Environmental correlates of Walking and Cycling: Findings From the Transportation, Urban Design, and Planning Literatures

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Environmental Correlates of Walking and Cycling: Findings From the Transportation, Urban Design, and Planning Literatures

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ABSTRACT

Research in transportation, urban design, and planning has examined associations between physical environment variables and individuals' walking and cycling for transport. Constructs, methods, and findings from these fields can be applied by physical activity and health researchers to improve understanding of environmental influences on physical activity. In this review, neighborhood environment characteristics proposed to be relevant to walking/cycling for transport are defined, including population density, connectivity, and land use mix. Neighborhood comparison and correlational studies with nonmotorized transport outcomes are considered, with evidence suggesting that residents from communities with higher density, greater connectivity, and more land use mix report higher rates of walking/cycling for utilitarian purposes than low-density, poorly connected, and single land use neighborhoods. Environmental variables appear to add to variance accounted for beyond sociodemographic predictors of walking/cycling for transport. Implications of the transportation literature for physical activity and related research are outlined. Future research directions are detailed for physical activity research to further examine the impact of neighborhood and other physical environment factors on physical activity and the potential interactive effects of psychosocial and environmental variables. The transportation, urban design, and planning literatures provide a valuable starting point for multidisciplinary research on environmental contributions to physical activity levels in the population.

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INTRODUCTION

Physical activity is an important lifestyle component of improving long-term health (1). Walking is the most common form of adult physical activity (2). Brisk walking has been identified as protective of physical health, independent of the benefits of more vigorous activity (3), particularly if it is done consistently (4). Public health recommendations emphasize the need to accumulate physical activity of at least moderate intensity on most days of the week, including walking and cycling (1). *Healthy People 2010* targeted a greater than 50% increase in walking trips made by adults for trips that are less than 1 mile (5).

It is necessary to understand influences on walking and other moderate physical activity behaviors to provide an empirical basis for public health action. Psychosocial correlates of physical activity, including such factors as self-efficacy and perceived benefits, have been extensively studied, and reviews exist for that literature (6,7). However, most studies have examined only vigorous physical activity, and a few studies have examined correlates of "walking for exercise" (8). Furthermore, psychological and social factors explain much less variance in moderate intensity than vigorous physical activity (6). Unlike most vigorous physical activities engaged in for health-related or recreational purposes, activities such as walking and cycling can be done for multiple purposes, likely making them more susceptible to environmental influence. Walking and cycling can be done for leisure, recreation, or exercise; for occupational purposes; and for basic transportation, including shopping or going to work.

Ecological models emphasize that behaviors have multiple levels of influence that include intrapersonal, interpersonal, environmental, and policy variables (9). Ecological hypotheses suggest that the combination of psychosocial and environmental–policy variables will best explain physical activity (6,10,11). Physical activity research to date is limited in the examination of physical environment influences (12), although recent evidence documents that physical activity is associated with environmental variables (13) and neighborhood context in particular (14,15). Researchers in fields other than physical activity and health have explored ways the physical environment is related to walking and cycling, particularly in and around urban areas, in which most Americans reside. Physical activity and health researchers are generally unfamiliar with this literature from the fields of transportation, urban design, and planning. This article is designed to (a) introduce terms and methods from the transportation and planning research literatures to health and physical activity professionals, (b) provide a brief review of findings from transportation studies that have explored the relation between neighborhood environment and nonmotorized transport (i.e., walking and cycling), and (c) consider the implications of this literature for the health and physical activity fields and future directions.

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Community Design and Land Use Variables Related to Transport Choices

Researchers in transportation, urban design, and planning have long understood that neighborhood design and the way land is developed and used may affect transport choice (auto, transit, walking/cycling) (16). A glossary of some fundamental transportation and urban design and planning terms relevant to walking/cycling for transport and this review is provided in Table 1. Transportation research has been focused largely on the study of vehicular travel but has recently become more concerned with human-made environment determinants of nonmotorized or "human-powered" modes of travel. The assessment of walking and cycling makes these studies pertinent to the understanding of an individual's physical activity. For instance, approximately 83% of all "trips" (each instance of moving from a point of origin to a destination) are short, for nonwork purposes, and occur relatively close to home (17). The majority of nonwork trips are within walking or cycling distance and are therefore of interest to the physical activity, air quality, and transportation planning fields.

