Transport, urban design, and physical activity: an evidence-based update

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Abstract

The urban environment and modes of transport are increasingly being linked to physical activity participation and population health outcomes. Much of the research has been based on either health or urban design paradigms, rather than from collaborative approaches. Previous health reviews in the urban design area have been constrained to perceptions of the neighborhood or walking behaviors, consequently limiting the understanding of built environment influences on physical activity modalities. This review focuses on existing evidence surrounding various urban design factors and physical activity behaviors. Based on the available evidence, fostering suitable urban environments is critical to sustaining physical activity behaviors. In turn, these environments will provide part of the solution to improving population health outcomes. Key urban design features attributable to transport-related physical activity are density, subdivision age, street connectivity, and mixed land use. Future directions for research include consistent use of transport and health measurement tools, an enhanced understanding of traffic calming measures, and further collaborative work between the health, transport, and urban design sectors. Presenting these findings to transport and urban design audiences may influence future practice, thereby increasing the sustainability of health-related physical activity at the population level.

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1. Introduction

Sedentary lifestyles in industrialized countries are increasingly becoming a major health risk, and it is estimated that insufficient physical activity causes 1.9 million deaths worldwide annually (World Health Organization, 2004, Department of Health Physical Activity and Health Improvement and Promotion, 2004). Local streets have been consistently identified as the most common place for engaging in physical activity (Giles-Corti and Donovan, 2002a, Brownson et al., 2001), with a substantial body of evidence linking leisure time physical activity (LTPA) and transport-related physical activity (TPA) to built environment and transport fundamentals.

Over the last few decades, immense urban changes have occurred in many industrialized countries, including reduced population density in cities and increased sprawl of housing, resulting in the residential migration to suburban developments (Frank, 2000). In many cases, urban design has caused a population-level reliance on automobiles for daily travel (Land Transport Safety Authority, 2000), reduced accessibility to facilities (Estabrooks et al., 2003), and alterations of community perceptions and cohesion (Timperio et al., 2004). Concurrently, many countries are reporting low physical activity levels and increases in obesity prevalence (World Health Organization, 2004). Although the link between the urban environment and health has been established, understanding the impact of the built environment on physical activity behavior has been inadequately addressed by both the health and transport sectors.

Health promotion, transport, and urban design policies all have similar objectives. These are to produce practical, cost-efficient, and successful interventions that apply to a broad cross-section of the population. Urban design principles can easily be aligned with ecological health models to increase incidental physical activity, and therefore total energy expenditure. Examples of these collaborative approaches include restricting city blocks to pedestrian only access, placing car parks away from building entrances, and making stairways more accessible and convenient. The aforementioned design modifications are conducive to physical activity, providing small individual changes. At the population-level, such changes could bring considerable long-term benefits, including reductions in healthcare expenditure, local traffic congestion, pollution, and infrastructure costs. Despite these advantages, the potential for such changes is based on a limited understanding of travel behavior influences.

Several general reviews of the built environment and physical activity relationship exist. Humpel et al. (2002) examined 19 studies in diverse settings, detailing consistent associations between physical activity and perceptions of accessibility, opportunities, and the aesthetics of the environment. Weaker relationships were demonstrated between weather and safety with physical activity, possibly due to the subjective nature of these variables. A strength of the paper was that the authors attempted to separate out aggregate environmental measures by isolating numerous variables that could potentially impact on physical activity levels. More recently, McCormack et al. (2004) examined 30 physical activity studies, and evaluated the findings under the broad categories of neighborhood functionality, safety, aesthetics, and destinations. The review added little to the existing body of knowledge, but reaffirmed previous findings detailed by Humpel et al. Another review focused on 18, predominantly cross-sectional, walking environment studies. Three of the four TPA studies detailed positive associations between walking for transport and open space access, higher composite environmental scores, and high neighborhood walkability (Owen et al., 2004).
Transport literature has also been evaluated from a public health perspective. One review by Sallis et al. (2004) provided the basis for merging urban design, transport, and physical activity at a policy level, but demonstrated limited exploration of previous evidence. Readers were directed to another paper where a small number of United States studies were evaluated (Saelens et al., 2003b). Consistent positive correlations existed between physical activity levels and mixed land use, density, and street connectivity. Although the previous general and transport-related physical activity reviews are comprehensive in their own right, all are primarily limited to cross-sectional designs, walking behavior, homogenous groups, and were reliant on small study numbers, subsequently limiting the amalgamation of knowledge from urban design and physical activity fields. The aim of the present paper is to build upon these previous reviews, as well as incorporating other relevant academic literature from health, urban design, and transport disciplines. This paper systematically draws together the evidence surrounding neighborhood differences and traffic calming effects based on urban design fundamentals, the impact of the localized environment for at risk populations, non-motorized travel characteristics, and measurement issues associated with merging physical activity, urban design, and transport research.

