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Built Environment Correlates of Walking: A Review

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Abstract

Introduction—The past decade has seen a dramatic increase in the empirical investigation into the relations between built environmental and physical activity. To create places that facilitate and encourage walking, practitioners need an understanding of the specific characteristics of the built environment that correlate most strongly with walking. This paper reviews evidence on the built environment correlates with walking.

Method—Included in this review were 13 reviews published between 2002 and 2006 and 29 original studies published in 2005 and up through May 2006. Results were summarized based on specific characteristics of the built environment and transportation walking versus recreational walking.

Results—Previous reviews and newer studies document consistent positive relations between walking for transportation and density, distance to non-residential destinations, and land use mix; findings for route/network connectivity, parks and open space, and personal safety are more equivocal. Results regarding recreational walking were less clear.

Conclusions—More recent evidence supports the conclusions of prior reviews, and new studies address some of the limitations of earlier studies. Although prospective studies are needed, evidence on correlates appears sufficient to support policy changes.

Keywords

walking; built environment; physical activity; urban design

Introduction

Walking is one of the most common forms of physical activity, with documented benefits for health [36,48]. Research on walking behavior has traditionally focused on individual factors such as socio-demographic characteristics and attitudes [59]. Intervention studies have usually addressed the individual or social environment, through incentives, individually targeted behavior change programs, worksite programs, and walking clubs and other activities designed to increase social support for walking [38] although some have targeted more changes in environment (e.g., building/extending walking paths) [53]. Researchers and practitioners alike have come to appreciate the importance of the built environment in facilitating or constraining walking. Walking occurs primarily in neighborhood streets and public facilities [44], and the character of such places influences

the degree to which they are safe, comfortable, and attractive for walking. To create places that facilitate and encourage walking, practitioners need an understanding of the specific characteristics of the built environment that correlate most strongly with walking.

The built environment has been defined in different ways by different researchers. Most generally it is defined as the part of the physical environment that is constructed by human activity. By one definition, the built environment consists of the following elements: land use patterns, the distribution across space of activities and the buildings that house them; the transportation system, the physical infrastructure of roads, sidewalk, bike paths, etc., as well as the service this system provides; and urban design, the arrangement and appearance of the physical elements in a community [32]. Researchers have also focused on different types of walking, whether walking for recreation or exercise, or walking to reach a destination. This latter category has a variety of labels, including active travel, non-motorized travel, transport-related physical activity, destination-oriented walking, and utilitarian walking. Bicycling and transit use, which usually involves walking and sometimes involves bicycling, are often included with walking under the first three labels, though walking is generally the largest component.

Research on the built environment correlates of walking has proliferated in recent years. Two different fields have contributed to this body of work. The transportation planning field has for several decades studied the connection between the built environment and travel behavior. Although the motivation for this work has been a concern over the growing amount of automobile traffic, researchers have also considered the effect of the built environment on walking as a mode of transportation [32,58]. The public health field has long studied walking as a form of physical activity but in the last decade has increasingly focused on the connection between the built environment and walking for recreation or exercise or walking in total [37,44,54]. In the last several years, researchers from these two fields have worked together to better understand these connections. This paper reviews what the research so far tells us about the characteristics of the built environment that correlates with walking and discusses outstanding questions and policy implications.

Method

Many reviews of the research on built environment correlates of walking have been published. A review of these reviews is provided before examining more recent studies. To identify all relevant reviews, reviews already known (and some written) by the authors were examined and searches were conducted in the Pub Med, TRIS, and Academic ASAP databases using the terms “walk”, “walking”, “pedestrian”, “non-motorized”, and “active travel” for reviews. After screening obtained reviews for relevance, we considered nine reviews published between 2002 and 2006 [2,18,33,37,44,49,52,54,58], three additional articles that discuss research issues but do not systematically review results [27,32,47], and one extensive review published as appendix to an Institute of Medicine – Transportation Research Board report [29]. Conclusions based on studies reviewed, limitations of those studies, and recommendations made for future studies were extracted from these review articles.

Previous reviews provide important insights into specific characteristics of the built environment correlated with walking behavior and into the limitations of this research. Only two of the reviews we identified focus on walking specifically [54,58], while the other reviews include studies of physical activity more generally but distinguish results for walking. Although there is considerable overlap in the studies included in the different reviews, each review used somewhat different criteria and search procedures for identifying relevant studies. As several of these reviews note, differences across studies in measures of

walking and characteristics of the built environment as well as study design make comparisons and conclusions difficult [2,3,58]. Still, these reviews provide tentative conclusions that are largely consistent with one another, as summarized in Table 1.

A systematic search was conducted in order to identify articles published in 2005 and up to May 2006 that examined the link between built environment and walking. Search terms used in PubMed, TRIS, and Expanded Academic ASAP limited to articles published in 2005 or 2006 included “walk”, “walking”, “environment”, “urban form”, “pedestrian”, “design”, and “neighborhood”. The bibliographies compiled by the Robert Wood Johnson Foundation Active Living Research Program were also searched. In addition, the *Journal of Physical Activity and Health* and the *Journal of the American Planning Association* were searched given their recent supplement issues on physical activity and built environment. The bibliographies of all articles derived from these searches were examined to identify any other pertinent articles.

The articles met the following inclusion criteria: 1) examined some aspect of the physical environment, either objective or/and perceived, up to and including the broad distinction of urban versus rural, 2) measured walking or walking and cycling as a distinct type of transport and/or activity (e.g., not included within another specific type of physical activity [64] or when grouped among all physical activity), and 3) written in English. Physical environment was operationalized as the built or natural environment, but also included constructs examined in transportation and urban planning literatures as potentially relevant to non-motorized transport, including population density. In addition, potential derivatives from the physical environment, including aesthetics and safety are also considered. To more specifically focus on physical environment, intra- and interpersonal/social, cultural, and economic environmental factors were not examined (and not included as results), although many studies of physical environment reviewed included such factors.

Table 2 details the sample, environmental data source, environmental factor(s) examined, the analyzed geographic unit of environmental factor(s), walking metric, non-environmental covariates examined, and a summary of results of studies conducted among adult samples that examined relations between physical environment and walking. For the environmental data source, “survey” or “interview” denotes that sample respondents were queried about their perceptions or awareness of environmental factors near their residence or in their neighborhood (see geographic unit column for specific area). Under environmental factor(s) examined, objective environmental data were considered data derived from non-respondent sources, including Census, land use, network, and professional or trained raters. In contrast, perceived environment data were considered data about the environment derived from respondents who were also providing information about their walking. When specified, the geographic unit for the objective environment data is provided in Table 2, with the geographic unit for most perceived environment factors being vague in many studies (e.g., respondents asked to describe their “neighborhood”). In Table 2, environmental factors examined are succinctly described, but for brevity reasons other variables that were also considered and/or are statistically significant correlates (e.g., demographics, psychosocial variables) are not detailed in Table 2. However, the types of covariates, if any, used in the multivariate models in these studies are provided in Table 2. Demographic covariates (“Demos”) include such factors as individual respondent age, race/ethnicity, and education level, as well as household level factors including car ownership and household income information; psychosocial-physical activity covariates (“Psych-PA”) include individuals’ cognitions and other perceived support or barriers to walking or physical activity (e.g., self-efficacy, enjoyment, social support); self-select covariates (“Self-select”) include individuals’ preferences for or attitudes about neighborhood or transport characteristics (e.g., reasons for moving to neighborhood, preference for being able to walk to stores, pro-transit

attitudes). All studies presented in Table 2 relied on participant report (usually through surveys) of walking behavior; none used a more objective assessment of walking. Results are presented for findings for each walking outcome available that is statistically significant as described by the study authors (usually $p < .05$, but at times $p < .10$). When multiple models are provided in the article (e.g., base models with a limited number of variables), the final or most complete model results are presented.