Factors that influence the choice to use motorized or nonmotorized transport are based primarily on two fundamental aspects of the way land is used: (a) proximity (distance) and (b) connectivity (directness of travel) (16). Other factors, such as travel cost, environmental quality, and aspects of convenience and access (e.g., parking availability) are also likely influential. Proximity relates to the distance between trip origins (i.e., where one is) and destinations (i.e., where one is going). Proximity is determined by two land use variables. The first is *density,* or compactness of land uses. For example, if a person lives in a dense area with many apartment buildings, it will be more convenient for him or her to walk to visit a neighbor than if he or she lives in a low-density area with single-family homes where there are likely few friends within easy walking distance. The second component of proximity is *land use mix*, or the distance between or intermingling among different types of land uses, such as residential and commercial uses. In older cities there are many residences above street-level shops, making it more convenient to walk to shops

TABLE 1
Glossary of Transportation and Planning Terms Relevant to Walking/Cycling for Transport

Term	*Definition*
City planning	The profession that studies physical, social, and political systems and how the interactions between these systems can create urban environments that have desired effects on people, communities, and economies.
Connectivity	The directness or ease of travel between two points that is directly related to the characteristics of street design.
Employment density	The number of employees or jobs per unit of land area (e.g., acre).
Geographical information systems (GIS)	Computer-based systems designed to integrate different types of spatial and attribute information. Data relevant to physical activity can include topography, existing land uses, geological features (e.g., hills), infrastructure systems (streets, mass transit, sewer, water, utilities), recreation facilities, and residences. Each spatial feature can be linked with attributes about that feature. For example, size, shape, and amenities for a park and demographic variables of a person living near the park can be linked.
Land use mix	The level of integration within a given area of different types of uses for physical space, including residential, office, retail/commercial, and public space. Land use is controlled by zoning ordinances that reflect political decisions most often made at the local level.
New Urbanism	An approach to development and redevelopment championed by a group of architects, planners, and urban designers that has similar goals to Smart Growth. Towns and cities developed before widespread use of the automobile are seen as having multiple environmental, social, and health benefits when compared to the sprawling, suburban developments that have dominated land use decisions in the United States since the 1940s (see http://www.cnu.org).
Proximity	The straight-line distance between different land uses such as residential, office, retail, and commercial activities.
Residential density	The number of residential dwelling units per unit of land area (e.g., acre).
Smart Growth	An approach to neighborhood development that considers impacts on environmental quality, social interactions, population diversity, and transportation choices. Smart Growth is often contrasted with suburban sprawl that assumes automobile dependence. Smart Growth advocates promote development that is higher in density, built around public transit, contains a mixture of residential and commercial uses, and provides housing for a range of income levels. Smart Growth is the efficient usage of transportation infrastructure (e.g., roads and railways) and therefore encourages growth to be located in areas served by existing transportation investments (see http://www.epa.gov/livability).
Urban design	A profession that makes decisions about how natural (topography, vegetation) and built (buildings, roads, plazas) elements in a particular space will relate to one another. Urban designers consider how people will perceive and interact with the human-made environment.

or to get to work. In modern suburbs, different land uses are purposefully separated, so it may be practically impossible to walk from one's home to the nearest shopping center or place of employment. High mixed use is characterized by a diversity of land uses within a smalls area. By contrast, much modern development is based on single use, with land uses widely separated, resulting in a lack of land use mix.

Whereas proximity considers straight-line distances between land uses, connectivity characterizes the ease of moving between origins (e.g., households) and destinations (e.g., stores and employment) within the existing street and sidewalk–pathway structure. Connectivity is high when streets are laid out in a grid pattern and there are few barriers (e.g., walls, freeways) to direct travel between origins and destinations. With high connectivity, route distance is similar to straight-line distance. In addition to direct routes, grid patterns offer the choice of taking different routes to the same destination. By contrast, low connectivity is found in the layout of modern suburbs and is characterized by a low density of intersections (e.g., long block size), barriers to direct travel (e.g., cul de sacs), and few route choices. Methods for systematically evaluating pedestrian connectivity of a given area have been developed (18).

