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Mismatch between Perceived and Objectively Measured Land Use Mix and Street Connectivity: Associations with Neighborhood Walking

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ABSTRACT *Studies on the mismatch between objective and perceived measures of walkability and walking provide insights into targeting interventions. These studies focused on those living in more walkable environments, but perceiving them as less walkable. However, it is equally important to understand how the other mismatch (living in less walkable areas, but perceiving them as walkable) is related to walking. This study examined how the mismatch between perceived and objective walkability measures (i.e., living in less walkable areas, but perceiving them as walkable, and living in more walkable areas, but perceiving them as less walkable) was associated with walking. Baseline data from adult participants (n=1466) of the RESIDential Environment Project (Perth, Australia in 2004-06) collected self-report neighborhood walking for recreation and transport in a usual week and participants' perceptions of street connectivity and land use mix in their neighborhood. The exposure was the mismatch between objective and perceived measures of these. Multilevel logistic regression examined associations of walking with the mismatch between perceived and objective walkability measures. Perceiving high walkable attributes as low walkable was associated with lower levels of walking, while perceiving a low walkable attribute as walkable was associated with higher levels of walking. Walking interventions must create more pedestrian-friendly environments as well as target residents' perceptions.*

KEYWORDS *Walkability, Built environment, Walking, Street connectivity, Land use mix, Perceptions, Urban design*

INTRODUCTION

Regular physical activity confers numerous health benefits, including reduced risk of chronic diseases such as type 2 diabetes, cardiovascular disease, obesity, and some cancers.[1] However, population-wide physical activity levels are low across the world.[2] Given the limited success of individually based approaches to health behavior change,[3,4] socioecological models are increasingly used as a theoretical

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basis for understanding and encouraging the adoption of health-enhancing behaviors, including physical activity.[4,5] Socioecological models emphasize the importance of the built environment as a potential facilitator of, or barrier to, physical activity.[6] Consistent evidence demonstrates that certain neighborhood attributes, such as the availability of different types of destinations (e.g., local stores, services, transit stops, and parks) and properties of routes to access these destinations, are associated with adults' walking behaviors.[7,8]

In assessing how neighborhood characteristics are associated with walking, environmental attributes have been identified either subjectively using participants' self-report (perception) or objectively using geospatial data.[9] The latter approach has progressed considerably over the last decade through the use of Geographic Information Systems (GIS) applications, enhanced computational power, and increased availability of spatial data.[10,11] These advancements allow researchers to develop and apply composite spatial measures of "walkability," which quantify the suitability of certain areas for walking. Walkability indices usually consist of three objectively identified spatial attributes: residential density, street connectivity, and land use mix.[12,13] These indices can be derived either for individuals (e.g., within a certain distance of their home address) or for predefined administrative areas, such as census tracts, postcode areas, and suburbs. Walkability indices have been applied in many studies across different countries and contexts, with most reporting positive associations with walking for transport.[10,14–18]

Studies have shown that objectively derived measures of neighborhood walkability do not always match residents' perceptions of their neighborhood's walkability. For instance, two studies report that approximately one third of participants living in an area objectively measured as being highly walkable *perceived* it as being low walkable.[19,20] This mismatch between objective and perceived measures is not simply a methodological issue because levels of disagreement between objective and perceived built environment attributes are found to be associated with the levels of physical activity, i.e., those who live in high walkable areas perceived to be walkable tend to be more active than those who live in a high walkable area perceived to be low walkable.[21]

To date, these mismatch studies have focused only on those living in more walkable environments perceived to be less walkable.[21] However, equally important is a mismatch in the opposite direction, i.e., whether living in objectively measured less walkable areas perceived to be walkable is related to active living.[22] If a mismatch in this direction is found to be associated with higher levels of physical activity, it suggests a need to actively promote positive environmental perceptions in both walkable and less walkable environments.

Another evidence research gap is the possibility of reverse association. It is possible that people who are not active (and hence spend less time outdoors) know their local environments less well; thus, it may be more likely to perceive it as less walkable. Limited exposure to the neighborhood may partly explain the association between misperceptions and lower levels of physical activity. In order to rule out this rival explanation, the association between misperceptions and physical activity excluding those who are inactive needs to be examined.

The current study first examined how the mismatch between selected perceived and objective measures of neighborhood walkability (both perceiving higher walkable areas as lower and lower walkable areas as higher) was associated with residents' walking for recreation and for transport in their neighborhood. It then examined whether these results were the same after excluding inactive participants, a potential proxy measure for those who are less engaged with their local neighborhood environment.