Table 3 is an extracted summary of the studies detailed in Table 2, with information for each study on how the environment was measured (through objective means or respondent perceptions), categorizing the scale of the environmental measures and type of walking examined, and summarizing the results into whether the association(s) between the environmental factors were expected, null, or unexpected. Expectedness was based on prior empirical literature and active living conceptual models in the areas of built environment, physical activity, and walking. “Greater or better” of the following built environment constructs were “expected” to be related to more or more frequent walking: density, proximity to non-residential, street connectivity, parks/open space, pedestrian infrastructure, aesthetics, and non-park physical activity facilities. In contrast, “less or lower” of the following built environment constructs were “expected” to be related to more or more frequent walking: distance to specific non-residential land uses, crime, traffic safety or volume/noise. For simplicity sake and based on the relative lack of empirical evidence regarding specificity of built environment factors for recreational walking, “expectedness” was considered the same for transport, recreation, and general walking outcomes. If an environmental factor was reported as being measured, but not discussed in the article as either significant or non-significant, the association between that environmental factor and the walking outcome was categorized as “null”. “Urban” versus “rural” comparisons were assigned to the environmental factor of density (based on the Census distinction), although these types of areas also differ on many other environmental factors.

Table 4 is a further extracted summary, grouping each result provided in Table 3 into specific environmental factor types by walking type and result expectedness (expected versus null or unexpected). Thus, it is possible for any given study or sample to provide more than one result (e.g., if a study looked at more than one type of walking, or if a study found some environmental factors related to walking but others not related to walking). For results with composite environmental measures (e.g., [23]), each environmental factor type within the composite was assigned a result in Table 4.

Table 5 details studies looking at physical environmental factors related to children’s walking, with most studies examining walking to school. The format of Table 5 mimics that of Table 1, with information provided about sample, environmental data source, environmental factor(s) examined, the geographic unit of the environmental factor measured, the walking metric, and results of each study. Similar to the studies among adults, children’s walking behavior was usually assessed by self- or parent-report, with one exception where walking behavior to school was observed at the beginning of the school day [60].

Results

Review of prior reviews

The most consistent set of conclusions relates to proximity to potential destinations. Five reviews found sufficient evidence to conclude that accessibility based on distance to destinations is associated with more walking (Table 1). Three reviews concluded that mixed land use is also associated with more walking. Because mixed land use means destinations are within closer proximity, this finding is consistent with the findings for accessibility.

Three reviews point to density as an important correlate of walking. This finding is also probably related to proximity: in areas with higher density, destinations can be closer together because the number of people needed to support any activity is found within a smaller area. However, both mixed land use and density might also influence the aesthetic qualities of the walking environment and thus as correlates of walking would reflect the combined effect of proximity and aesthetics.

Indeed, six reviews found sufficient evidence to conclude that aesthetic qualities – the attractiveness of the environment – are associated with walking. However, measures of this attribute of the built environment are especially variable across studies. Sidewalks (pedestrian infrastructure) and the connectivity of routes/network, attributes of the built environment related to the transportation system, were also found to be correlated with walking. The role of sidewalks in creating safe environments for walking is obvious, while street connectivity is important because of its effect on proximity: greater street connectivity generally means more direct routes and thus shorter distances from home to potential destinations. Street connectivity might also affect walking by expanding the choice of routes, thereby enabling some variety in routes within the neighborhood or to destinations. Attributes related to safety were found by four reviews to be correlates of walking. Finally, three reviews concluded that neighborhood type, defined by “walkability” (generally composite of the above attributes) or by age of development, is a correlate of walking.

The reviews are consistent in their conclusion that the built environment is associated with walking, though they are also consistent in noting that the specifics of this association are less clear. Evidence suggests, for example, that different attributes of the built environment are associated with walking for exercise than with walking as a mode of transportation [29,54]. One review found that only one out of four studies showed significant associations between built environment attributes and utilitarian walking [54], while another concluded that utilitarian walking accounts for most of the difference in walking between neighborhoods that differed on built environment characteristics [58]. As of the writing of these reviews, the number of available studies was insufficient to produce “definitive conclusions” on the relationship of particular attributes of the built environment with particular walking behaviors [54,58].

The reviews also point to many limitations of this research and provide recommendations for future studies with respect to conceptual models, the specificity of behaviors and environments, measures of the built environment, measures of walking, sampling, focus on specific populations, research design, and collaborations. Many reviews point to the need for better conceptual models to guide future studies [2,29,32,37,54,58]. Most generally, researchers need to look at “structural relationships between variables” and undertake a “deeper examination of direct and indirect relationships, interactions, and hypothesized paths of causality” [52]. Researchers must give further consideration to confounding factors, which have been inconsistently evaluated in previous studies [44,58]. Multilevel models that take into account moderators and mediators should be used, and theoretical models “that account for environmental influences and their interactions with other determinants” are needed [54]. Examining the interaction between psychosocial and environmental variables [29,54,58], as well as the interaction between social and physical environments [33] may also be important. Others call for behavior-specific and environment-specific models [27,54]. Reviews by researchers from the planning field recommend that planners make use of the social ecological model widely used in health behavior research [29,44].

Another common recommendation is to study specific behaviors in specific environments [27,29,37,49,54]. Such an approach will “help identify the particular environmental attributes that might prompt and maintain habitual physical activities” [54]. One of the

challenges in carrying out a behavior-specific approach is to properly define neighborhoods in terms of boundaries and scales [27]. At issue is the scale at which the neighborhood environment is most strongly correlated with walking and other physical activity [33]. In these studies, data on walking must be spatially matched with data on the built environment [32].

Validated, consistent, and objective measures of specific features of the built environment are essential for this work [18]. Many reviews call for the use of objective measures generated with the help of geographic information systems (GIS) [18,33,49,54,58]. Others suggest that both perceived and objective measures should be included, and researchers should examine the relationship between them, particularly for characteristics such as safety [18,33,49,58]. One review calls for a better conceptualization of the built environment to guide the measurement of its components [33], and another review offers one: the Behavioral Model of Environment categorizes characteristics as relating to origin-destination, route, or area [44]. The measurement of the quality of built environment elements, not just their presence, is another recommendation [27]. Specific characteristics of the built environment identified as in need of better measurement include: personal safety as differentiated from traffic safety [49]; walking infrastructure such as sidewalks, pedestrian signals and islands, bicycle lanes and trails [58]; and traffic calming measures [2].

Although less of a problem, improved measures of walking are also needed, particularly separate measures for different types of walking [29,44,54]. Optimal methods for collecting self-reported data on walking by type, i.e. for recreation versus for transportation, has not yet been established [33]. In the planning field, data on walking for transportation are incomplete [32] and the measures are not usually validated [44]. In addition, separating walking for recreation from walking for transportation is not necessarily straightforward [29].

Sampling has also been identified as a problem in the reviews. As of the writing of these reviews, studies had been conducted in only a small number of cities [58] and were country-specific [2]. Future studies, one review suggests, should select subject samples from heterogeneous environments rather than selecting random sample from general population to ensure sufficient variation in measures of the built environment [27]. Another review discusses the problem of spatial multicollinearity of neighborhood characteristics, which makes it hard to identify the unique contribution of specific characteristics; to solve this problem, researchers should compare neighborhoods that differ on only one walkability factor [58].

Few studies have focused on specific segments of the population, leaving open the question of whether the built environment has similar effects by race/ethnicity, socioeconomic status, age, or ability [33]. Very little research has been done on the relationship between the built environment and children's walking [52]. This situation is much the same for older populations, for whom "surprisingly little is known" about the effect of the built environment on walking [18]. Further investigation to understand perceived and real barriers for different populations, especially groups with low SES and limited auto access, is needed [2].

