Mismatch between perceived and objectively assessed neighborhood walkability attributes: Prospective relationships with walking and weight gain

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ABSTRACT

We examined prospectively whether persons who perceive their objectively measured high walkable environment as low walkable decrease their walking more and gain more weight than those with matched perceptions. Walkability was measured objectively using GIS. Corresponding perceptions were collected using the Neighborhood Environment Walkability Scale from 1027 urban Australian adults. Objective and perceived measures were dichotomized and categories of match and mismatch were created. Overall, walking levels decreased and BMI increased significantly over the four year follow-up period. Those who perceived high walkability, dwelling density or land use mix as low decreased their walking for transport significantly more than those with matched perceptions. Those who perceived high walkability, land use mix or retail density as low increased their BMI significantly more than those with concordant perceptions. These prospective findings corroborate recommendations from previous cross-sectional studies. Interventions to improve negative perceptions of walkability among those living in high walkable areas may be a relevant public health intervention to increase physical activity and support weight maintenance.

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1. Introduction

There is a consistent body of evidence on the health benefits of physical activity (Pate et al., 1995; US Department of Health and Human Services, 1996; Haskell et al., 2007). Over the last decade there has been an increasing interest in the role of the physical environment as a determinant of physical activity: neighborhood built-environment attributes have been shown to be associated with walking (Owen et al., 2004; Transportation Research Board, 2005; Heath et al., 2006; Gebel et al., 2007; Saelens and Handy, 2008), and with obesity (Frank et al., 2004; Papas et al., 2007; Black and Macinko, 2008; Joshi et al., 2008; Mujahid et al., 2008). According to ecological models of health behavior, appropriate opportunities and settings that facilitate particular forms of activity, such as walking for recreation and exercise, or walking to get to and from places, help adults to achieve sufficient levels of physical activity for health benefits (Owen et al., 2000; Sallis et al., 2008).

However, the provision of such built-environment facilitators alone might not automatically influence the behavior in the absence of awareness of them, or without relevant awareness-raising initiatives (Kahn et al., 2002; Salmon et al., 2003; Timperio et al., 2004; Humpel et al., 2004; Mowen et al., 2007; Frohlich et al., 2007; McCormack et al., 2008; Ball et al., 2008). It has been hypothesized that the level of concordance of perceptions with actual characteristics of the environment might affect physical activity behavior (Kirtland et al., 2003; Gebel et al., 2009; Napolitano et al., 2006). If the outcomes of such spatial...
cognition processes mediate the relationship between environmental attributes and behavior, then the targeting of environmental cognitions (and particularly the awareness of settings for physical activity) could be a promising public health communication strategy (Mowen et al., 2007; van Stralen et al., 2008).

The potential mediating role of environmental cognitions on the relationships between environmental attributes and physical activity may be moderated by socio-demographic factors (Kremers et al., 2006). Such factors could either influence the relationships between the environmental attributes and cognitions, or the relationships between such cognitions and physical activity (Kremers et al., 2006). For example, in a cross-sectional study (Gebel et al., 2009) we found that adults of lower socio-economic status, who had children in the household, or who were overweight were more likely to perceive a high-walkable neighborhood as low-walkable.

Few longitudinal studies have investigated either objectively assessed or perceived environmental attributes in relation to prospective changes in physical activity. For example, a prospective study in the USA (Li et al., 2005) examined objectively assessed environmental correlates of change in neighborhood walking among older adults. One year after baseline measurement, walking levels had declined. Those living in neighborhoods with low accessibility to playgrounds, parks, or gyms, or with low perceived safety for walking showed greater decreases in walking than those living in more walkable neighborhoods. Another study from the USA (Li et al., 2009) found that objectively assessed high neighborhood walkability positively moderated the relationship between people's eating and physical activity habits and prospective changes in their weight and waist circumference. An Australian study (Humpel et al., 2004) examining perceptions and behavior at two time points, found that improved perceptions of accessibility to destinations and aesthetics were associated with increased walking levels. These findings from prospective studies provide some evidence for the relevance of both objectively assessed and perceived environmental attributes in relation to prospective changes in physical activity; one study has shown a prospective association with weight gain (Li et al., 2009).