METHODS

Participants and Procedures

Data from the RESIDential Environment Project (RESIDE) were used. The RESIDE was a longitudinal study of adults building new homes in 74 new housing developments across metropolitan Perth, Australia. The RESIDE included 18 developments classified as "liveable" (i.e., higher density and grid street layouts), 11 as "hybrid" (i.e., those identified as having many, but not all of the liveable elements), and 45 "conventional" (i.e., cul-de-sac and curved street layouts and single detached houses) housing developments. Eligible participants were the following: proficient in English, aged 18 years or older, and intending to move into their new home between 2002 and 2004. This study uses data from the second survey ($n = 1466$), which was administered after participants moved into their new residences (2004–2006). Participants had lived in their neighborhoods for approximately 2 years at the time of data collection. Detailed data collection methods have been described fully elsewhere.[23] The RESIDE study protocols were approved by the Ethics Committee at The University of Western Australia.

Measures

Outcome Variables. Self-report measures of walking for recreation and for transport within the neighborhood in a usual week were collected using the Neighborhood Physical Activity Questionnaire (NPAQ). This has acceptable test-retest reliability for walking for recreation (ICC$\geq$0.82) and transport (ICC$\geq$0.84) within the neighborhood.[24,25] Two dichotomous measures of walking in the neighborhood, "any walking for transport (yes, no)" and "any walking for recreation (yes, no)", were created. The neighborhood was defined as the area within a 10–15-min walk distance from a participant's home. Participants were considered to be inactive if they reported no walking in their neighborhood for any purpose.

Exposure Variables. Only those variables with both objective and perceived measures available were considered. Hence, two components of walkability were assessed: street connectivity and land use mix.

First, using ArcGIS software, street connectivity and land use mix were identified within a 1.6-km road network buffer area from each respondent's residential address. This corresponded to a neighborhood setting, which was also used to obtain participant's perceptions. Street connectivity was defined as the number of intersections (three-way or more) per square kilometer within the road network buffer area. Land use mix was calculated using an entropy index, where the proportion of land use types within the road network buffer area, including: residential; retail; office; health, community, and welfare; entertainment, recreation, and culture; public open space and sporting infrastructure; education; and rural land classifications, were included.[14] A higher value indicates greater land use heterogeneity. Both objective measures were categorized into tertiles. To create greater variability of the objective built environment,[23] the first and third tertiles were modelled in the analysis as "lower" and "higher" classifications, respectively. The second tertile was excluded from further analysis.

Second, perceived measures of street connectivity and land use mix were derived using related items in a modified version of the Neighborhood Environment Walkability Scale (NEWS).[26,27] Participants were asked to rate perceptions of street connectivity (“The streets in my local area do not have many or any cul-de-sacs,” “There are walkways in my local area that connect cul-de-sacs to streets, pathway or other cul-de-sacs” “The distance between intersections in my local area is usually short”, “There are many four-way intersections in my local area,” and “There are many alternative routes for getting from place to place when walking in my local area”) and land use mix (“I can do most of my day to day shopping in my local area”, “There are many shops within easy walking distance of my home” and “There are many places to go within easy walking distance of my home”) items in their neighborhood using a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). The summed response values for each walkability component were categorized into tertiles, and the first and third tertiles were included in the analysis as lower and higher classifications respectively, and the second tertile was excluded from further analysis.

Objectively measured and self-reported walkability components were combined to create two-by-two categories separately for street connectivity and land use mix: (1) higher objective, higher perceived; (2) higher objective, lower perceived; (3) lower objective, higher perceived; and (4) lower objective, lower perceived.

Socio-demographic Variables. Participants reported their age, sex, educational attainment, marital status, employment status, annual household income, and children living at home.

Statistical Analysis

The levels of agreement between objective and perceived measures were assessed using the intraclass correlation coefficient. Multilevel logistic regression analyses examined associations of mismatch between objective and perceived walkability measures with walking for recreation and for transport in the neighborhood. Multilevel analyses were used to account for clustering of the data (individuals nested in housing estates). The regression models were adjusted for socio-demographic variables (age, sex, education attainment, marital status, employment status, annual household income, and children living at home). Further regression analyses excluding “inactive” participants were also conducted. Stata 11.0 IC (Stata Corp, College Station, TX) was used to conduct the analyses.

RESULTS

Participants were aged 20–79 (mean 42)years, and the majority were women, married, and employed (see Table 1). About a quarter of participants (27 %) did not walk for transport or for recreation in their neighborhood; thus, they were considered to be inactive.