Figure 1 illustrates two distinct community designs. The top portion, above the large street that horizontally bisects the figure, depicts a conventional suburban layout, and the bottom portion depicts a traditional layout. The community on the top requires one to traverse large distances within the given street network to achieve actually relatively short straight-line distances (low connectivity). In contrast, the community on the bottom provides an interconnected street network and more direct and shorter pathways between where trips would start and end (high connectivity). The top community also possesses lower density of land use per unit area and poor land use mix, whereas the bottom community integrates, within small areas, more and different types of land uses.

It is these and other related environmental factors that transportation and urban planning researchers have explored in investigations of the ways neighborhood characteristics are related to nonmotorized transport. Findings from this research have the potential to inform physical activity research in the area of environmental influences.

METHODS

Studies from the transportation and urban planning research literature were identified through a search of TRANSPORT, a comprehensive transportation bibliographic database containing the Transportation Research Information Services database (from the Transportation Research Board) and other bibliographic transportation data sources. Independent search terms used included *walk*, *walking*, and *cycling*. Study titles and abstracts resulting from this search were screened to identify research examining environmental factors related to walking/cycling that contained some measurement of individuals' actual or reported walking/cycling rates as an outcome variable. For example, most studies investigating pedestrian safety were not reviewed, as individuals' walking/cycling rates were not an outcome in these studies. Reference lists from eligible studies were scanned to identify additional relevant studies. A more detailed review of study methodologies and limitations regarding nonmotorized transport research are available elsewhere (19,20).

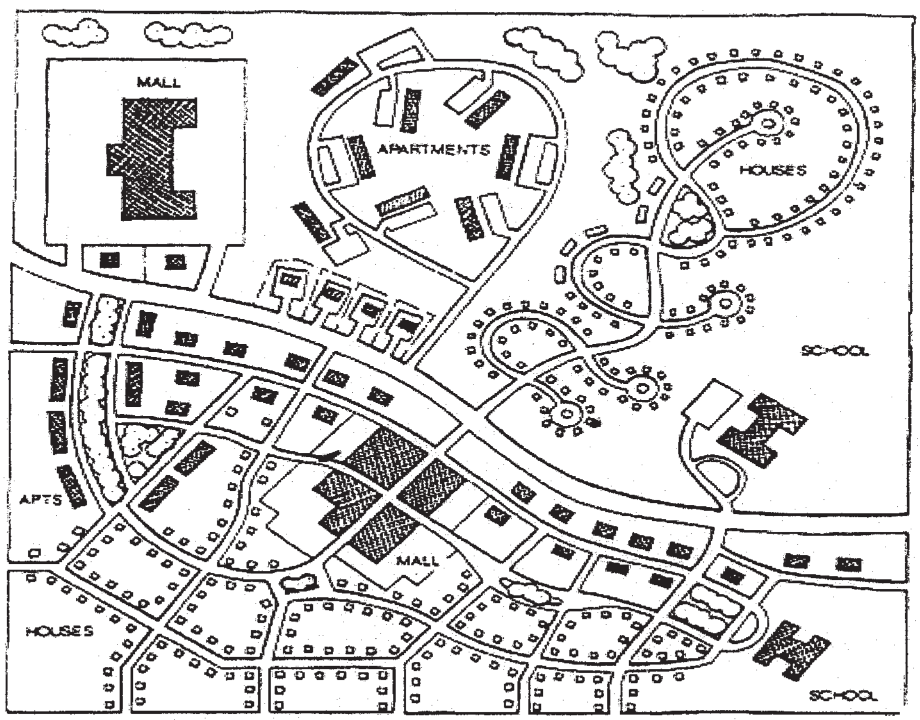

FIGURE 1 Two distinct community designs. From "The Traditional Neighborhood Development: How Will Traffic Engineers Respond?" by F. Spielberg, 1989, *ITE Journal, 59*, 18. Copyright 1989 by the Institute for Transportation Engineers. Reprinted by permission.