However, cross-sectional studies have found agreement between these objective measures of walkability and participant’s perceptions of the corresponding environmental attributes to be low (McCormack et al., 2008; Ball et al., 2008; Reed et al., 2004; Kirtland et al., 2003; Boehmer et al., 2006; McGinn et al., 2007; Macintyre et al., 2008; Gebel et al., 2009; Lackey and Kaczynski, 2009; Prins et al., 2009). As well, at baseline, we found that those with more positive perceptions are more likely to be physically active (Gebel et al., 2009). In the baseline study, we examined the correlates of non-concordance between perceived and objective measures of environmental attributes, and found that about a third of those living in objectively determined high walkable neighborhoods perceived their local environment as low in walkability. Similarly, a third of those living in neighborhoods with low walkability perceived them to be high walkable. This was the case for a composite measure of walkability, and for the sub-domains of dwelling density, street connectivity, land use mix, and retail density (Gebel et al., 2009). It has been suggested that strategies to improve perceptions of the relevant environmental attributes particularly among those who live in objectively determined high walkable neighborhoods may have the potential to increase physical activity levels (Reed et al., 2004; Gebel et al., 2009) and improve other health outcomes (Parra et al., 2010). No study has examined whether mismatch between perceived and objectively determined walkability influences change in walking and weight.

Here, we examine prospective relationships of perceiving objectively measured high walkability as low with changes in adults’ walking, and weight gain. We hypothesized that over time, those who perceive their objectively measured high walkable environment as low walkable would decrease their walking more and would gain more weight than those with matched perceptions.

2. Methods

2.1. Data collection procedure

Data were from the PLACE (Physical Activity in Localities and Community Environments) study conducted in 2003 (baseline) and in 2007 (follow-up) in the city of Adelaide, Australia. Ethical approval for the study was given by the Behavioural and Social Sciences Ethics Committee of the University of Queensland. Prior to being enrolled in the study, all participants provided informed consent and were explicitly informed that they were free to withdraw from the study at any time.

An account of the design of the PLACE study (baseline) has been provided elsewhere (Owen et al., 2007; Leslie et al., 2007). Briefly, the aim of the PLACE study was to investigate how neighborhood environmental characteristics, in particular walkability, influence residents’ physical activity patterns. Walkability was a composite measure of four objectively measured environmental attributes: dwelling density, street connectivity, land use mix, and net retail area ratio. Several studies have found these environmental attributes to be consistently associated with walking behavior (Owen et al., 2004; Saelens et al., 2003b). Data were derived from street centerline files, land use, zoning, shopping center locations, and census, and were compiled in Geographic Information Systems (GIS). The four objective environmental attributes were calculated for each of the urban census collector districts (CCD) within the Adelaide Statistical Division; and they were then converted into deciles, with 1 representing the lowest and 10 the highest level of walkability. A CCD is the smallest spatial unit for census data collection defined by the Australian Bureau of Statistics, and contains approximately 250 households. The walkability index was the sum of these four decile scores with a possible score from 4 to 40. The resulting composite measure was divided into quartiles, with the first and fourth quartiles standing for the lowest and highest walkability. Thirty-two neighborhoods from these two quartiles were selected for the study, with a total of 156 CCDs represented.

For the baseline data collection, simple random sampling without replacement was used to select households within the selected neighborhoods. To be eligible for the study, people had to be between the age of 20 and 65, English speaking, residing in private dwellings, and able to walk without any assistance. If there was more than one eligible participant in a household, then the most recent birthday method was used. A total of 2650 respondents completed the baseline questionnaire (74.2% of those that were approached). The response rate did not differ significantly by socioeconomic status or walkability of the identified study areas. Compared with the 2001 census data from the Australian Bureau of Statistics (Australian Bureau of Statistics, 2001), older adults, females, and people in paid work were overrepresented in the sample.