Table 2 shows the proportion of participants with matched and mismatched perceptions and objective measures of street connectivity and land use mix. Overall, there was a high level of disagreement between objective and perceived walkability measures. The intraclass correlation coefficients were 0.02 for street connectivity and 0.01 for land use mix, indicating poor agreement between objective and perceived measures. For street connectivity, 47 % of perceptions were mismatched with the objective measure. In particular, more than 50 % of participants misperceived higher street connectivity as being lower. Similarly, 42 % of participant’s perceptions did not match with the objectively derived land use mix classification. Misperceiving lower street connectivity and land use mix as high was

TABLE 1 Study participant characteristics

	Total ($n = 1466$)
Sex, % women	62
Age (years), mean (SD)	42 (12)
Highest education attainment, %	
Secondary school or lower	38
Trade/certificate	38
Bachelor degree or higher	24
Marital status, %	
Married/de facto	85
Separated/divorced/widowed	8
Single	7
Employment status, %	
Full/part time work	80
Does not work	15
Retired	5
Annual gross household income (AUD), %	
< \$50,000	22
\$50,000–\$69,999	23
\$70,000-\$89,999	24
≥\$90,000	31
Children at home, % yes	50
Reported any walking for transport in the neighborhood during a usual week, %	29
Reported any walking for recreation in the neighborhood during a usual week, %	67

AUD Australian dollar, *SD* standard deviation

less common (compared to the other direction of mismatch), yet more than one third of participants were classified in this mismatch category.

Table 3 shows the results of multilevel logistic regression analyses. The odds of walking for transport and recreation were significantly lower for those who perceived objectively measured higher street connectivity as being lower (33 %, $p<0.05$ and 37 %, $p<0.01$, respectively) compared with those who correctly perceived higher street connectivity as being higher. Conversely, the odds of walking

TABLE 2 The proportion of participants with matched and mismatched perceptions

	Objective versus perceived measures	Total *N* (%)
Street connectivity	Higher objective and higher perceived	404 (46)
	Higher objective and lower perceived	475 (54)
	Lower objective and lower perceived	439 (60)
	Lower objective and higher perceived	288 (40)
Land use mix	Higher objective and higher perceived	426 (57)
	Higher objective and lower perceived	322 (43)
	Lower objective and lower perceived	467 (59)
	Lower objective and higher perceived	318 (41)

Data shown are *n* (%)

TABLE 3 Associations between mismatch of perceived and objective walkability components with walking for transport and for recreation inside the neighborhood (*n*=1466)

		Any walking for transport inside neighborhood OR (95 % CI)	Any walking for recreation inside neighborhood OR (95 % CI)
Street connectivity	Higher objective and higher perceived	1.00	1.00
	Higher objective and lower perceived	0.67*(0.49, 0.92)	0.63**(0.46, 0.85)
	Lower objective and lower perceived	1.00	1.00
	Lower objective and higher perceived	1.60*(1.11, 2.30)	1.15 (0.83, 1.60)
Land use mix	Higher objective and higher perceived	1.00	1.00
	Higher objective and lower perceived	0.50**(0.35, 0.71)	1.16 (0.84, 1.62)
	Lower objective and lower perceived	1.00	1.00
	Lower objective and higher perceived	1.57* (1.10, 2.22)	1.32 (0.96, 1.82)

All models are corrected for clustering at the housing estate level and adjusted for age, sex, education, marital status, work status, household income, and children at home

OR odds ratio, *CI* confidence interval

*$p<0.05$; **$p<0.01$

for transport (but not recreation) was 60 % ($p<0.05$) higher in those perceiving lower connectivity as being higher.

Perceiving objectively measured higher land use mix as being lower was associated with a 50 % ($p<0.001$) lower odds of walking for transport (compared with those who correctly perceived high land use mix), yet no such relationship was found with walking for recreation. Conversely, perceiving lower land use mix as being higher was associated with a 57 % ($p<0.05$) higher odds of walking for transport, but no significant relationship existed for walking for recreation.

Sub-analyses examined whether misperceiving high street connectivity and land use mix as low was associated with walking after excluding those inactive. After removing inactive participants from the sample, the associations of perceiving higher street connectivity as lower with walking for transport or for recreation were attenuated just beyond significance (OR 0.75 95 % CI, 0.53, 1.06; $p=0.1$ for walking for transport and OR 0.55 95 % CI, 0.26, 1.15; $p=0.1$ for walking for recreation). Perceiving higher land use mix as low remained significant after exclusion and was associated with 56 % lower odds of walking for transport compared with those who perceived it as high (OR=0.44; 95 % CI, 0.30, 0.66; $p=$

0.0). Similar to the whole sample analysis, this mismatch in land use mix was not associated with walking for recreation (OR=1.55, 95 % CI, 0.78, 3.07; p=0.2).