As each of these reviews notes, almost all previous studies have been cross-sectional. Cross sectional studies need to be complemented by and lead to prospective studies to more definitively establish causal relationships between the built environment and walking [2,27,29,33,37,44,49]. Research designs that could prove useful in exploring causal relationships include intervention studies that examine change in behavior before and after a

change in the built environment [29,53,58], and studies that examine changes in behavior before and after a move from one environment to another [29,58].

Finally, several reviews point to a need for collaborations among a wider range of professionals [2,32,58]. It is clear from our review of more recent research that such collaborations are increasing in number and paying off in terms of an improved understanding of the relationship between the built environment and walking.

Evidence from Recent Research

For the 2005 and up to May 2006 publication years, we found 29 studies examining 28 different adult samples that examined the relation between built or physical environment factors and walking (see Table 2). These studies were drawn from samples across the U.S., Australia, Portugal, Belgium, and the Netherlands. Almost half the studies included an environmental measurement based solely on objective information, a significant improvement over prior research. There was considerable variability in the type of walking assessed, ranging from walking to a specific location [5], to a specific type of walking such recreational walking [21] or walking to a store [30] to total [26] or general walking (e.g., walking activity [46]). Although most studies obtained a continuous assessment of frequency or duration from participants, it was common to evaluate categorical outcomes of walking [7]. It is noteworthy that demographic variables were a common type of covariate included in the existing multivariate analyses, with most studies examining individual-level demographic factors rather than both individual- and neighborhood-level demographic characteristics (see [26] as an example of an exception).

As evidenced in Table 3, most studies have investigated environmental factors at the micro-level, using an individual's residential location and walking distance radius around that location as the environmental scale. As encouraged by others [27], there is more focus on matching specific environmental factors to specific types of walking (transport-related or recreational) and more studies than in the past that have evaluated separately transport and recreational walking.

Studies published in 2005 and the first part of 2006 document consistent positive relations between walking for transportation and density, distance to non-residential destinations, and land use mix (see Table 4). For transportation walking, findings for route/network connectivity, parks and open space, and personal safety are more equivocal with approximately equal numbers of expected versus null/unexpected results. In contrast, there was little or no evidence in these studies for relations between transportation walking and pedestrian infrastructure conditions, traffic-related issues, aesthetics, or accessibility of physical activity facilities.

Results for the 2005–2006 studies regarding recreational walking were less clear, in part due to the fewer number of such results. In contrast to transportation walking, pedestrian infrastructure and aesthetics evidenced associations with recreation walking, as did personal safety and land use mix, although these later two factors also had similar number of expected and null/unexpected results. There was little or no evidence among these studies for associations between recreational walking and density, distance to non-residential destinations, route/network connectivity, parks and open space, traffic, and accessibility of physical activity facilities.

For most of the environmental factors, findings for general or total walking were balanced between expected versus null/unexpected. There were two more expected than null/unexpected findings for route/network connectivity and traffic, but little evidence that general or total walking was related to distance to non-residential destinations.

The evidence for environmental factors related to children's walking is considerably more scant than for adults, and with the exception of one study [13], focus on the trip to/from school. Although not universally found [13,60], walking to school appears consistently positively related to closer proximity to school, greater population density, and good pedestrian infrastructure and traffic safety on the walk to school route. Indeed, sidewalk and traffic safety improvements along the route increased walking to school rates [6]. Findings regarding walking to school and either personal/crime safety or land use mix were more equivocal.

Discussion

Empirical investigation into associations between walking and built environment factors has expanded considerably during the past few years. Indeed, based on prior reviews of this literature, the number of publications in 2005-early 2006 on this topic appears to have exceeded any other prior time period. Many of the conclusions from prior reviews are supported by this more recent evidence, particularly in the consistent associations found between walking for transportation purposes and density, land use mix, and proximity of non-residential destinations. More recent evidence also suggests that these factors are not necessarily related to recreation walking or to total amount or frequency of walking, providing some confirmation of this conclusion of some prior reviews. In contrast to some prior work, recent evidence less consistently found a relation between transportation walking and pedestrian infrastructure, such as sidewalk presence and condition, although pedestrian infrastructure was more consistently related to recreation walking.

In addition to recent evidence bearing upon prior results, the past few years have seen considerable progress toward addressing some limitations raised in prior reviews. One advancement has been the greater use of more objective measures of physical or built environment when examining correlates of walking. This is particularly evident with objective measures at the micro-level scale, that is objectively operationalizing the built environment around an individual respondent's residence [23,42,43,46] rather than at a larger scale (e.g., Census tract, city) that may or may not be completely applicable to a given individual. Whereas many studies purposefully include whole neighborhoods or communities that are most uniform within and in contrast to others [14], objective measures at the micro-scale also allow for simultaneous evaluation and direct comparisons to perceptions of the built environment around one's residence. However, these comparisons are made challenging by the different strategies used to evaluate perceived environmental factors and the lack of information about how individuals define their neighborhood. For example, when queried about their neighborhood, it is not clear whether individual respondents are considering a specific radial distance from their home in all directions with influence diminishing with greater distance or an area surrounding their home having an equal amount of influence across that area. In the former case, measures differ from household to household, depending on their location within the neighborhood, and are referred to as micro-level measures; in the latter case, every household within the neighborhood is assumed to experience the same built environment characteristics, and measures are labeled meso-level. Other advancements include the greater diversity in environmental factors studied from the street- to the neighborhood- and even regional-level, more specificity in measurement for environmental factors and walking, the inclusion of more age-diverse samples and examination of demographic variables as moderators (e.g., gender, [15]), although middle-aged adults are still predominantly studied.

The evidence regarding children is primarily restricted to factors related to walking to school, for which proximity, density, and the quality of the pedestrian infrastructure and traffic safety appear to play roles. Proximity and density findings for active commuting to/

from school are among the potent correlates among adults' transportation walking, but the later factors of pedestrian infrastructure and traffic safety may be more important for children for this type of walking trip. In addition to the limited types of walking outcomes (e.g., walking to school only rather than walking for other purposes or overall), the studies involving children were less likely to consider potential confounding factors, such as demographic or psychosocial variables related to physical activity. To our knowledge, no child-sample studies have examined whether self-selection factors are potentially confounding environment-walking associations in children, perhaps because such factors could be considered more under caregiver control.

The issue on which researchers have made the least progress in examining relations between environment and walking is causality. Prospective designs, a better approach for establishing causality than cross-sectional designs, are costly and complex. Until such studies are completed and replicated, it is not possible to say with certainty that changes in the built environment will lead to increases in walking. Still, by identifying environmental correlates of walking, cross-sectional studies offer guidance as to how to increase opportunities for walking. Further, the measurement and control for potential confounding factors in the relation between built environment and walking, including demographic and self-selection factors [11], lends more credence to a true causal relationship. It was common in recent studies to include demographic covariates (e.g., age, gender, income/education level), with some variability in the specific demographic factors considered across studies, but less common to include psychosocial correlates of physical activity and self-selection as potential confounders. More uncommon, although likely warranted, is the need to evaluate and analyze demographic and other potential confounding variables at both the individual respondent and larger environment level (e.g., neighborhood). This is particularly important given the multilevel nature of the data and the need for corresponding multilevel analyses [9], with such type of analyses not universal in the studies reviewed.