The follow-up survey was conducted four years after the baseline survey (September 2007). A total of 1027 valid responses were received. The relatively high attrition rate was partly due to a large number of participants who had moved their place of residence after the baseline survey. Participants for whom follow-up data were available lived in neighborhoods with lower objectively assessed neighborhood walkability (p = 0.001) and were older (p < 0.001) than those who dropped out after the baseline survey.
2.2. Measures and instruments

The outcome variables for this study were the change in walking, and body mass index (BMI) between the baseline and the four-year follow-up. Data on physical activity were collected in both the baseline and follow-up surveys using the long form of the International Physical Activity Questionnaire (IPAQ). This reliable and validated survey (Craig et al., 2003) distinguishes between domain-specific walking behavior. For this study, weekly minutes of walking for transport, and for recreation or exercise, were examined separately. Participants were also asked to report their height and weight, from which BMI was calculated, in both surveys.

The independent variable was the mismatch between the objectively determined and perceived walkability at the baseline. In addition to the GIS measures of walkability, participants rated aspects of their environment by completing the reliable and validated Neighborhood Environment Walkability Scale (NEWS) (Saelens et al., 2003a; Brownson et al., 2004; Cerin et al., 2006; Cerin et al., 2008). The geographical scale for the self-reported environmental measures was a 10–15 minute walk from participants’ homes. Perceived measures corresponding to dwelling density, street connectivity, land use mix, and net retail area ratio were calculated, and categorized into deciles (or quartiles depending on variability). In line with the procedure for the objective measures, perceived walkability was calculated as the sum of four sub-domain scores resulting in a possible range from 4 to 40. Moreover, in the follow-up survey study participants had to rate perceived changes in neighborhood walkability across six categories (access to shops and services or public transport, quality of places to walk, attractiveness of neighborhood and safety from traffic and crime).

2.3. Statistical analysis

Both the objective and perceived measures of walkability were dichotomized, using median splits. Then, participants were categorized into the following four quadrants: high objective/high perceived; high objective/low perceived; low objective/high perceived; and low objective/low perceived. This applied to the composite walkability score, and to its sub-domains of dwelling density, street connectivity, land use mix, and net retail area ratio. Outliers in reported minutes of walking per day were truncated to 120. Participants who had a change in walking for leisure (n=3), or walking for transport (n=3) of 840 min per week were excluded. Subjects whose BMI changed by more than 20 (n=2) were also excluded. Multiple linear regression analyses were carried out to examine the longitudinal effect of perceiving objectively measured high walkability as low on changes in walking for transport and leisure, and BMI. The regression coefficients show the differences in changes in walking, and in BMI, between participants whose perceptions of walkability matched the objective measurements (high objective/high perceived) and those who perceived their neighborhood as less walkable than objectively determined. In the regressions, we controlled for baseline levels in walking, or BMI, and adjusted for age, sex, and income. The duration of living in a residential location is related to familiarity with the neighborhood (Liben, 1981). For instance, one study found an inverse relationship between the time subjects had lived in their neighborhood and mismatch between objective and perceived measures of the environment (Ball et al., 2008). Therefore, we also adjusted for the length of residency. The distributions for all variables related to changes in perceptions of walkability were skewed, with almost all participants not reporting differences in their neighborhood. As there was hardly any change in perceptions, we did not control for these variables. Statistical analyses were carried out using the Statistical Package for Social Sciences (SPSS 17).

3. Results

3.1. Agreement between objective and perceived measures of neighborhood walkability

Consistent with the baseline study (Gebel et al., 2009), there was only a modest agreement between the objective and the perceived environmental measures. One third of the subjects who lived in objectively determined high walkable neighborhoods perceived them to be low walkable. Among those in low walkable environments, a third perceived walkability to be high (Table 1). The agreement between objective and perceived measures for the four sub-domains of walkability was similar (data not provided here).

As mentioned above, there were hardly any sociodemographic differences between the baseline and the follow-up samples. Therefore, for descriptive data on sociodemographic attributes and for cognitive and walking variables by the four quadrants of objective and perceived walkability we refer to the baseline study (Gebel et al., 2009).