2. Neighborhood differences

Pre-World War II, cities were highly localized places that subsisted on the premise of low automobile ownership. The infrastructure that existed allowed daily requirements to be achieved within a comfortable walking distance, or with the combination of transit. Post-war economics led to increased disposable income and decentralization of cities to suburban centers and single land uses (Frank et al., 2003). As a result, automobiles are relied on for traveling the long inter-destination distances associated with suburban sprawl. Traffic congestion, single-occupant automobile travel, increased pollution, rising infrastructure costs, and degeneration of communities have now become serious concerns for transport sectors in developed nations (Lavisso-Mourey and McGinnis, 2003, Frank et al., 2003). Consequently, in many urban environments physical activity opportunities have shifted from TPA to LTPA.

Subdivision age has been used as a proxy measure of urban form. Older urban environments often show increased walkability because of higher population and building density, grid street design, complete sidewalks, and mixed land use diversity associated with pre-World War II necessities (Berrigan and Troiano, 2002, Handy and Clifton, 2001, Handy et al., 2002). At the aggregate level, living in older homes has been associated with walking. Adjusted findings indicated that residents in pre-1973 dwellings walked at least one mile more, 20 times per month, when compared to those living in newer residences (Berrigan and Troiano, 2002). The non-specific walking associations existed for residents in urban and suburban neighborhoods, but not for those in rural areas and for other types of physical activity. Surprisingly, no discernable differences were shown in walking behavior between those dwelling in residences built pre-1946 and 1946–1973. Nevertheless, a relationship may have been evident if transport-related physical activity was specifically examined. In contrast, one study showed that residents in a newer neighborhood development demonstrated higher walking levels in comparison to residents in an older neighborhood (Leslie et al., in press). The anomaly could have been linked to differences in public
transport accessibility. Based on the presented evidence, it still remains to be determined if localized urban design is more influential than residential age (Table 1).

The mean age of a developed area (an informal proxy measure of sprawl) has also been associated with household non-motorized travel. Residents of older subdivisions make less automobile and more non-motorized trips than those in newer subdivisions. For example, Friedman et al. (1994) compared Bay Area Transportation Survey travel data from pre- and post-World War II neighborhoods in San Francisco. Post-War suburban residents engaged in almost two more auto driver trips per day, and walked less than pre-War neighborhood residents (8% versus 15%, respectively). Comparison groups however were not adjusted by potential confounders and all data were self-report. To support this relationship further, three years of self-reported health and localized county sprawl have been investigated, with lower sprawl values indicating greater residential sprawl. Residents in areas one standard deviation above the mean county sprawl walked 14 min more for leisure each month compared to residents living in localities one standard deviation below. A reverse trend was shown with BMI, detailing a 0.085 kg/m² reduction with each standard deviation increase (Ewing et al., 2003). Leisure time walking behavior was the only variable investigated in the study, although other research has linked urban sprawl to TPA behavior (Table 1).

Studies repeatedly show that mixed land use diversity is the urban design variable most likely to affect the walkability of neighborhoods, primarily by influencing the accessibility and convenience of locations (Leslie et al., in press, Saelens et al., 2003a, Giles-Corti and Donovan, 2002b, Handy and Clifton, 2001). An Australian study detailed those who reported better access, mixed land use, density, and connectivity, resided in more walkable neighborhoods and were more physically active (Table 1). On a cautionary note, the low walkability neighborhood contained hillier topography and the residents reported reduced access to public transport (Leslie et al., in press). Nevertheless, residents’ neighborhood walkability differences are estimated to be between 15–30 min (Sallis et al., 2004) and 70 min (Saelens et al., 2003a) per week, with the latter value based on a small pilot study. In practical terms, residents in high walkability neighborhoods accumulate current physical activity recommendations (30 min of moderate intensity activity on most days) at least one additional day per week.

3. Traffic calming

Modifying traffic patterns through calming mechanisms may be a logical way to influence physical activity levels. Traffic calming measures such as speed humps, traffic circles, and pedestrian refuges have merit as self-regulating automotive speed designs, and may provide opportunistic occurrences for non-motorized travel such as utilizing road closure thoroughfares and pedestrian crossings. Although traffic calming may increase activity opportunities, it is unknown what effect the devices have on modifying LTPA and TPA levels. It has been shown that traffic calming reduces pedestrian injuries, where the risk of injury or death for child pedestrians were significantly higher for traffic volume (OR = 14.30; 95%CI = 6.98–29.20) and high density curb parking (OR = 8.12; 95%CI = 3.32–19.90) in a case-control study (Roberts et al., 1995). Increases in pedestrian injuries were evident in streets that had greater than 10% curb space allocated for parking and 250 automobiles traveling the road per hour. The curb parking variable requires further
<table>
<thead>
<tr>
<th>Reference</th>
<th>Number</th>
<th>Environmental variables</th>
<th>Setting</th>
<th>Physical activity behavior</th>
<th>Statistical adjustment</th>
<th>Significant associations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berrigan and Troiano (2002)</td>
<td>N = 14,827 Adults M = 7117</td>
<td>Age of residence</td>
<td>Local neighborhood</td>
<td>Walking</td>
<td>A, E, I, L, R, S</td>
<td>Age of residence was associated with urban walking frequency and all demographic variables apart from gender</td>
</tr>
<tr>
<td>Ewing et al. (2003)</td>
<td>N = 206,992 Adults M = unknown</td>
<td>Urban sprawl</td>
<td>Census tracts</td>
<td>Walking</td>
<td>A, E, R, S, SP, SS</td>
<td>Risk of increased BMI and hypertension, and decreased walking were associated with increased county sprawl</td>
</tr>
<tr>
<td>Friedman et al. (1994)</td>
<td>N = 7091 Adults M = unknown</td>
<td>Number of trips per household Travel mode per trip</td>
<td>Census tracts</td>
<td>Transport-related physical activity</td>
<td>None</td>
<td>Post-World War II suburbs were associated with residents making more automobile trips Pre-War suburbs were associated with residents using alternative transport modes</td>
</tr>
<tr>
<td>Leslie et al. (in press)</td>
<td>N = 87 Adults M = 23</td>
<td>Residential density Land use mix diversity Land use mix access Street connectivity Walking infrastructure Neighborhood aesthetics Traffic safety Level of crime</td>
<td>Local neighborhood</td>
<td>Walking</td>
<td>None</td>
<td>High walkability neighborhoods were associated with higher residential density, street connectivity, and land use mix</td>
</tr>
<tr>
<td>Saelens et al. (2003a, 2003b)</td>
<td>N = 107 Adults M = 50</td>
<td>Land use diversity Residential density Street connectivity Walking/cycling facilities Neighborhood aesthetics Traffic safety Level of crime</td>
<td>Local neighborhood</td>
<td>Walking and cycling</td>
<td>A, E</td>
<td>Those reporting mixed land use diversity, higher density, street connectivity, aesthetics, and safety were more likely to reside in high walkability neighborhoods</td>
</tr>
</tbody>
</table>