RESULTS

Neighborhood Comparison Studies

Because it is not feasible to conduct controlled intervention trials manipulating neighborhood built design, researchers have relied on quasi-experimental designs. One strategy is to examine differences in walking/cycling rates between residents of neighborhoods that differ in environmental characteristics. This is consistent with the case study designs often used in transportation and urban planning research. Traditional neighborhoods purported to be highly walkable and bikable are characterized by high population density, a good mixture of land use, high connectivity, and adequate walk/bike design (e.g., continuous sidewalks). Such neighborhoods are compared with those having lower population density, more uniform land use (e.g., only residential), poorer street connectivity, and inadequate pedestrian and bike facilities (e.g., lack of sidewalks, bike lanes, or stop signs at intersections), which are deemed low-walkable and low-bikable neighborhoods. After neighborhood selection, residents from identified neighborhoods are sampled and asked to keep a travel behavior log. Ten studies from published transportation research were identified that used or approximated this design approach (see Table 2).

On the basis of these studies, estimates can be made of differences between high versus low-walkable and low-bikable neighborhoods in the amount of walking/cycling for transport done by neighborhood residents. Estimates of average walking and the summation of walking and biking trips per week for the average resident in high- versus low-walkable neighborhoods are provided in Table 2. When not provided in the published article or report, absolute weekly walk/bike trip estimates were derived from the percentage of trips made by walking/cycling, based on the assumption that individuals make approximately 30 trips weekly across various modes (e.g., car, transit, walk/bike) (17). Studies that used the method of observing pedestrian and cyclist rates or surveying pedestrians and cyclists around or within specified locations within a neighborhood (e.g., around commercial centers) are not included in the table because, for various reasons (e.g., respondent's residence unknown, multiple counts of the same individual), these procedures prevent estimating walking/cycling rates per average resident within a given neighborhood. These targeted observational studies, however, can be very informative regarding influences of specific environmental factors on pedestrian or cycling behavior and generally support the findings reviewed regarding comparisons between high- and low-walkable communities (21–25).

The frequency of walking trips per week in comparison to other travel modes (e.g., automobile) is relatively low in the United States, regardless of neighborhood environment (17). As seen in Table 2, however, the number of estimated weekly walking/biking trips reported by residents of high-walkable neighborhoods appear to be consistently higher than those for low-walkable neighborhood residents. If one sums across trip purpose for studies that provided walk rates by trip purpose (26–29), and using an unweighted average across all studies presented in Table 2, one sees that high-walkable neighborhood residents reported approximately two times more walking trips per week than residents of low-walkable neighborhoods (3.1 vs. 1.4 trips). The magnitude differences between high- and low-walkable neighborhoods (high–low) range from –0.1 to 5.7 walk trips and are partially dependent on the purpose for the walk trip. For instance, walking to work and walking for errands appear more likely in high- than low-walkable neighborhoods (26–29). Handy's findings (28,29) suggest that these utilitarian trips (e.g., to go shopping) are the source of overall differences in walking trips between high- and low-walkable neighborhoods because walking for exercise did not differ between high- and low-walkable neighborhoods (28–30).

TABLE 2

Estimated Average Walking or Walking and Cycling Trips per Week Among Residents of High-Walkable Versus Low-Walkable Neighborhoods

		High-Walkable Neighborhoods					*Low-Walkable Neighborhoods*				
		Nonwork					*Nonwork*				
Reference Number	*Geographic Location*	*Errand*		*Exercise*	*Work*	*Total*	*Errand*		*Exercise*	*Work*	*Total*
(26)	San Francisco Bay area and Los Angeles		—		0.9	—		—		0.3	—
(27)	San Francisco Bay area		1.4		0.7	—		0.4		0.1	—
(53)	Palm Beach County, FL		—		—	0.2		—		—	0.3
(34)	San Francisco Bay area		2.8		0.4	3.6		2.0		0.3	2.4
(28)[a]	San Francisco Bay area	1.9		2.7	—	—	0.7		2.6	—	—
(29)[a]	Austin, TX	1.5		2.4	—	—	0.3		2.0	—	—
(30)[b]	Austin, TX		—		—	4.3		—		—	0.8
(40)[b]	San Francisco Bay area		—		—	6.8		—		—	1.1
(33)[b]	Orange County, CA		—		—	2.2		—		—	2.1
(36)[c]	Portland, OR		—		—	2.1		—		—	0.5

Note. Estimates are for walking trips, unless otherwise noted. Dashes indicate not estimated in the study.