Cross-sectional studies of the built environment and walking have been most loudly criticized on the issue of self-selection: observed associations between the built environment and walking are potentially explained by the prior self-selection of residents into a built environment that is consistent with their predispositions toward walking. The limited evidence available suggests that self-selection occurs but that the built environment influences walking even after accounting for self-selection [30]. Several different methods short of prospective design have been used to control for self-selection in the transportation planning field; these studies also point to an impact of the built environment after controlling for self-selection, though the magnitude of the effect varies across studies [12]. These methodologies might profitably be applied to future studies of walking.

Studies on the built environment and walking have also been criticized on the grounds that they do not account for the possibility that walking, particularly transportation walking, substitutes for other forms of physical activity. There is however little empirical evidence examining substitution between transportation-related and recreational walking, with the exception of a few studies among youth samples that found that children who walked to school were more physically active than their non-active commuting peers (no evidence of substitution; [1,17]). This issue can in part be addressed by better matching of behaviors such as walking with the specific environments in which the behavior occurs. As noted earlier, several reviews stress the importance of matching specific measures of the built environment to specific types of physical activity [27]. For example, neighborhood built environment should be most closely linked to physical activity that occurs outdoors within the neighborhood. From a conceptual standpoint, the connection between neighborhood built environment and overall physical activity should be rather tenuous, as physical activity occurs in many settings other than the neighborhood. Nevertheless, it is important to

understand how different types of walking contribute to overall physical activity. It is possible that an increase in transportation walking resulting from a change to the built environment substitutes for other forms of physical activity without increasing overall physical activity, but empirical evidence regarding this potential substitution is generally lacking.

There are limitations to the present review of reviews and evaluation of recent evidence. First, some of the prior reviews were representative reviews and not meant to be comprehensive of all available prior evidence. Further, to our knowledge, there exists no rigorous quantitative review (e.g., meta-analysis) of this evidence, perhaps in part due to the multitude of environment factors examined, differences in operationalizing of these factors, differences in analysis structures (e.g., multilevel versus not multilevel; examining independent effects of a given environmental variable in the context of others or as a composite) and different methods for measuring walking. Such issues and inconsistency in data/analysis reporting preclude even the more recent evidence from being reviewed systematically and make a meaningful assessment of effect sizes impossible. The lack of more complete conceptual models for recreational walking distinct from transportation walking also makes ambiguous the assignment of result expectedness in the present review of recent empirical articles. For example, a positive relation between recreation walking and density was “expected”, but theoretically it is not surprising that recreational walking is not positively or at all related to density.

Other researchers who have reviewed the evidence have concluded that it is sufficient as a basis for advocating for changes in planning policies. For example, one review concludes that a “preponderance of evidence” suggests that community-scale urban design and land use policies and practices “can be effective in increasing walking and bicycling” and that mixed land use and sidewalk quality and connectivity are “helpful practices,” as are improved lighting and enhanced aesthetics at the street scale [33]. Another review offers these lessons for practice: evidence points to latent demand for walking suggesting an opportunity to increase walking through improved environments; needed improvements include increased land use intensity and mix along with investments in walking infrastructure; and planners should focus efforts on enablers and constraints on walking [44]. The review of prior reviews and recent empirical evidence regarding built environment factors and walking support such recommendations. The available evidence backs the efforts of cities throughout the United States to increase the viability of walking through innovative planning policies. These policies shape both land use patterns and the transportation system and influence aesthetic qualities as well [31]:

- **Land Use Patterns:** Many cities have designated mixed-use zoning districts, in which residential, commercial, and other uses are allowed or even required. In these areas, residents are in close proximity to places to work, shop, and recreate, and the potential for walking is greater. Infill development and redevelopment programs provide incentives for developers to use parcels within an existing urban area and can help with the adaptation of older buildings for new uses. Designation of selected areas as historic districts helps to protect the neighborhood character. In suburban areas, older strip malls have been rebuilt as mixed-use projects, with retail, office, and residential on one site, an approach called “grayfield” redevelopment. Each of these programs aims to retain or attract work, shopping, and leisure activities in or near residential areas and foster attractive and interesting environments, thereby supporting walking.
- **Transportation System:** Traffic calming programs, common in cities throughout the U.S., attempt to slow down or discourage automobile traffic and thus make streets safer and more attractive for pedestrians and others. Traffic calming techniques

emphasize the physical design of streets and their surroundings, including widening sidewalks, narrowing the width of streets at pedestrian crossings, adding landscaping, adding measures to slow vehicles such as speed bumps, altering road alignments, adding traffic circles, or installing pavement treatments. In addition, a growing number of cities have adopted ordinances designed to increase street connectivity. Although the primary aim of these ordinances is to spread vehicle traffic more evenly through the network, they also make routes from one point to another more direct, making walking more feasible. Cities often ensure adequate infrastructure for walking in new developments by requiring private developers to provide amenities such as sidewalks, bus stops, recreational trails, parks, and sites for schools.

Future work, buffeted by a strong research agenda [4], will likely enhance the specificity of these recommendations, including better specification of the population behavior and health impact, the applicability across the spectrum of demographic factors (e.g., age groups), and the expected change resulting from environmental change.

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Table 1

Summary of Correlates Identified in Previous Reviews

Correlate	Review
Accessibility or proximity	[29,37,44,49,52]
Mixed land use	[2,33,58]
Density	[2,29,58]
Aesthetics	[18,29,33,37,44,49,52]
Sidewalks	[29,33,49,52]
Street connectivity	[2,58]
Safety	[18,37,44,54]
Neighborhood type	[2,29,58]

Table 2
Original data articles published in 2005–2006 examining the relation between environmental factors and adults’ walking

Reference	Sample	Environmental factor(s) data source	Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
Besser [5]	3312 transit users out of 105,942 adults in survey	2001 U.S. National Household Travel Survey	Objective population density	Census block group	1 % walking to/from transit 2 Mean walk time to transit 3 % walking more than 30 mins/day to/from transit	Demos	1,2. Higher transit walking and walk time to transit with higher population density 3. Greater likelihood of walking more than 30 mins to/from transit in highest versus lowest population density; finding not significant in multivariate model with demographics but odds ratio of similar magnitude to bivariate
Bopp [7]	572 adult African-American Methodist Episcopal congregation members	Survey	Composite score of dichotomous coded perceptions of neighborhood: <ul style="list-style-type: none">walkablecrime presentsidewalksstreet lightingpublic parks	Individual respondent	Met or did not meet recommendation of walking ≥30 mins ≥5 days/week	Demos, Psych-PA	Odds of meeting walking recommendation not related to environmental score
Burton [10]	1827 adults living in Brisbane, Australia	Survey	Perceived physical features (e.g., footpaths), aesthetics (e.g., cleanliness), traffic, and facilities (e.g., gyms, pools)	Individual respondent	Likelihood of none or some walking activity	Demos, Psych-PA	Environment accounted for 0.6% of the unique variance in walking activity
Cao [11]	1368 adults in Austin, TX area	Survey	Perceived neighborhood characteristics (safety, tree shade, aesthetics, traffic, distance to store, route comfort, store quality); objective factors of above perceived characteristics as well as street characteristics and sidewalk information via GIS databases, maps, aerial photos, site visits	Individual respondent; neighborhood level for objective factors	1 Strolling frequency in last 30 days 2 Walk to store frequency in last 30 days	Demos, Self-select	1 Higher strolling frequency related to greater perceived neighborhood safety & shade 2 Higher walking to store frequency related to perceived less traffic and closer proximity to the store, greater perceived local store quality, walk distance to store, route comfort, and pedestrian connections Neither type of walking related to any objective neighborhood factors; walking related to perceived factors after accounting for residential preference
Clifton [15]	Various samples	Survey; local land use and street network data	Objective:	Census tract or transportation analysis zone	1 Walk trips in last week	Demos	1 Greater walk trips with increasing housing density (particularly