Statistical adjustment key: A = age, E = education, I = income, L = activity limitations, R = race/ethnicity, S = sex, SES = socioeconomic status, SS = smoking status, SP = sprawl.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Number</th>
<th>Environmental variables</th>
<th>Setting</th>
<th>Physical activity behavior</th>
<th>Statistical adjustment</th>
<th>Significant associations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balfour and Kaplan (2002)</td>
<td>$N = 883$ Older adults $M = 383$</td>
<td>Traffic safety&lt;br&gt;Loneliness&lt;br&gt;Level of crime&lt;br&gt;Presence of litter&lt;br&gt;Presence of lighting&lt;br&gt;Public transport accessibility</td>
<td>Local neighborhood</td>
<td>Overall and lower extremity functional loss</td>
<td>A, BRF, E, H, I, R, S</td>
<td>Residents that reported multiple neighborhood problems were associated with increased risk of overall and lower extremity functional loss. Excessive noise, inadequate street lighting, and heavy traffic were associated with an increased risk of functional loss in residents.</td>
</tr>
<tr>
<td>Estabrooks et al. (2003)</td>
<td>$N = 133,046$ Adults $M = unknown$</td>
<td>Availability of user pays physical activity facilities&lt;br&gt;Availability of free physical activity facilities</td>
<td>Census tract</td>
<td>Facility accessibility</td>
<td>None</td>
<td>Availability of free physical activity facilities was positively associated with SES increases.</td>
</tr>
<tr>
<td>Giles-Corti and Donovan (2002a, 2002b)</td>
<td>$N = 1803$ Adults $M = 532$</td>
<td>Spatial access to individual facilities&lt;br&gt;Perceptions of the physical environment&lt;br&gt;Use of facilities</td>
<td>Census tract</td>
<td>Walking&lt;br&gt;Leisure time&lt;br&gt;Physical activity</td>
<td>A, E, I, NC, O, S</td>
<td>Time spent walking for transport was associated with low SES. Sufficient physical activity, spatial access to facilities, facility use, and vigorous activity were associated with increases in SES.</td>
</tr>
<tr>
<td>Langlois et al. (1997)</td>
<td>$N = 1249$ Older adults $M = 560$</td>
<td>Difficulty crossing the street&lt;br&gt;Crossing controlled intersections in designated time</td>
<td>Local neighborhood</td>
<td>Walking</td>
<td>A, HO, MH, S, V</td>
<td>Low walking speed, required daily assistance, history of strokes, fractures, or diabetes, were associated with increased risk of difficulty in crossing the street.</td>
</tr>
<tr>
<td>Roberts et al. (1997)</td>
<td>$N = 13,423$ Children $M = unknown$</td>
<td>Number of streets crossed</td>
<td>Environment between home and school</td>
<td>Walking and cycling</td>
<td>SCE</td>
<td>Increase in numbers of streets crossed was associated with increased age of child. Increased household car ownership was associated with a reduced likelihood of a child walking to school.</td>
</tr>
</tbody>
</table>
Number of streets crossed by a child was inversely associated with household car ownership

<table>
<thead>
<tr>
<th>Source</th>
<th>N</th>
<th>Measurement</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ross (2000)</td>
<td>2482</td>
<td>Number of days walked per week, Vigorous activity participation</td>
<td>Census tract A, E, I, MS, R, S</td>
</tr>
<tr>
<td>Adults</td>
<td>1015</td>
<td></td>
<td>Residential neighborhood A, L, MS, S, SES</td>
</tr>
<tr>
<td>Takano et al.</td>
<td>3001</td>
<td>Space near residence for a stroll, Local park accessibility, Tree-lined</td>
<td>Walking A, L, MS, S, SES</td>
</tr>
<tr>
<td>(2002)</td>
<td>1312</td>
<td>residential street, Automobile and factory noise, Level of crime, Hours</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>of sunlight, Residential garden, Public transport accessibility,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Communication with neighbors, Preference to live in the community</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Five year survival was associated with adequate neighborhood walking</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>space, neighborhood parks and tree-lined streets, and preference to live</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>in the community</td>
</tr>
</tbody>
</table>