[a]Values for nonwork are errand, exercise. [b]Comparison of neighborhoods with highest versus lowest pedestrian-friendly characteristics on percentage of combined walking/cycling trips. [c]Comparison of average of neighborhoods with three highest versus three lowest ratings of pedestrian-friendliness on combined estimate of walking and cycling trips.

Methodological issues, study design differences, and the relatively small number of transportation studies documenting walking/cycling rates render difficult a definitive conclusion about the magnitude of the transport-related physical activity associated with environmental factors. For instance, some studies assessed the percentage of all trips taken by walking or cycling relative to other transport modes (e.g., transit, automobile), whereas some assessed the absolute number of walking/cycling trips. The lack of a consistent or any quantified objective walkability index assigned to high- and low-walkability neighborhoods based on environmental factors is a common limitation of the studies. The lack of individual or composite reliable and valid walkability measures makes it difficult to compare neighborhoods and walking/cycling rates across studies. Well-specified procedures for determining walkability and neighborhood selection will allow for translation across neighborhoods and regions (31). Advancements in the quantification of environmental factors, such as connectivity and land use mix, will be instrumental to improving comparability across neighborhoods (32).

Studies have also been inconsistent in evaluating potential confounding variables. Most transport studies examining walking/cycling in high- and low-walkable neighborhoods have matched on or statistically controlled for differences in neighborhood socioeconomic status (26–29,33) or eliminated neighborhoods at socioeconomic extremes (34). Cervero and colleagues matched neighborhoods on transit access (26,27), a potentially important factor in neighborhood walkability (e.g., walking to transit stops). However, measuring and controlling for individual factors that may affect walking/cycling rates (e.g., residents' median age and ethnicity [28]) rarely have been considered in comparing residents' walking/cycling for transport from high- and low-walkable neighborhoods. Walking/cycling rates provided in most neighborhood comparison studies and those in Table 2 are not adjusted for these potential individual-level confounding variables. The influence of such variables has been examined more consistently in transportation and planning studies that have used correlational and regression designs and analyses.

Correlational Analyses of Neighborhood Characteristics

Correlational analyses and regression models that provide continuous measures of neighborhood characteristics can quantify the relation between neighborhood characteristics and nonmotorized transport while controlling for either or both individual and neighborhood sociodemographic variables (e.g., age, income, automobile ownership) known to be associated with walking and cycling. Table 3 provides information from four studies that examined neighborhood characteristics related to walking/cycling rates, after controlling for the indicated sociodemographic variables.

Population density is among the most consistent positive correlates of walking trips (17,35,36). In the 1995 Nationwide Personal Transportation Survey, travel by walking/cycling was approximately five times higher in the highest versus lowest density areas (17). Frank and Pivo (37) found that population and employment density were independent positive correlates of walking rates for commuting and shopping purposes, after accounting for such factors as vehicle ownership, residents' age, and driver's license status. An examination of 32 cities around the world revealed a positive association between city population density and the percentage of workers walking or cycling to work (38), although, as with the Nationwide Personal Transportation Survey, these associations did not control for potential confounding variables. Studies relying on observational measurement of rates of pedestrian and cycling behavior within selected neighborhood areas document higher walking/cycling rates in the highest density areas, even after controlling for differences in population demographic characteristics (25).

Land use mix, especially the close proximity of shopping, work, and other nonresidential land use to housing, appears related to greater walking/cycling among residents. As detailed in Table 3, commuting to work by walking/cycling was higher in areas of more mixed land use (37) and where commercial facilities existed nearby (less than 300 ft, or 0.1 km) (35). Kockelman (32) and other researchers (39) have found that the closer proximity or accessibility of jobs and services is associated with more walking and cycling. In contrast, long trip distances are negatively related to the likelihood of walking/cycling.