Reference	Sample	Environmental factor(s) data source	Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
	<p>a. 23,068 U.S. households in 2001 NHTS</p> <p>b. 7,784 adults in Portland, OR regional activity survey</p> <p>c. 1,536 households in 2001 NHTS Baltimore add-on</p>		<p>1 Density (and perceived sidewalk presence)</p> <p>2 Pedestrian environment, land use mix, transit access at household level</p> <p>3 Access to parkland within Census tract (low 0–10% of land area; medium 10–40%, high >40%)</p> <p>4 Street connectivity, land use mix, and housing density within buffers at census tract level</p>	for objective factors; individual respondent for perceived factors	<p>2 Walk trips total and by type; percentage of individuals taking walk trips and by type</p> <p>3 Number of walk trips on travel day</p> <p>4 Number of walk trips on travel day</p>		<p>>5000 housing units per square mile); greater odds of walk trip if did not perceive lack of sidewalk as a problem</p> <p>2 Individual taking at least one and having higher total walk trips and utilitarian walk trips more likely living in urban areas with transit access, good pedestrian environment, and high land use mix areas (highest walkable); similar results when examining yes/no utilitarian walk trip, controlling for demographics for individuals in highest walkable areas or in areas with transit access and good pedestrian environment</p> <p>3 Greater walk trips with greater park access (men only)</p> <p>4 Walk trips negatively related to street connectivity, housing unit density (men only), percent vacant (men only), and transit access (not separately for men or women); walk trips positively related to land use mix</p>
Cole [16]	3,392 New South Wales adults	Australian Bureau of Statistics' Remote and Rural Index	Urban or rural based on distance to goods/services and population density	Health region	Any walking at all in past 2 weeks for 1 transport 2 recreation/exercise	Demos	<p>1 Higher likelihood of any transport walking at moderate or brisk pace among urban area residents</p> <p>2 Only among men, higher likelihood of any recreation/exercise walking at moderate or brisk pace among urban area residents</p>
DeBourdeaudhuij[19]	247 adults from Oeiras, Portugal; 279 adults from Ghent, Belgium	Survey	Perceived residential density, land use mix, transit access, pedestrian infrastructure, traffic and crime safety, street connectivity; convenience of physical activity facilities	Individual respondent	Long IPAQ usual week time spent 1 walking/cycling for transport 2 walking for leisure	Demos, Psych-PA	<p>1 Walking/cycling for transport related to higher land use mix</p> <p>2 Walking for leisure related to higher availability of sidewalks (Portuguese sample only) and higher land use mix (Belgian sample only) Associations between walking and environmental variables attenuated after accounting for</p>

Reference	Sample	Environmental factor(s) data source	Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
							psychosocial factors (e.g., self-efficacy)
Doyle [20]	9,229 U.S. adults from NHANES III	Street network in 35 large counties	Walkability composite of block size, percent of blocks with area < .01 square miles, number of 3-, 4-, 5-way intersections divided by number of road miles	County level	Ever walk 1 mile or more without stopping in the last month	Demos	Higher likelihood of ever walking among residents in counties with higher walkability scores, even after controlling for individual demographic factors (effect stronger for lifelong residents of an area); walkability had stronger influence than crime on likelihood of walking
Duncan [21]	1,215 adult Rockhampton, Queensland residents	Survey; Rockhampton City Council GIS, telephone directory, state's electric supplier	Perceived proximity to shops/services and open space, aesthetics, footpaths condition, traffic, street lighting; Objective distance to: <ul style="list-style-type: none">• nearest parkland• shopping center• pathway network of 300m• busy street• newsagent Objective measure of registered dogs within certain radii, amount of roadway within 20m of streetlight	Distance from residence	Any recreational walking in past week	Demos, Psych-PA	Higher likelihood of recreational walking related to having poorer perceptions of footpath conditions Higher likelihood of recreational walking related to greater objective proximity of footpath (<4km from home), middle tertile of number of registered dogs within .8km radius of home, and having a newsagent > 600m away from home
Frank [23]	1,228 adult King County, WA residents	Census, King County parcel-level land use and street data	Walkability composite of net residential density, street connectivity, land use mix, retail floor area ratio	1-km network buffer around residence	Long IPAQ usual week time spent walking/cycling for transport	Demos	Greater time spent walking/cycling for transport related to walkability
Gauvin [25]	Individuals from 112 Montreal census tracts responding to 'walk to work?' Census question	Independent rater observation	Activity friendliness (e.g., quality of pedestrian system), safety (e.g., from crime, traffic), density of destinations (e.g., number of people- oriented destinations, variety of destinations)	Econometric street segment evaluation	Percentage of individuals who walk to work	None	Walking to work related to density of destinations (positive), safety (negative), and activity friendliness (negative)
Giles-Corti [26]	1773 adults in Perth, Australia: observations of 772 people using public open space	Public open space observations of environment and users	Public open space <ul style="list-style-type: none">• proximity• size• attractiveness (e.g., activities, quality, amenities, safety)	Individual respondent or observed individual	<div><div>1</div>5 or more walking sessions/week totaling 150+ minutes (sufficient walking)</div> <div><div>2</div>6 or more walking sessions/week totaling 180+ minutes (high walking)</div>	Demos	<div><div>1</div>Sufficient walking not related to public open space accessibility</div> <div><div>2</div>High walking more likely among individuals' with shorter distance to highly attractive and large public open space</div> <div><div>3</div>70% of walkers were using public open space with high attractive scores</div>

Reference	Sample	Environmental factor(s) data source		Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
Ham [28]	NPTS (Year 1995) and NHTS (2001)	Census		Urbanization classification (urban, second city, suburban, town, and rural)	Census block group in which respondent lived	3 Type of public open space used	None	Adult walk trips less likely for rural and town residents
Handy [30]	1,627 adults in 4 ‘traditional’ and 4 ‘suburban’ neighborhoods	Survey		Perceived accessibility, physical activity options, safety, socializing, outdoor spaciousness, and attractiveness (and change in these factors for movers) Objective measure of network distance to selected destinations and number of destinations within specified network radii Travel attitudes and neighborhood preferences	Individual respondent	1 Number of times walked to store in past 30 days 2 Number of times strolled around neighborhood in past 30 days 3 Number of times walked to selected destinations in typical month 4 Likert rating of amount of change in walking	Demos, Self-select	1 After accounting for significant travel attitudes and neighborhood preferences, walking to store frequency related to perceptions of safety, attractiveness, and proximity and positively related to objectively measured proximity of nearest grocery store and number of business types within 800m radius 2 After accounting for significant travel attitudes and neighborhood preferences, strolling frequency related to perceived neighborhood attractiveness 3 Higher rate of walking to each destination type among ‘traditional’ neighborhood residents 4 Smaller decrease or larger increase in walking positively related to minimum distance to a bank (unex), number of banks within 800m, and number of types of businesses within 1600m; negatively related to current spaciousness perception
Hoehner [34]	1,053 adults in St. Louis, MO (“low- walkable” city) and Savannah, GA (“high- walkable” city)	Survey; street segment audits (objective)		Perceived and objective land use mix, proximity of recreational facilities, active transport infrastructure (e.g., sidewalks present), transit access, traffic safety, aesthetics, crime safety	Street segment audit information aggregated into 400m buffers around respondents’ residence	1 Any versus no active transport in past 7 days 2 Met/did not meet 150+ minutes of activity through active transport only recommendation	Demos	1 Active transport likelihood increased with greater perceived and objective land use mix, objective transit access, and objective pedestrian comfort amenities (e.g., tree, benches); decreased likelihood with greater objective sidewalk quality and objective neighborhood cleanliness 2 Recommended walking levels model had same significant environmental factors, but