Takano et al. (2002) N = 3001 Older adults M = 1312  
Space near residence for a stroll, Local park accessibility, Tree-lined residential street, Automobile and factory noise, Level of crime, Hours of sunlight, Residential garden, Public transport accessibility, Communication with neighbors, Preference to live in the community

Appropriate distance for child to walk, Traffic safety, Stranger danger, Child and parental (proxy) perceptions of the neighborhood

Statistical adjustment key: A = age, BRF = behavioral risk factors, E = education, H = health status, HO = housing, I = income, L = activity limitations, MH = mental health status, MS = marital status, NC = number of children (under 18 years old), O = occupation, R = race/ethnicity, S = sex, SCE = school clustering effects, SES = socioeconomic status, V = vision.
investigation however, as other research suggests that automobiles parked on the road increases the perception of pedestrian safety from street traffic (Frank et al., 2003).

4. At risk populations

Interaction with the built environment is a key component of LTPA and TPA for children. Despite this, the opportunities presented are largely dependent on socioeconomic status (SES). Not surprisingly, Roberts et al. (1997) detailed a positive relationship between the number of streets crossed and chronological age, and a negative association between household vehicle ownership and reduced walking. Unfortunately, a more comprehensive understanding of children’s travel behavior could not be determined as accompanied and unaccompanied child trips were not ascertained. Timperio et al. (2004) also supported the relationship between household automobile ownership and walking behavior in children. However, the findings were based on a low response rate (36%) and questionable research methodology, resulting in variable test-retest reliability measures (Table 2). Parental SES also influences residential location with many parents choosing to move to the suburbs on the premise of providing play areas and safe environments for children. As a consequence, unsupervised child active transport occurrences may be restricted because of inter-destination suburban distances (Sallis et al., 2004) and associated parental traffic concerns (Roberts, 1993), with travel modes of children strongly influenced by parental perceptions (Timperio et al., 2004). Perceived parental safety of the environment has also been related to reluctance of allowing children to play freely outside (Frank et al., 2003), where active childhood outdoor pursuits may be replaced with ‘safer’ sedentary activities where children can be monitored.

Many older adults also face health risks due to inactive lifestyles. The elderly take fewer trips overall by any transport mode, and their travel is largely dependent on automobiles (Federal Highway Administration and Bureau of Transportation Statistics, 1997, Land Transport Safety Authority, 2000). High suburban automobile speeds and incomplete sidewalks convey the perception that it is unsafe for elderly to use the local environment for walking (Lavery et al., 1996). For example, 99% of adult pedestrians aged 72 years or older could not cross electronically controlled street crossings in the allocated time, and 11% reported general difficulties crossing the road (Langlois et al., 1997). The findings were based on the time it took participants to walk 8 m down a corridor from a standing start. The test however, was not environment specific and potentially underestimated walking speeds.

A link has been established between self-defined neighborhood problems and functional loss in older populations (Table 2). One cohort study examined self-reported functional deterioration over a year and associated perceived neighborhood problems. Those who reported multiple neighborhood problems were more at risk of overall physical (OR = 2.23; 95%CI = 1.01–4.60) and lower extremity (OR = 3.12; 95%CI = 1.15–8.51) functional losses than elderly who reported no, or one neighborhood problem (Balfour and Kaplan, 2002). Inadequate street lighting was the greatest single neighborhood variable associated with functional loss, followed by excessive noise. Interestingly, limited accessibility to public transport was associated with elevated risk of functional deterioration, suggesting that accessibility and localized mobility may be critical to sustaining functional independence in older adults. Regardless of SES and baseline functional capacity, positive associations also exist between
longevity and favorable attitudes toward the community, walkable green spaces, and quality of residential streets (Takano et al., 2002).

The most pronounced urban design and transport differences exist around SES. A geographical information systems (GIS)-based study compared physical activity facilities with census tracts, indicating SES variances with facility accessibility. Significant unadjusted group differences existed regarding accessibility to free structured facilities, with low and medium SES tracts having less number of facility sites (4.5 ± 2.3 and 4.9 ± 2.6, respectively) in comparison to high SES census tracts (8.4 ± 3.5). The amount of user pay facilities however, were similar for all groups (3.1 ± 1.5) (Estabrooks et al., 2003). This is concerning, as low SES groups are least likely to have disposable income and are most at risk to suffer from chronic illnesses associated with physical inactivity.

In contrast, Australian researchers detailed residents in low SES census areas had better network access to facilities, including sidewalks, but were less likely to use them for LTPA. After adjusting for various confounding factors, significant associations were shown with low SES residents reporting increased walking for transport in comparison to their high SES counterparts, but were more likely to be classified as inactive (Giles-Corti and Donovan, 2002b). Caution should be applied when interpreting these data as the sample consisted predominantly of women, and was based on socio-economic extremities (Table 2). On the other hand, a multi-level analysis associated a higher level of leisure time walking in low SES groups with enhanced perceptions of convenience. This was purported as a potential normalization effect of the local environment, although potential confounders, such as automobile accessibility and public transport data, were not investigated (Ross, 2000).