The walking and cycling infrastructure (e.g., existence of bike paths, sidewalk continuity) has been evaluated infrequently in relation to transport choice. Some empirical evidence suggests that sidewalks and bicycle paths increase the number of walking/cycling trips (40). When sidewalk continuity is used as one of the criteria for determining neighborhood walkability, high-walkable neighborhoods evidence higher rates of walking/cycling (36). In one study, better pedestrian facilities were related to higher pedestrian rates at commercial centers even when other environmental characteristics, including density and land use mix, were constant (22). Although they did not specifically examine walking/biking rates in their study, Cervero and Kockelman (41) found that better pedestrian infrastructure, including sidewalks and street lighting, was related to greater nonautomobile travel, particularly for nonwork trips originating from home. Further evaluation of the effect of the walking/cycling infrastructure on nonmotorized transport is required; this research has already begun in the health and physical activity empirical literatures (42,43).

Studies that have used correlational designs demonstrate consistent associations of neighborhood walkability factors with walking and cycling for transport. The inclusion of neighborhood variables significantly adds to the regression models for walking/cycling beyond sociodemographic variables (32,37,40), albeit with small magnitude increments. As seen in Table 3, there is variability in the magnitude of model estimates and variables included. As with the neighborhood comparison studies, this could be the result of methodological differences and limitations in the current transportation studies. Nevertheless, the current findings support the hypothesis that neighborhood environmental variables are related to walking and cycling for transport and provide guidance for environmental constructs to consider in future physical activity research.

TABLE 3

Regression Model Findings on the Relations Between Neighborhood Environments and Walking/Bicycling

Reference Number	*Geographic Location*	*Walking/Cycling Outcome*	*Sociodemographic Variables Remaining in Regression Model*	*Neighborhood Characteristics That Contributed Significantly to Regression Model*	*Estimate of Model Fit*
35	Various metropolitan statistical areas in U.S.	Probability of commuting to work by walk/bike	No. of autos owned (–)	Residing in center of city (+), higher density (+), commercial or other nonresidential building within 300 ft (+), grocery or drug store > 300 ft and < 1 mile (–), adequate public transportation access (+), distance to work (–)	ρ^2 = .532
37	Puget Sound area (WA)	Percentage of walking for 1. work trips 2. shopping trips	1. No control variables enter model of walk to work 2. < 1 vehicle (+), age (–), having driver's license (–)	1. % walk to work: employment density at origin (+), population density at trip origin/destination (+), and mixed land use (+) 2. % walk to shop: employment density at destination (+), population density at trip origin and destination (+)	% walk to work, adj. R^2 = .31; % walk to shop, adj. R^2 = .35
40	San Francisco Bay area (CA)	No. walk/bike trips	None in final mode of number of walking/cycling trips containing neighborhood variables	Neighborhood variables: specific neighborhood (+), having sidewalks/bike paths (+), and transit access (+) Urban attitude variables: pro-environment (+), pro-transit (+), desiring automotive mobility (+)	R^2 = .0303 for neighborhood variable model; R^2= .0946 for neighborhood plus attitude variable model
32	San Francisco Bay area (CA)	Likelihood of taking walk/bike trips	Age (–), having driver's license (–), employed (–), autos owned (–), having a professional job (+), inverse of household size (+), male (+)	Accessibility (proximity of jobs, services) of origin and destination zone (+), trip distance (–); mean land use mix of non-work origin and destination	ρ^2 = .219 for control variable only model; ρ^2 = .226 for neighborhood

Note. (+) = positive association; (–) = negative association; adj. = adjusted.