Reference	Sample	Environmental factor(s) data source	Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
							pedestrian comfort amenities was not a significant correlate
Hooker [35]	1,165 adults in 21 census tracts in a rural South Carolina county	Survey	Perceived traffic, street light quality, unattended dogs, crime safety, public recreation facility safety	Individual respondents asked to consider neighborhood as within ½ mile or 10- minute walk from home	Walking (regular walking) or not walking at least 150 minutes per week	Demos	Regular walking likelihood was associated with greater perceived neighborhood safety; regular walking likelihood was lower in moderate traffic versus heavy traffic neighborhoods (both findings only present among White, not African-American, samples)
Khattak [40]	310 adults from single-family high income households in two neighborhoods in North Carolina	Unclear	Neighborhoods differed on objective residential density, street connectivity, and commercial space (higher = neo- traditional neighborhood; lower = conventional neighborhood)	Neighborhood	Walk trips	Demos, self-select	Higher percentage of trips were walk trips in the neo- traditional (17.2%) versus conventional (7.3%) neighborhood
Krizek [41]	1,653 adults in Minneapolis and St. Paul, MN	Employment records	Objective network proximity to nearest neighborhood retail establishments	Individual resident	Walk trips	Demos	Walk trips were more likely among households <200 meters from a retail establishment than households ≥ 600 meters away from one; finding diminished when controlling for demographic factors, but walk trips still more than twice as likely among retail proximal households
Lee [43]	438 adults in Seattle, WA	Survey; parcel-level and street network GIS	Many objective variables, including network proximity to closest individual and “combination” of destinations, land use mix, residential density, pedestrian infrastructure, route directness and topography; perceived environmental variable included neighborhood type (residential versus mixed residential/commercial), aesthetics, and traffic	Individual resident (usually with 1km buffer); spatial sampling	<div>1Any transportation and/or recreation walk trips (walker by type versus non-walker) in a usual week</div> <div>No, moderate (1–4 times), or frequent (5 or more times) walking per week for:</div> <div>2transportation</div> <div>3recreation (all comparisons relative to non- walker)</div>	Demos, self-select	<div>1a. More likely to be both a transportation and recreation walker if perceive neighborhood as mixed, area has objectively lower residential density, proximity to daycare and a bank, and farther away from an office and combination of office and other land uses mixed, and higher within-parcel density</div> <div>1b. More likely to be a recreation walker if perceive area as mixed, area has objectively lower residential density, greater slope, closer to daycare, farther away from an office and the combination of office and other land uses mixed</div> <div>1c. More likely to be a transportation walker if perceive area as mixed, area has objectively lower residential density, closer to a bank, and farther away from the combination of office and other land uses mixed</div> <div>2a. Moderate transportation walkers more likely to perceive area as mixed,</div>

Reference	Sample	Environmental factor(s) data source	Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
Lee [42], Vernez Moudon [65]	608 adults in King County, WA	Survey; parcel-level and street network GIS	943 objective environmental variables, including network and airplane proximity to closest individual and “combinations” of destinations, destination counts and percentages, residential density, pedestrian infrastructure, route directness, traffic, and topography; perceived presence of destinations	Individual resident; spatial sampling to assess <ol style="list-style-type: none">1 Destinations2 Distance3 Density4 Route	Odds of sufficient (>150 mins) versus moderate (1–149 minutes) versus non- walkers	Demos	<p>have objectively less route directness to closest church, and are closer to bank</p> <p>2b. Frequent transportation walkers have lesser slope, greater objective proximity to a grocery store, restaurant, post office, and bank, and higher parcel density</p> <p>3a. Moderate recreation walkers more likely to perceive positive area aesthetics, have objective greater slope, closer to day care, and less route directness to an office</p> <p>3b. Frequent recreation walkers more likely to perceive positive area aesthetics, have greater objective sidewalk length, greater slope, and closer to daycare</p>
							<p>243 objective environmental variables significant at bivariate level; After controlling for demographic and perceived environment factors, more walking related to:</p> <p>1 Fewer grocery stores, fewer education land uses, more grocery + restaurant + retail combinations within 1 km airline; more destinations within the nearest church + school combination; smaller size of the closest office only combination</p> <p>2 Shorter airline distance to closest grocery store, eating/drinking place, shorter network distance to closest bank and closest grocery + restaurant + retail combination; longer network distance to the closest offices and longer airplane distance to the closest office + mixed use combination; shorter mean network distance between destinations within the closest offices</p> <p>3 Higher residential density within parcel; higher residential density within 1 km buffer (comparison of sufficient versus moderate walking), but lower residential</p>

Reference	Sample	Environmental factor(s) data source		Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
								density within airline 1 km buffer (comparison of moderate versus no walking) 4 More direct route to the closest grocery store; more and less direct route to the closest school; longer total sidewalk length in 1km airline buffer; smaller size of household block within airline buffer
Li [46]	577 adults 65+ years old in 56 neighborhoods in Portland, OR		Survey; existing geographical databases from regional land information system	Objective number of residential households, places of employment, street intersections; total green and open spaces for recreation (area); perceived proximity to local recreational facilities, walking and traffic safety, and number of nearby recreational facilities	Neighborhood; multi-level analysis examining effects at the level of: 1 neighborhood 2 resident	Likert rating of frequency of walking activity in neighborhood	None	1 Higher walking activity at neighborhood level related to higher employment place and residential household density, more street intersections, and more green and open space 2 Higher walking activity at resident level related to more neighborhood recreational facilities and better walking safety; higher walking activity among residents reporting more traffic safety in neighborhoods with more street intersections (interaction)
Li [45]	303 adults 65+ years old in 28 neighborhoods in Portland, OR		Survey	Perceived recreation facility availability and safety	Individual respondent aggregated to neighborhood level	Likert rating of frequency of walking and related physical activity in neighborhood measured 4 times over 1 year	Demos; Psych-PA	Greater recreation availability and safety were related to lesser declines in neighborhood-level walking
Plaut [55]	About 41,000 working adults in the 2001 American Housing Survey		Survey	Perceived location within metropolitan statistical area (MSA), living near green space, living near commercial properties	Individual respondent	Walk versus car commuting to work	Demos	Walking to work more likely if living within central city of MSA (among renters only) and less likely in secondary urban and rural areas of MSA; walking to work more likely if commercial properties nearby
Reed [56]	1,148 adults in 21 census tracts in Sumter County, SC		Survey	Perceived sidewalk presence	Neighborhood defined as ½ mile radius or 10 min drive from home	Regular (≥150 mins), irregular (1–149 mins), or no walking per week	Demos	Irregular walkers more likely to report presence of sidewalks than non-walkers; finding not significant in separate models based on race
Rutt [57]	452 adults in El Paso, TX		Aerial photography, Census, local and commercial databases, and yellow pages	Objective sidewalk	¼ mile (sidewalks) and 2.5 mile (PA facilities) radius of respondent's home; shortest network distance	Walking for exercise in the past month: 1 frequency 2 duration	Demos; Psych-PA	1 Higher walking frequency among individuals doing at least some walking was related to more commercial land uses in neighborhood and fewer number of physical activity facilities