5. Non-motorized transport

Recognized travel mode considerations include distance, modal speeds, costs, and convenience, although modal user characteristics warrant further investigation. Inter-destination design features such as density, accessibility, mixed land use, and street connectivity are also mitigating factors for engagement in non-motorized transport. A review of trip-chaining analyses of people in three European countries detailed commuting to education or work were the main bicycle traveling motives. As expected, the extent of bicycle network development was positively associated with bicycle use (Martens, in press). Other analyses indicate that cycling and walking in Europe were safer than other non-European industrialized countries. Specific urban design fundamentals linked to reduced European injury levels included traffic calming, automobile restrictions, extensive traffic education policies surrounding non-motorized transportation, and pedestrian and cyclist sensitive designs. Incorporating these design features and policies into future initiatives may be useful to encourage cycling, particularly in many non-European industrialized countries where cycling levels are low across all age groups (Goldsmith, 1992, Land Transport Safety Authority, 2000).

In non-European countries, potential causes of low cycling rates may be because of the lack of cycle corridors leading to practical destinations and residential proximity to cycle trails. To support this finding, Australian inner city residents who used and resided 1.5 km away from a cycle trail were more likely to use a cycle trail approximately one hour extra per person per week
than suburban users who lived between 1.5 and 5 km away from it (Merom et al., 2003). The cohort study also indicated that males and younger adults (18–34 years old) were more likely to have used the trail at least once (Table 3). Aside from accessibility and connectivity, negative correlates of bicycle use include heavy intersection traffic and the presence of steep hills (Troped et al., 2001). These last findings however, may not have been based on sufficient participant variability, as the cross-sectional sample was predominantly white and well educated. In the study, unadjusted significant positive relationships were shown with light traffic and mixed land use diversity, but were not evident in the adjusted models. Based on the presented information in Table 3, it appears that environmental variables are not strongly related to recreational cycling behavior.

Walking is the most common and preferred form of physical activity for the general population, and is the principle reason why numerous physical activity reviews that have focused on the behavior. Walking popularity likely stems from its accessibility, negligible equipment specialization, and acceptability as a form of exercise for various sub-populations (Siegel et al., 1995). Although it may be the most pursued form of physical activity, only a small portion of Australians engage in adequate walking for health benefits (Giles-Corti and Donovan, 2003). The study detailed one significant relationship between self-reported walking behavior and access to public open space. This is somewhat of an anomaly as an extensive body of research has reported significant relationships with the other study variables investigated. It is likely however, that research findings for walking are culturally specific. For example, Indian travelers without vehicles were simulated to engage in walking distances between 1.3 and 2.5 km, with distance discrepancies based on economic positions (Thamizh Arasan et al., 1996). In contrast, a cross-sectional study with limited statistical analysis, demonstrated that 8% of Americans did not think it was acceptable to walk any distance for transport (Rafferty et al., 2004). Rafferty et al. (2004) cited the three most common barriers associated with walking for transport were time inconveniences, poor weather, and substandard health. Conversely, trip distances were the most defining barrier when travel modes were limited (Thamizh Arasan et al., 1996).

6. Measurement tools

Public health researchers have predominantly been concerned with tracking activity changes, instead of measuring the contextual environment, whereas transport and urban design practitioners have spent little time focusing on non-motorized activity levels (Sallis et al., 2004). In order to ensure mutually beneficial research, urban design, transport, and physical activity objectives need to be integrated into comprehensive studies. In the first instance, measurement strategies need to be incorporated at a cross-sectional level with practitioners seeking to develop cohort studies that track behavior in differing environments. Table 4 outlines pertinent studies that have incorporated some of these measures in the study designs.

6.1. Audit tools

Audit tools show promise for collaborative approaches as they are relatively easy to use and can incorporate a large number of variables. Sallis et al. (1997) developed a 43-point scale that examined physical activity at home, in the neighborhood, and on frequently traveled routes.
Table 3
Environmental variable studies associated with non-motorized transport