Alternative Research Designs

One limitation to examining environmental correlates of physical activity that will require innovative research designs is the inability to randomly assign individual residents to different neighborhoods or the feasibility of manipulating the walkability of neighborhood environments. Quasi-experimental designs do not prevent the possible confound of individual biases and values affecting the choice an individual makes about where to live. For example, residential choice is influenced by numerous variables, perhaps including the surrounding urban form. If individuals choose to live in neighborhoods because of the characteristics that contribute to their walkability, this makes it difficult to disentangle the direction of causality between individual values and attitudes, the built environment, and that individual's nonmotorized travel (30). For example, individuals who choose to live in communities with higher environmental walkability may value physical activity and health; conversely, low-walkable communities may be selected by individuals with a lower propensity to be physically active through transport. Walking for transport is commonly perceived as a health-promoting activity, and nonmotorized transport is preferred by individuals for short-distance travel (44). However, the perceived healthfulness of walking is not necessarily related to the intention to walk or actual rates of walking for transport (45), as would be likely if all walking/cycling for transport were determined by psychosocial factors related to physical activity and not the neighborhood built environment. Such issues have been partially addressed among transportation and urban planning researchers in the discussion of whether travel is *derived*. Derived models suggest that travel is engaged in only as a means to an end destination, and thus the travel behavior itself is largely, if not completely, influenced by nonintrapersonal variables (e.g., cost, distance to destination, transportation infrastructure). Alternative models suggest that travel behavior is an activity with its own set of individually based values, beliefs, and attitudes, or at least influenced by other variables than built form (24,44,46). The contribution to walking/cycling behavior of attitudes and values regarding physical activity needs to be investigated (see Future Directions for Physical Activity and Health Research section), as do methodological design strategies that control for these variables.

In attempt to isolate environmental influences, research designs would benefit from keeping the same individuals within an environment that is subsequently modified, with the assumption that individual attitudes and values about travel and physical activity would remain stable. Measurement of walking/cycling for transport prior to and following a modification in a neighborhood environment could begin to test causal hypotheses about neighborhood environment factors. Pre–post designs to examine effects of environmental changes are common in transportation and urban planning research (e.g., 47). Strategies have been proposed for neighborhood retrofitting that would enhance factors purported to increase walking (e.g., increasing connectivity [18,48]). Future research needs to evaluate the impact of these environment modifications on actual walking and cycling among residents before and after retrofitting.

Moving residences also provides another strategy for examining environmental impact on transport. An 11-year prospective panel design study in Seattle, Washington, assessed the changes in individuals' travel patterns that occurred after they relocated to a different community. The study concluded that some shifts in household members' "alternative" (e.g., transit, nonmotorized) travel behavior occurred with the introduction of a different neighborhood environment (49). The study author stressed the need to continue exploring the influence of individuals' and households' attitudes around transport and possible self-selection into neighborhoods based on the existing built environment. There is a need to control for other events associated with relocation that could affect changes in household travel patterns, including household size and employment status. With these caveats under consideration, panel designs may offer a better control of individual attitudinal and demographic factors than cross-sectional research designs and could serve as a model for the longitudinal examination of physical activity change secondary to change in environmental exposure.

DISCUSSION

Implications for Health and Exercise Science Research

Neighborhood environment characteristics were related to walking and cycling for transport in virtually all of the studies reviewed. The strength of the associations varied but was usually substantial. From a physical activity and health perspective, the estimated mean difference between high- and low-walkable neighborhoods of approximately one to two walk trips per week translates into 1 to 2 km, or about 15 to 30 min more walking per week for each resident of high-walkable neighborhoods. Across 1 year, for a 150-lb (68-kg) person, this translates into energy expenditure of approximately 3,000 to 6,000 kcal, or about 0.85 to 1.75 lb (0.39–0.79 kg). Results from a study in China, where motorized transport is less common, found that ownership of a motorized vehicle was related to higher weight and obesity prevalence. Moreover, weight gain and increased obesity prevalence accompanied the transition from not owning a motor vehicle to acquiring one, particularly for men (50). Additional energy expenditure, through more nonmotorized transport, could help mitigate the estimated average yearly adult weight gain in the United States (51). Moderate-intensity physical activity acquired through more nonmotorized transport, undertaken by a large proportion of the population over time, would have significant public health impact. Indeed, walking or cycling for transport to work appears to be associated with lower body weight and less adult weight gain over time, independent of the effects on body weight of more vigorous physical activity (4). Especially in the current context of no apparent increase in adult physical activity during the 1990s (5), the potential to enhance physical activity in entire communities by 15 to 30 min per week should be taken seriously.