Reference	Sample	Environmental factor(s) data source		Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
						3 total time		2 Walking duration not related to any environmental variables 3 Total time walking was higher in the whole sample in areas with less commercial land use; total time walking among individuals doing at least some walking was higher in areas with fewer physical activity facilities
Spence [61]	3,144 Canadians who visited the <i>Canada on the Move</i> website	Survey		Perceived land use mix, sidewalk presence, crime safety, recreation availability, aesthetics, street connectivity	Individual respondent	Sufficient walking in the past week (5 or more days of at least 30 minutes of walking per day)	Demos	Sufficient walking more likely among individuals reporting greater neighborhood aesthetics and land use mix, especially among women
Suminski [62]	474 adults in a large midwestern U.S. metropolitan area	Interview		Perceived route functionality (e.g., sidewalk condition), traffic and crime safety, aesthetics, and destinations (e.g., shops) to walk to in neighborhood	Individual respondent	In the past 7 days, within-neighborhood 1 transportation walking 2 exercise walking 3 walking a dog	Demos	1 Transportation walking more likely among women reporting moderate versus low walk destinations; transportation walking less likely among men reporting moderate route functionality and aesthetics compared to low levels of these factors 2&3. Exercise and dog walking more likely among women reporting moderate versus low neighborhood safety
Van Lenthe [64]	8,767 adults in 78 neighborhoods in Eindhoven, Netherlands	Local professionalperceptions of neighborhood characteristics		Perceived (by professionals) attractiveness, green space quality, traffic noise, proximity to food shops, crime safety	Neighborhood	< ('almost never walking') or >15 mins per day walking or cycling to shops or work	Demos	Greater walking likelihood associated with less traffic noise (for adults ≤49 years old) and greater proximity to food shops (for adults >49 years old and particularly in lower socioeconomic neighborhoods)
Zlot [66]	Adults from 34 MSAs present in the U.S. 1996 and 1998 BRFSS and 1995 NPTS	Trust for Public Land data		Parkland acreage as a percentage of city area	City	1 Rates of walking or biking for recreation in past month (at MSA level) 2 Rates of walking or biking for transportation in the past week (at city level)	None	1 Recreational walk/bike rates not related to parkland acreage 2 Walk/bike for transportation related to parkland acreage

Note. The walking metric for each study is specified to reflect how the investigators used the walking outcome in analyses; where applicable, the enumerated different walking metrics are linked to their corresponding number in the results.

Table 3

Summary of original data articles published in 2005 - mid 2006 examining the relation between environmental factors and walking

Reference	How environmental factor measured		Environmental scale			Walking type			Result summary		
	Objective (O)	Perceived (P)	Micro (Mi)	Meso (Me)	Macro (Ma)	Transport (T)	Recreation (R)	General (G)	Expected	Null	Unexpected
Besser[5]	X			X		X			OMeT ¹		
Bopp[7]		X	X					X		PMiG ⁵⁺⁶⁺⁷	
Burton[10]		X	X					X	PMiG ⁶⁺⁸⁺¹⁰		
Cao[11]	X	X	X (S)	X (O)		X	X		PMiR ^{6,7} PMiT ^{2,3,4,7,8}	OMeT ^{2,3,4,6,8} OMeR ^{2,3,4,6,8}	
Clifton[15]	X		X			X			OMiT ^{1,3,5,6}		OMiT ⁴
Cole[16]	X				X	X	X		OMaT ¹ OMaR ¹		
DeBourdea udhuij[19]		X	X			X	X		PMiT ³ PMiR ^{3,6}	PMiT ^{1,4,7,8,10} PMiR ^{1,4,7,8,10}	
Doyle[20]	X				X			X	OMaG ⁴		
Duncan[21]	X	X	X				X		OMiR ^{6,7}	PMiR ^{2,7,8} OMiR ^{7,8}	PMiR ⁶ OMiR ³
Frank[23]	X		X			X			OMiT ¹⁺³⁺⁴		
Gauvin[25]	X		X			X			OMiT ^{3,7}		OMiT ⁶
Giles- Corti[26]	X		X					X	OMiG ^{2,5}	OMiG ²	
Ham[28]	X			X		X			OMeT ¹		
Handy[30]	X	X	X			X	X	X	OMiT ^{2,3} PMiT ^{2,7,9} PMiR ⁹ OMiG ^{3*}	PMiT ^{5,10} PMiR ^{2,5,7,10} PMiG ^{2,7,9,10*}	OMiG ^{2*} PMiG ^{5*}
Hochner[34]	X	X	X			X			OMiT ^{3,6} PMiT ³	OMiT ^{7,8,10} PMiT ^{6,7,8,9,10}	OMiT ^{6,9}
Hooker[35]		X	X					X	PMiG ^{7,8}	PMiG ¹⁰	
Khattak[40]	X			X		X			OMeT ¹⁺³⁺⁴		
Krizek[41]	X		X			X			OMiT ²		

Reference	How environmental factor measured		Environmental scale			Walking type			Result summary		
	Objective (O)	Perceived (P)	Micro (Mi)	Meso (Me)	Macro (Ma)	Transport (T)	Recreation (R)	General (G)	Expected	Null	Unexpected
Lee[43]	X	X	X			X	X		PMiR ^{3,9} OMiR ^{2,6} PMiT ³ OMiT ^{1,2,4}	PMiR ⁸ OMiR ^{3,8} PMiT ^{8,9} OMiT ^{3,6,8}	OMiR ^{1,2,4} OMiT ^{1,2,4}
Lee[42], Verez Moudon[65]	X		X					X	OMiG ^{1,2,3,4,6}	OMiG ⁸	OMiG ^{1,2,3,4}
Li[46]	X	X	X	X				X	PMiG ^{7,10} OPMiG ^{4X8**} OMeG	OMiG ^{1,4,5} PMiG ²	
Li[45]		X	X					X	PMiG ^{5/10,7***}		
Plaut[55]		X	X			X			PMiT ^{1,2}	PMiT ⁵	
Reed[56]		X	X					X			PMiG ⁶
Rutt[57]	X		X				X		OMiR ³	OMiR ^{1,4}	OMiR ^{3,5+10}
Spence[61]		X	X					X	PMiG ^{3,9}	PMiG ^{4,5,6,7}	
Suminski[62]		X	X			X	X		PMiT ³ PMiR ⁷⁺⁸		PMiT ^{6,9}
vanLenthe[64]		X		X		X			PMeT ^{2,8}	PMeT ^{5,7,9}	
Zlot[66]	X				X	X	X		OMaT ⁵	OMaR ⁵	

Note. Each result is defined as either an expected, null, or unexpected finding for objective or perceptual nature of the environmental measure (objective (O) or perceptual (P) – 1st digit of findings listed in the result summary columns) at one environmental scale (micro (Mi), meso (Me), or macro (Ma) – 2nd and 3rd digit in the result summary columns) for one walking type (transport (T), recreation (R), or general (G) – 3rd digit in the result summary columns); ‘micro’ environments are defined as the environments immediately around and radiating from where an individual lives (or assumed to be the perceived environments of an individual respondent), such that even neighbors on the same street could have potentially different micro-environments; ‘meso’ environments are defined as the small scale (e.g., neighborhood, Census block group) environments in which an individual lives, but in which all individuals within that small scale are considered to have the same environment (i.e., an individual and his/her neighborhoods share a ‘meso’ environment); ‘macro’ environments are defined as the larger scale (e.g., city, county, metropolitan area) environments in which an individual lives, in which all individuals within that scale are considered to have the same environment;

1=Density (population or employment), 2=Distance to specific non-residential land uses, 3=Proximal non-residential destinations (including land use mix measures and transit access), 4=Network characteristics (including connectivity and topography), 5=Parks and open space (including availability, area, and quality), 6=Pedestrian infrastructure (including sidewalk presence and condition), 7=Crime or personal safety, 8=Traffic safety or volume/noise, 9=Aesthetics or cleanliness, 10=Non-park physical activity facilities (e.g., gyms); subscripted numbers separated by commas indicate that each environmental factor associated with that number was examined individually; subscripted numbers separated by ‘+’ indicate that different environmental factors were considered together at the measurement (e.g., composite measure of walkability) or analysis level and effects for each individual environmental factor could not be ascertained;

* these results were regarding environmental factors related to the perceived change in walking among individuals who had moved;

** the interaction between objective and perceptions of environment were examined;

these results were regarding environmental factors related to perceived change in walking among non-movers;

Number of study results in considered 2005 - mid 2006 published articles in the expected or null/unexpected direction by environmental factors and by walking type

Table 4

	Type of Walking					
	Transportation			Recreation		General
	Expected	Null or unexpected	Expected	Null or unexpected	Expected	
Environmental factors						
Density (population or employment)	6	2	1	3	2	2
Distance to non-residential destinations	7	2	1	4	2	5
Proximal non-residential destinations (e.g., land use mix)	8	3	3	4	3	1
Route/network connectivity	3	4	0	4	3	3
Parks and open space	2	3	0	2	2	3
Pedestrian infrastructure	2	6	4	2	2	2
Personal safety	3	4	1	4	2	2
Traffic	2	6	0	6	1	1
Aesthetics	1	4	2	0	1	1
Physical activity facilities (non-park)	0	4	0	2	1	2
Composite/interaction *	2	0	1	1	3**	1

Note.

