore mediating relationships. Notably, our findings do not suggest that objective measures of the neighborhood environment are not important determinants of local recreational walking. Rather, they highlight that individuals' perceptions of their environment are more proximal determinants of behavior change than the environment. Thus, they exert a greater influence on walking behavior. Yet, the actual neighborhood environment likely determines these neighborhood perceptions (Giles-Corti and Donovan 2002; Giles-Corti et al. 2005b). Future studies may wish to further explore the importance of this relationship, and interventions need to focus on people and places to maximize physical activity outcomes (Giles-Corti 2006).

Study Limitations

A potential source of bias was the lower participant retention rate at the fourth survey, which may have been due to a considerably longer survey than in previous waves. Analysis of the factors associated with participant dropout was associated with various demographic variables (being younger and male, having children at home), but not with prior walking behavior. Dropout patterns such as this (conditionally on the covariates) are called missing completely at random. Estimates from our longitudinal repeated measures models are unbiased under this pattern of dropout, provided the covariates related to dropout are included in the models as time-varying covariates and there are no further unmeasured covariates related to dropout (Fitzmaurice et al. 2012).

This study was not able to examine the impact of other relevant objectively measured built environment attributes, as data was not available across all time points. For example, future studies should consider evaluating the impact of footpath length, traffic exposure, quality of public open space (which in this study was only measured at two but not four time points), neighborhood greenness, and terrain on local recreational walking. This study was also limited by the potential confounding from unmeasured time-varying factors, such as general health status. Finally, the study site, Perth, Western Australia, represents an above-average quality of life and a low-density city with a Mediterranean climate. Thus, findings may not be representative of other lower-income medium- to high-density cities with different climatic conditions. For instance, patterns of walking tend to differ by neighborhood disadvantage, whereby residents in relatively disadvantaged areas tend to walk less for recreation, but more for transport than those in advantaged areas (Miles et al. 2008; Turrell et al. 2010, 2013). Further, residents in low-income settings face an increased exposure to many potential barriers to recreational walking, such as crime and disorder, poorer upkeep and esthetics (Foster et al. 2011, 2015), and increased traffic (Giles-Corti and Donovan 2002). Disorder, in particular, tends to cluster near nonresidential land uses (e.g., shops and parks) (Perkins et al. 1992), so even when access is equitable, the quality of these spaces may not be, thereby potentially rendering these sites less appealing as walking settings/destinations.

Conclusions

Longitudinal repeated measures studies allow a stronger assessment of the effect of the built environment on recreational walking than cross-sectional studies. Perceived neighborhood attractiveness and safety influences recreational walking, and this influence grows with more positive perceptions. The provision of larger (but not small) public open space and street connectivity supports more recreational walking. In areas with smaller parks and connected street networks, it may be possible to encourage recreational walking by creating a network of smaller parks. These findings provide urban planners and policy makers with stronger evidence of a causal relationship between the neighborhood environment and recreational walking, and highlight specific interventions required to increase recreational walking and meet residents' health needs when planning new or retrofitting established neighborhoods.

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