<table>
<thead>
<tr>
<th>Reference</th>
<th>Number Age Gender</th>
<th>Environmental variables</th>
<th>Setting</th>
<th>Physical activity behavior</th>
<th>Statistical adjustment</th>
<th>Significant associations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giles-Corti and Donovan (2003)</td>
<td>$N = 1773$ Adults $M = 564$</td>
<td>Presence of sidewalks, trees, sidewalks, land use diversity, access to river, public open space, beach, golf club, road, trees, open space, dogs, lighting</td>
<td>Local neighborhood</td>
<td>Walking</td>
<td>A, E, I, NC, S</td>
<td>Access to public open space was associated with increased walking.</td>
</tr>
<tr>
<td>Merom et al. (2003)</td>
<td>$N = 450$ Adults $M = 248$</td>
<td>Recall of trail promotional campaign message, bicycle trail use</td>
<td>Suburb</td>
<td>Cycling</td>
<td>A, AR, MS, R</td>
<td>Inner city cyclists, males, trail launch, and recollection of baseline message associated with increased cycling. Minimum daily temperature and rainy days were negatively associated with cycling.</td>
</tr>
<tr>
<td>Rafferty et al. (2004)</td>
<td>$N = 3808$ Adults $M = 1512$</td>
<td>Distance walked for transport</td>
<td>State-wide</td>
<td>Walking for transport</td>
<td>A, R, S</td>
<td>Men and African-Americans were more likely to walk for transport. Warmer seasons were associated with increases in walking for transport.</td>
</tr>
<tr>
<td>Troped et al. (2001)</td>
<td>$N = 413$ Adults $M = 164$</td>
<td>Presence of sidewalks, topography, level of crime, land use diversity, street lights, distance to trails, scenery, traffic safety, unattended dogs</td>
<td>County</td>
<td>Cycling for transport and recreation</td>
<td>A, SE, SO</td>
<td>Pleasant scenery, presence of street lights, neighborhood sidewalks, and no hills were associated with increased cycling for transport. Increased distance to trails was negatively associated with cycling for transport.</td>
</tr>
</tbody>
</table>

Statistical adjustment key: A = age, AR = residential area, E = education, I = income, MS = marital status, NC = number of children (under 18 years old), R = race/ethnicity, S = sex, SE = self-efficacy, SO = social support, TS = transit service.
Table 4
Environmental variable studies that have utilized measurement tools

<table>
<thead>
<tr>
<th>Reference</th>
<th>Number</th>
<th>Environmental variable</th>
<th>Setting</th>
<th>Physical activity behavior</th>
<th>Statistical adjustment</th>
<th>Significant association with main outcome variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boarnet and Sarmiento (1998)</td>
<td>$N = 769$ Adults $M = 377$</td>
<td>Residential density Land use mix Street connectivity</td>
<td>Local neighborhood</td>
<td>Trips</td>
<td>None</td>
<td>Women were more likely to engage in non-work trips. Children and elderly were least likely to make non-work trips.</td>
</tr>
<tr>
<td>Cervero and Radisch (1996)</td>
<td>$N = 1460$ Adults $M = $ unreported</td>
<td>Mixed land use diversity Modal travel use Street network length</td>
<td>Census tracts</td>
<td>Transport related physical activity</td>
<td>I, TS</td>
<td>Neo-traditional neighborhood residents were more likely to engage in non-motorized, non-work trips and make less daily automotive trips than suburban residents. Residents in mixed use, compact areas were more likely to access public transport by walking and cycling than residents in more sprawling areas.</td>
</tr>
<tr>
<td>De Bourdeaudhuij et al. (2003)</td>
<td>$N = 521$ Adults $M = 270$</td>
<td>Side walk quality Activity facilities Home activity equipment Residential density Land use mix diversity Land use mix access Street connectivity Walking/cycling facilities Aesthetics Traffic safety Level of crime Public transport accessibility</td>
<td>Local neighborhood</td>
<td>Physical activity</td>
<td>None</td>
<td>Enhanced accessibility to shops, public transport, and facilities were associated with increased minutes walking and moderate intensity physical activity for men. Enhanced accessibility to shops, public transport, and facilities were associated with increased minutes walking and moderate intensity physical activity for women. Vigorous activity was positively associated with proximity of activity facilities and home activity equipment.</td>
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<tr>
<td>Study</td>
<td>N</td>
<td>Sample Description</td>
<td>Key Factors</td>
<td>Study Outcome</td>
<td></td>
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<tr>
<td>Humpel et al. (2004a, 2004b)</td>
<td>800</td>
<td>Adults M = 402</td>
<td>Residing in coastal versus non-coastal locations</td>
<td>Men residing in a coastal location who held positive perceptions of their neighborhood were more likely to engage in neighborhood walking than non-coastal men. Reduced accessibility to services was associated with an increase in neighborhood walking for women.</td>
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<td></td>
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<td>Local neighborhood</td>
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<td></td>
<td></td>
<td></td>
<td>Walking A, E</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>King et al. (2003)</td>
<td>149</td>
<td>Older adults M = 0</td>
<td>Proximity to park, Proximity to trail, Land mix diversity, Aesthetics, Traffic safety, Level of crime</td>
<td>Those who lived within walking distance of a trail, retail store, or park were more likely to have higher pedometer scores than those who did not live within walking distance. Neighborhood walkability scores increased as the number of destinations accessible by walking from home intensified.</td>
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<td></td>
<td></td>
<td></td>
<td>Community</td>
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<td></td>
<td></td>
<td></td>
<td>Walking None</td>
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<td></td>
<td></td>
<td></td>
<td>Leisure time physical activity</td>
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<tr>
<td>Sallis et al. (1997)</td>
<td>110</td>
<td>Adults M = 27</td>
<td>Home physical activity equipment, Physical activity facilities, Presence of sidewalks, Hilly landscape, Enjoyable scenery, Level of crime</td>
<td>Presence of home equipment was associated with an increased likelihood of physical activity.</td>
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<td></td>
<td></td>
<td></td>
<td>Local neighborhood</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Physical activity A, E, FA, HE, I, S</td>
<td></td>
<td></td>
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<tr>
<td>Wendel-vos et al. (2004)</td>
<td>11541</td>
<td>Adults M = 5353</td>
<td>Neighborhood green space, Neighborhood recreational space, 300–500 m radius around respondent’s home</td>
<td>Size of sports ground was associated with an increased likelihood in general bicycling in the 500 m radius. Size of parks was associated with an increased likelihood in bicycling for transport in the 300 m radius.</td>
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<td></td>
<td></td>
<td>300–500 m radius around respondent’s home</td>
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<td></td>
<td>Walking and cycling A, E, S</td>
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</table>