3.2. Changes in walking levels and BMI in total sample

For the total sample, walking for transport decreased by 22.7 min/week (SD=198.6; p < 0.0001) and walking for leisure decreased by 9.8 min/week (SD=165.1; p=0.05) in the four years between the baseline and the follow-up survey. Mean BMIs increased by 0.6 units (SD=2.4; p < 0.001).

3.3. Changes in walking for transport by mismatch between perceived and objective walkability

Those who perceived objectively measured high walkability as low (see Table 2) decreased their walking for transport significantly more than those whose perception matched the objective measure (b=-55.7, p < 0.001). The same applied to misperceptions of dwelling density and land use mix. There was a trend towards an effect of misperceiving retail density on changes in walking for transport, but no difference for misperceiving street connectivity.

3.4. Changes in walking for leisure by mismatch between perceived and objective walkability

Participants who perceived their neighborhood as less walkable than objectively measured decreased their walking for leisure by 23.6 min/week more than did those who perceived it as high walkable. However, this difference was not statistically significant. Misperceiving street connectivity was the only significant factor

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Participants with matched/mismatched perceived and objective measurements of neighborhood walkability.</th>
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<tbody>
<tr>
<td></td>
<td>Objective walkability</td>
</tr>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Perceived</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>340</td>
</tr>
<tr>
<td>Low</td>
<td>154</td>
</tr>
<tr>
<td>Total</td>
<td>494</td>
</tr>
<tr>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
predicting changes in walking for leisure ($b = -29.4$, $p = 0.01$). There were trends in the expected direction for misperceiving land use mix and retail density (non-significant) and there was no difference for dwelling density.

3.5. Changes in BMI by mismatch between perceived and objective walkability

Participants who perceived objectively measured high walkability as low gained significantly more weight than did those whose perception matched the objective measure ($p = 0.03$). As well, there were significant effects for misperceiving land use mix and retail density. Those who perceived the density of shops as lower than objectively determined increased their BMI by 0.6 more than those whose perception matched the objective measure ($p = 0.01$). There was a trend for an effect for misperceiving high dwelling density as low. There was no effect of perceiving street connectivity as lower than objectively measured on the changes in BMI (Table 2).

4. Discussion

In the overall sample, there was a statistically significant increase in body weight over four years. Misperceiving overall walkability, land use mix, and retail density were significant predictors of BMI change. The composite measure for perceived retail density incorporated 11 items, including accessibility of supermarkets and greengrocers. The frequency of trips to these two destinations can be expected to be higher than for most other items, such as post offices, hardware stores, or pharmacies. Furthermore, previous studies have shown that high accessibility of supermarkets and greengrocers can not only affect the body mass index by improving energy expenditure through facilitating active transport, but also by reducing energy intake through better availability of healthy food with lower energy density (Morland et al., 2006; Morland and Evenson, 2009; Spence et al., 2009; Poortinga et al., in press). There was a significant effect of misperceiving land use mix as lower than it actually is. A high variety of different land uses, such as residential, commercial, industrial, or educational, are associated with shorter travel distances between the places of interest. Thereby, land use mix might act to facilitate more physically active transport choices, which in turn would mediate weight maintenance.

A strength of our study is that participants were sampled from neighborhoods with diverse urban form, for whom both objective and self-reported measures of four domains of walkability were analyzed and compared. Environmental cognitions and familiarity with the neighborhood have been shown to be related to the

### Table 2

Prospective relationships of perceiving high walkable environmental attributes as low with changes in walking for transport, walking for leisure, and BMI.