* Composite/interaction is for findings in which environmental factors were combined or interacted for examining their association with walking behavior;

** one of these findings was an interaction of an objective and perceived measurement of different environmental factors

Table 5
Original data articles published in 2005–2006 examining the relation between environmental factors and children's walking

Reference	Sample	Environmental data source	Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
Boarnet [6]	862 parents of 3 rd –5 th graders in 10 school	Direct observation of urban design within ¼ mile of school; California Safe Routes to School	Objective sidewalk, crossing, or traffic control improvements	Street segment level	Parent report of child walk or bike to school less, more, or same as before improvement made	None	<ul style="list-style-type: none"> Overall higher rate of decreased walking to school than school after improvement (unexpected) 15.4% walked/biked to school more if improvement was on route versus 4.3% walked/biked to school more if improvement was not on route Higher more walk/bike rates along route when improvements were changes in sidewalk or traffic control (i.e., traffic signals installed)
Braza [8]	2993 5 th graders in 34 schools participating in 1999 Walk to School Day	Census and local street network data	Objective residential population density, street connectivity	0.5 mile radius around each school	Percentage walk/bike or not to school on day 1 week prior to Walk to School Day	Demos	<ul style="list-style-type: none"> Residential population density ($r = 0.732$), street connectivity ($r = .496$) positively related to walk/bike to school rate Residential population

Reference	Sample	Environmental data source	Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
Carver [13]	347 12–13 year olds	Survey	Perceived neighborhood characteristics (e.g., safety, traffic, stores nearby)	Parent and child respondents	Walking frequency and duration for 1 travel to/from school 2 exercise 3 transport 4 walking the dog	Demos	<p>1 No environmental factors related to walking to school frequency; time spent walking to school negatively related to traffic difficulty (girls only)</p> <p>2 Weekday walking for exercise frequency negatively related to traffic difficulty and positively related to road safety (girls only); weekday time spent walking for exercise negatively related to traffic difficulty (girls only); weekend time spent walking for exercise positively related to road safety (girls only)</p> <p>3 Weekday transport walking</p>

Reference	Sample	Environmental data source	Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
							frequency positively related to road safety (girls only) and negatively related to traffic difficulty (boys only); weekend transport walking frequency negatively related to whether convenience store near home (girls only); weekday time spent walking for transport positively related to road safety (girls only); weekend time spent walking for transport negatively related to whether convenience store near home (girls only) 4 Weekend walking the dog frequency positively related to road safety and availability of good places for child to be active (girls only); weekend time spent walking the dog positively

Reference	Sample	Environmental data source	Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
Ewing [22]	709 Gainesville school children	Source for environmental data was not specified	Objective population density, balance of jobs/residents, job mix, commercial floor area ratio, sidewalk coverage, bike lane and paved shoulder coverage, street tree coverage, regional accessibility	Traffic analysis zone (TAZ) level	Probability of walking to school as mode choice	Demos	Lower walk time (proxy for distance to school) and greater sidewalk coverage at within home and school TAZ related to higher likelihood of walking to school
Fulton [24]	1,395 U.S. parent-child pairs	Survey	Perceived sidewalks available in neighborhood, child's perceived safety to play in neighborhood, and neighborhood type (rural, small city/town, suburb, central city)	Individual respondent	Respond walk or bike to query about how normally get to/from school	Demos	Active transport to school was more likely among residents of areas that were non-rural, had sidewalks, and in which the child felt safe (although child perceived safety was not significant in full model including other environmental, demographic, and behavioral factors)
Ham [28]	NPTS (Year 1995) and NHTS (2001)	Census	Urbanization classification (urban, second city, suburban, town, and rural)	Census block group in which respondent lived	Rate of walk trips (leisure/exercise walk trips excluded) relative to total trips < 1mile	None	Walk-to-school walk trips higher in urban areas
Kerr [39]	259 caregivers of 5-18 year old children in King County, WA	Census, King County parcel-level land use and street data	Objective walkability composite of net residential density, street connectivity, land use mix, retail floor area ratio; perceptions of walkability composite factors and perceived walk/bike infrastructure, aesthetics, and traffic and crime safety	1-km buffer around residence and neighborhood (adjacent census block groups) type (high versus low walkable based on composite; high versus low income)	Walked or biked to and from school at least once in typical week	Demos	Increased odds of walk/bike to school particularly among children in objectively high walkable neighborhoods with parents with low concerns (e.g., traffic safety) about children walking to school, in objectively high walkable high income neighborhoods, and in objectively high walkable neighborhoods with high perceived aesthetics Odds of walk/bike to school not related to objective overall neighborhood walkability when greater perceived proximity to stores or greater perceived walk/bike infrastructure in model

Reference	Sample	Environmental data source	Environmental factor(s) examined	Analyzed geographic unit	Walking metric	Covariates	Results
McMillan [50]	1,244 children in 3 rd -5 th grade (and caregiver) from 10 California schools in the Safe Routes to School program (post-intervention)	Survey	Perceived safety and whether school was <1 mile from home	Individual respondent	Probability of walking/biking to school	Demos; Psych-PA	Increased odds of walking/biking to school with greater perceived proximity to home
[51]	Children (and caregivers) from 16 California schools in the Safe Routes to School program (pre-intervention)	Survey; street segment evaluation on streets within .25 miles of school	Perceived neighborhood and traffic safety, whether school was <1 mile from home; Objective proportion of street segments with sidewalks on both sides of street, >50% of houses with windows facing street, with land use mix	Neighborhood surrounding the school	Probability of walking/biking to school	Demos; Psych-PA	Increased odds of walking/biking to school with greater perceived neighborhood and traffic safety, perceived proximity to home, greater objective proportion of houses with windows facing the street and greater land use mix
Sirard [60]	Children from 8 elementary schools in urban and suburban parts of Columbia, SC	Source of environmental data not specified	Urban versus suburban	School	Rates of walking to school	None	Walking to school rates were low and did not differ between urban and suburban schools
Timperio [63]	1,210 families with children in kindergarten, 5 th or 6 th grade from 19 elementary schools in high and low SES Melbourne, Australia	Survey; local databases	Perceived traffic and crime safety; objective distance to school, presence of busy road and busy road as a barrier on route to school, route directness, slope	Individual respondent	Never, infrequent/occasional (1-4 times), and frequent (5 or more times) walking to school during a typical week	Demos; Psych-PA	Among younger children, walking to school was less likely if parents perceived no lights/crossing on route, if busy or steep road barrier existed on route, or if school was ≥ 800m away from home Findings were the same for older children, except steep road barrier was not a factor, but better route directness (unexpected) to school reduced walking to school