Statistical adjustment key: A = age, E = education, FA = facilities, HE = home equipment, I = income, S = sex, TS = transit service.
Although adequate test-retest reliability existed (0.68–0.89) and construct validity was supported, the only significant association once confounders were adjusted for, existed between home physical activity equipment and strength exercise (Sallis et al., 1997). Environmental characteristics measured by the Neighborhood Environment Walkability Scale (NEWS) also showed moderate to high test-retest reliabilities (0.58–0.80) in a predominantly Caucasian sample (Table 1). Those who reported higher density, land-use mix, connectivity, safety, and aesthetics, accumulated more physical activity as measured by accelerometers. High walkability residents also reported more TPA for errands than those in low walkability localities (85.2% versus 59.6%), although there were no differences in reported vigorous activity (Saelens et al., 2003a).

NEWS has also been used in two Australian studies. Significant adjusted relationships were shown with men who held more positive neighborhood perceptions and women who perceived greater accessibility were most likely to engage in neighborhood walking (Humpel et al., 2004a). NEWS also detected differences between high and low walkable neighborhoods, showing the greatest neighborhood variability for mixed land use diversity and least group differences for adequate street connectivity (Leslie et al., in press). Pikora et al. (2002) has also developed a simple, reliable audit tool to measure the local physical environment. The Systematic Pedestrian and Environmental Scan (SPACES) defined a neighborhood as a 400 m radius from a respondent’s residence, and assessed components of functionality, safety, aesthetics, and destinations. Both the intra- and inter-reliability of the items in the SPACES audit were generally high, aside from subjective measures of attractiveness of the streetscape and difficulty in walking (Pikora et al., 2002).

6.2. Geographical information systems (GIS)

GIS is an objective spatial mapping tool that analyzes layers of the built environment. It is gaining popularity in the health and urban design sectors with several studies incorporating this technology to provide an in-depth objective analysis of the local environment. Pikora et al. (2002) incorporated GIS into the SPACES tool to ascertain geographic features of the audited environment. Similarly, GIS databases have been employed to measure green space around a respondent’s residence (300–500 m radius) in an attempt to understand physical activity influences (Wendel-vos et al., 2004). The study reported no significant findings for walking, and the cycling behaviors were dependent on the radius around the respondent’s home (see Table 4), reiterating the findings from Merom et al. (2003). Potential limitations of the study were that the GIS variables measured were restricted and the participants resided in exceptionally hilly terrain. Troped et al. (2001) also utilized GIS in a cycling study, showing a negative relationship between bicycle use and environmental variables (Troped et al., 2001) (Table 3).

GIS has also been used at a simulation level to model neighborhood pedestrian network connectivity (Randall and Baetz, 2001; Aultman-Hall et al., 1997). Modeling neighborhoods prior to development show promise for conceptualizing the urban environment relative to physical activity behaviors. Although several physical activity studies (both real and simulated) have used GIS, further attention is still required, including vigilant selection of information overlays to detect determinants of neighborhood level physical activity. The objectivity and level of detail of the tool
remains unsurpassed and many GIS uses remain untapped. Despite this, the cost and expertise required limits GIS uses to large, collaborative studies.

6.3. Self-report tools

Numerous physical activity questionnaires exist and have been used extensively in environmental research. The International Physical Activity Questionnaires (IPAQ) have been successfully used in environmental studies (Humpel et al., 2004b, De Bourdeaudhuij et al., 2003), and may show the most utility for international physical activity comparisons (Shephard, 2003). The IPAQ measure has shown acceptable international psychometric performance, reporting $r = 0.80$ for reliability and $r = 0.30$ for validity (criterion measure accelerometers) in adults (Craig et al., 2003). In one study, minutes spent walking were significantly correlated to environmental variables, although walking for transport or recreation could not be differentiated (Table 4). However, the IPAQ explained only minimal variance between reported physical activity and environmental correlates (De Bourdeaudhuij et al., 2003).

A common criticism of the short format seven-day IPAQ is that it is not sensitive enough to detect TPA (Humpel et al., 2004b, De Bourdeaudhuij et al., 2003). However, the long-form IPAQ scores higher activity level prevalence than other questionnaires, as it effectively accounts for transport, occupational, and recreational physical activity. Therefore, higher recommended activity guidelines may need to be devised if IPAQ is to be used systematically as a surveillance tool. On a cautionary note, the long form survey is lengthy and repetitive, making it costly for routine surveillance. Two studies have also found the IPAQ telephone protocol to over-report physical activity levels (Rutten et al., 2003, Rzewnicki et al., 2003).