DISCUSSION

This study examined two types of "mismatch" between objectively identified and perceived environmental attributes (in both directions) and the association with walking for transport and recreation in the neighborhood. Previous studies have shown perceiving high walkable areas, as low walkable is associated with lower levels of physical activity.[21] Our study confirmed and extended these findings by also showing that mismatch in the other direction (i.e., perceived low walkable areas as high walkable) was associated with more walking: Compared with others, those who lived in a neighborhood with lower levels of street connectivity or mixed use, but who perceived it as being more connected or with more mixed use, were more likely to walk locally for transport. However, we found no evidence of this relationship for recreational walking; it is likely that recreational walking, as a discretionary activity, is more influenced by individuals' attitudes rather than environmental factors.[7]

Findings from this study demonstrate the importance of residents' perceptions and how this also impacts on specific walking behaviors, even when living in areas that are more or less supportive of physical activity. The built environment is associated with residents' behaviors, but findings from this study highlight that it has to be perceived as supportive by people in order to influence people's behaviors.[28] These results suggest that environmental interventions designed to enhance physical activity may be less effective if efforts are not made to also enhance people's perceptions of their environment. Our results also provide some encouragement that in areas less supportive of walking, there is the potential to overcome environmental barriers by promoting a positive view of the available neighborhood attributes. Given that physical environmental changes typically require significant investment, these results suggest that residents' environmental perceptions may be enhanced to encourage their physical activity behaviors. Public mass media programs to introduce opportunities within neighborhoods for physical activity may be relevant in shaping residents' environmental perceptions[29,30] These initiatives can raise residents' awareness about their neighborhoods and, consequently, foster their perceptions of environmental attributes for physical activity.[31,32] Identifying sub-populations who are likely to misperceive relevant environmental attributes and examining what factors (individual, social, and environmental) contribute to mismatched perceptions is now warranted to further advance research on the influence of the built environment on physical activity.

Previous studies on the mismatch between objective and perceived environmental measures have suggested that the results may be attributable to limited exposure to local environments.[22] Inactive residents may have limited understanding of their neighborhood surroundings, which may lead to misperceptions. In order to test this explanation, we excluded those who were inactive from our analyses. There was some evidence to support previous suggestions that the inactive may have less knowledge about their neighborhoods,[22] but the results were inconclusive. Among three significant associations observed for the whole sample, one remained significant, but two became marginally significant after excluding those who may not be exposed to their local neighborhoods. Inactive residents' lack of knowledge about local environments remains one possible explanation for mismatch and lower levels of physical activity findings. Given the importance of encouraging those who are inactive to become more active, this warrants further investigation to explore how best to target these groups for physical activity interventions and the extent which they can be enticed into their neighborhoods.

Like previous studies,[19,20] we found that misperceptions were common, particularly for street connectivity, with more people tending to misperceive high walkability as being low. It is possible that objective and perceived measures capture distinct aspects of the built environment, and objective measures are not a valid measure of the construct assessed by people's perceptions.[33] Hence, they may have very different influences on behaviors such as physical activity.[34] The observed mismatches between objective and perceived measures might also be due to discrepancies between how participants defined and perceived their neighborhood (i.e., 10–15 min walk from home) and how geographically defined areas (i.e., 1.6 km network buffer) were applied to enable the calculation of objective measures.[35] Network buffers also do not typically consider the presence of barriers (e.g., major roads), which may affect residents' perceptions of local area boundaries. We found that more participants misperceived street connectivity than land use mix, and misperception of street connectivity rather than land use mix was associated with transport and recreational walking. It is possible that perceptions of land use mix may be relatively accurate even if residents rely heavily on cars for daily activities. However, assessment of street connectivity may depend more on how often residents walk in their local area. Finally, street connectivity is consistently found to be associated with physical activity.[36–38] While road networks are difficult to modify in existing neighborhoods, it may be easier to change people's perceptions of street connectivity by increasing signage, developing walking maps, and conducting awareness events. For example, to improve residents' awareness of walking distances, in "10,000 Steps Ghent" project, signs were assigned in every public parking showing the number of steps required to reach the city center.[32]

This study has several limitations. First, like other cross-sectional studies, we are unable to draw causal relationships between the mismatch of perceived and objective measures of neighborhood walkability and walking behaviors. Second, the self-report walking measures may be subject to recall error. Third, not all components of neighborhood walkability were considered in this study (i.e., self-report measures of residential density and net-retail area ratio were not captured). Last, by international standards, Perth is a relatively low walkable city and may lack variability in the built environmental attributes. In future, more culturally and physically diverse environments should be examined to gain a more comprehensive understanding of mismatch across the environmental and demographic spectrums.

CONCLUSION

In summary, this study found that perceiving higher walkable areas as low or low walkable areas as being highly walkable was common. Perceiving high walkable attributes as low walkable was associated with lower levels of walking, while perceiving a low walkable attributes as being high walkable was associated with higher levels of neighborhood walking. These results suggest that interventions to increase walking should not only seek to create supportive built environments but also understand how residents' perceive their local environments.

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