<table>
<thead>
<tr>
<th>Overall walkability</th>
<th>Dwelling density</th>
<th>Street connectivity</th>
<th>Land use mix</th>
<th>Retail density</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b$ (95% CI)</td>
<td>$p$</td>
<td>$b$ (95% CI)</td>
<td>$p$</td>
<td>$b$ (95% CI)</td>
</tr>
<tr>
<td>$\Delta$ Walking for transport</td>
<td>$-55.7$ to $-86.8$, $-24.5$</td>
<td>$&lt;0.001$</td>
<td>$-49.9$ to $-81.5$, $-18.2$</td>
<td>$&lt;0.01$</td>
</tr>
<tr>
<td>$\Delta$ Walking for leisure</td>
<td>$-23.6$ to $-54.7$, $7.5$</td>
<td>$0.14$</td>
<td>$2.4$ to $26.4$, $31.3$</td>
<td>$0.87$</td>
</tr>
<tr>
<td>$\Delta$ BMI</td>
<td>$0.54$ to $0.06$, $1.02$</td>
<td>$0.03$</td>
<td>$0.43$ to $0.14$, $0.99$</td>
<td>$0.14$</td>
</tr>
</tbody>
</table>

Analyses control for baseline levels of walking, BMI, and adjust for sex, age, income, and length of residency.

Farinelli et al., 2008; Gordon-Larsen et al., 2009).

Those who misperceived objectively measured high overall walkability, dwelling density, and land use mix as low had significantly greater decreases in walking for transport than did those whose perceptions matched the objective measure. As well, there was a non-significant trend in the relationship between the decrease in walking for transport and perceiving retail density as lower than it actually is. Overall, our findings provide some novel evidence that perceiving these domains of walkability as lower than they are objectively determined to be can negatively influence changes over time in walking for transport.

There was no effect for misperceiving street connectivity on changes in such utilitarian walking. This was somewhat surprising, as the literature relatively consistently states that street connectivity is a correlate of walking for transport.

With the exception of street connectivity, the influence of misperceiving high walkability as low was weaker for walking for leisure than for walking for transport. As stated above, research has found that the four domains of walkability used in this study are more related to walking for transport than they are to walking for leisure. Therefore, this finding is consistent with the literature. Studies have mostly linked street connectivity with walking for transport as more connected neighborhoods provide more direct routes and thereby higher accessibility to destinations (Saelens et al., 2003b). However, it has also been argued that connectivity could influence walking by offering more choice of routes (Saelens and Handy, 2008). This variety of routes might explain why there was a significant effect for misperceiving street connectivity on changes in walking for leisure.
duration of residence (Ball et al., 2008; Liben, 1981). Therefore, another strength of this study is that we could adjust our analyses for the duration of living in respondents’ current residential location. The study participants reported almost no differences in perceived walkability between the baseline and follow-up surveys. Thus, we can exclude that changes in perceptions over time could explain differences in changes in walking and BMI over time. A limitation is that older adults, women, and people in paid work were overrepresented in the sample, which might limit the generalizability of our findings. Another limitation is that self-report measures were used for physical activity and BMI.

Some longitudinal studies have examined environmental attributes as predictors of change in physical activity (Humpel et al., 2004; Li et al., 2005; Sallis et al., 2007) or weight (Li et al., 2009). However, Li et al. (2005) identified a limitation of their study as the one-year period between their baseline and final surveys may have been too short to detect meaningful changes in walking levels. In the related studies carried out in the USA (Sallis et al., 2007) and in Australia (Humpel et al., 2004), there were only six months and ten weeks, respectively, between the baseline and the follow-up surveys. Therefore, it is a major strength of our study that the time span of our follow-up was four years, which ought to have allowed us to capture meaningful changes in walking and BMI for the whole sample. We found a significant decrease in walking for transport, a borderline significant decrease in walking for leisure, and a significant increase in BMI during the four-year period.

We found that for those who misperceived objectively determined high-walkable attributes of their neighborhood to be less walkable, such misperceptions can negatively and significantly affect their walking for transport and for leisure, as well as their weight compared with those whose perceptions match the objective measures. Effects identified in this study are long term, and applicable to a considerable portion of residents, thus may have a significant, community-wide health impact. These prospective findings support recommendations from previous cross-sectional studies; interventions aiming at improving mismatched perceptions among those who live in high-walkable neighborhoods may be helpful in maintaining (or reducing declines in) physical activity and in facilitating weight maintenance.

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