Travel diaries have been used to form the basis of aggregate trip data. Current methods of self-report travel diary data appear to capture home-based travel better than work-based travel, potentially because work-related trips are underreported when trip chaining occurs (linking several travel modes to access one destination) (Fisher et al., 2004). Boarnet and Sarmiento (1998) used two-day travel diaries to estimate the number of residential non-work trips through regression modeling techniques. A complex non-significant relationship existed between socio-demographic and land use characteristics near the person’s place of residence for non-work trips, and no relationship was established with work-related travel (Boarnet and Sarmiento, 1998). Limitations were that the sample was biased towards highly educated, white people, and the measured area was too confined to capture many non-work trips. Other research has also utilized travel diaries, with participants recording their three main transport trips from the previous day (Cervero and Radisch, 1996). Although the response rate was low (18%), a substantial amount of information was gathered, including travel means, origin and destination information, and trip length and time. Matched-pair non-work travel appeared to be more elastic than work-related travel and was strongly linked to household vehicle ownership.

6.4. Motion sensors

Motion sensors, such as pedometers and accelerometers are objective physical activity monitors that record ambulatory activity, and have been successfully implemented in environmental studies. King et al. (2003) found a positive association between women with higher pedometer step
counts and living within walking distances of a park, walking trail, or specific shops ($p < 0.01$). Unadjusted findings demonstrated older women perceived that 20 min was an acceptable walking time to access destinations, and were more likely to walk when multiple destinations were present. Other research detailed a relationship between accelerometer measured minutes of physical activity, walkability of a neighborhood, and obesity prevalence. The relationship between residents’ weight status and neighborhood walkability was weakened once other covariates were included (Saelens et al., 2003a).

Tudor-Locke et al. (2003) used accelerometers with children to understand energy expenditure differences between different travel modes to school. Annual energy expenditure differences between walking and being driven to school equated to 8840 calories for boys and 6640 calories for girls (Tudor-Locke et al., 2003). Similar findings for children were reported elsewhere (Cooper et al., 2003). In both cases, urban design variables were not measured, as the objectives were to establish energy expenditure associated with school related travel. Although physical activity studies often seek to incorporate motion sensors, limitations do exist. These include the lack of measurement sensitivity to certain types of body movements (such as cycling), and the cost of both the unit and attaching the sensors to the participants. Nevertheless, motion sensors show promise in urban design studies as they are portable, non-invasive, and easy to use.

Infrared sensors are common automated measurement devices used in transport research, but are limited in the field of physical activity. The sensors are vulnerable to reliability and validity issues regarding non-motorized travel modes, including only being able to measure one person at a time, disturbances by environmental conditions, inability to distinguish between modal activity and individuals, and inconsistencies in open spaces (Granner and Sharpe, 2004). A study comparing infra-red beam counters (IRBC) with direct observation in five parks demonstrated that the IRBC overestimated people using walking paths by 14–78% and underestimated pedestrian volume count by approximately 20% (Milat et al., 2002). Presently, infrared sensor applications are limited for measuring physical activity in an urban setting.

7. Limitations

Understanding the association between the built environment and physical activity behavior is a challenging task, but one that is gaining momentum. Australian (Humpel et al., 2004b, Owen et al., in press, McCormack et al., 2004, Pikora et al., 2003, Giles-Corti et al., 2003) and United States (Ewing et al., 2003, Brownson et al., 2004, Cervero and Duncan, 2003, Frank, 2004, Sallis et al., 2002, 2004) researchers are leading the way in built environment and physical activity research, however more detailed international perspectives are needed. The majority of existing research is based on country-specific, self-report cross-sectional designs, which have led to inherent flaws and no establishment of causality. A problem facing researchers in the area of urban design, transport, and physical activity is sampling and measurement inconsistencies between studies, making inter-study comparisons often impossible. This is evident in the presented tables where contradicting information is shown. Furthermore, the present review is confined to existing academic publications, and a paucity of research has been highlighted around trip chaining, traffic calming, and a comprehensive understanding of how the environment impacts on travel mode choices.
8. Future directions

An opportunity exists to combine and develop ecological models that may increase the understanding of transport and physical activity behaviors. Further investigation is needed however, to understand perceived and real environmental barriers for different user groups, particularly low SES groups and those with limited vehicular accessibility. Urban and health planners need to prioritize settings that are most specific for these user-groups. Facility site selection and traffic calming mechanisms also need careful consideration to maximize population health outcomes. Parental environmental and safety concerns need to be targeted to encourage the sustainability of child non-motorized transport, and prospective research needs to investigate if travel modes utilized as a child track into adulthood.

This review supports the different urban design features that are conducive to discrete physical activity behaviors. However, we now need to understand which urban investments will maximize physical activity behaviors. Based on the presented evidence it appears that TPA shows the most promise in activity sustainability, but limited information is available regarding this behavior and much work remains in this field. Future prospective designs need to determine if individuals select their neighborhood, or if the relationship is reversed because of individual, social, economic, and logistical restrictions. This is a comment echoed by nearly all published urban design and physical activity research. Despite this, the present review goes someway to drawing together existing transport, built environment, and physical activity literature, however the complexity of the relationships need further systematic attention.

Acknowledgments

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