A 15- to 30-min per week increase in physical activity may seem small, and in fact many individually oriented interventions have produced larger improvements in physical activity (2,6). However, the potential effects on physical activity of urban form are fundamentally different from effects of behavior change programs. This literature review reflects differences in physical activity across the entire population living in the target neighborhoods rather than changes in the small proportion of people who are motivated and volunteer to participate in intervention studies. Thus, the potential reach of changing neighborhood environments is essentially complete, although it must be assumed there is wide variation in transport-related physical activity within neighborhood types. The other fundamental difference is that changes in the environment can be expected to be relatively permanent, in stark contrast to the well-documented lack of maintenance of health behavior change programs (52). Thus, modest effect sizes of environment on walking and cycling for transport may compare very favorably to the population effects of more traditional approaches to individual behavior change when the likely pervasive reach and maintenance of the effects are considered.

Confidence in the transportation findings is enhanced by the consistency of results. Virtually every study demonstrated associations between environmental variables such as density, connectivity, and land use mix and walking/cycling. With the exception of one study (53), residents from communities deemed high walkable according to environmental characteristics had higher rates of walking/cycling in comparison to residents from low-walkable communities. The similarly of findings across research designs and analytic methods adds further to confidence in the results. In the correlational studies, neighborhood environments may explain similar amounts of variance in physical activity as the combination of many psychosocial variables (6). In the health field, lack of conceptualization of specific environmental variables has been identified as a hindrance to research progress (9,12), so incorporating environmental variables described here into health research may stimulate advances in physical activity research.

Future Directions for Physical Activity and Health Research

A notable strength of transportation and planning research is the frequent use of objective measures of environmental variables. Land use and census data, combined with specialized software tools, provide a powerful approach to greatly improve research on environmental correlates of physical activity. The ability to evaluate community design and characteristics such as density and land use has improved substantially in recent years (16). Some 30 years ago, Ian McHarg, in his seminal landscape architectural work *Design With Nature* (54), outlined a procedure to "vertically overlay" environmental considerations, including topography, soils, vegetation, and sensitive areas (e.g., wetlands) with human-made considerations of the built environment (e.g., road, buildings). This pioneering work led to the vertical integration of data on which geographic information systems (GIS) operate. GIS have already been integrated into health research, especially epidemiology (55). Today's GIS software and modern computer capacity enable operationalization of spatial measures of the built environment not previously feasible. GIS can also provide spatial linkage that enables the integration of measures of proximity, connectivity, density, and other environmental factors with systematic assessment of household or individual behavior. For instance, GIS allow for measurement of the distances from where people live to parks, gymnasiums, and other recreational opportunities that may affect physical activity. Improvements in transportation research could include a more systematic way of determining the walkability/bikeability of a given environment based on objective environmental data. Existing transport methodologies and improvements in environmental assessment methodology could be readily integrated into physical activity research.

Transportation experts have identified nonmotorized travel usage and user characteristic research as of high priority and have identified the many gaps in the existing empirical literature on walking/cycling for transport (56,57). The transportation literature leaves unanswered many questions that are important for health and exercise science. Several research directions and priorities for health and exercise science can be suggested. For example, because travel choice is often measured categorically (e.g., walking trip vs. automobile trip), the duration and intensity of walking and cycling are unknown. Physical activity duration and intensity are important considerations for long-term health benefit. Thus, the contribution of walking/cycling for transportation to overall physical activity or energy expenditure is not currently known. Most transport studies assess only 1 or 2 days of travel, so there is limited generalizability to habitual physical activity. Reliance on unvalidated self-report measures of transport behavior also introduces error. Physical activity researchers can contribute to the transport literature by obtaining more objective measurements of physical activity (e.g., accelerometry) from individuals in specified environments.

The attempt to identify unique contributions of specific neighborhood characteristics is hampered by high interrelatedness of neighborhood–environmental characteristics. Neighborhoods with high density also tend to have greater mixed use and street connectivity. This phenomenon, known as *spatial multicollinearity*, makes it difficult to determine the independent contribution of urban form variables (e.g., density, land use mix) on travel mode choice (27). Researchers can overcome this by examining locations and neighborhoods that differ on only one environmental walkability factor (22). Expanding the range of neighborhoods examined for walkability will also improve our understanding of environmental impacts on physical activity. To date, transportation and urban planning research has been conducted in only a small number of cities (e.g., the San Francisco Bay area; Seattle, WA; Portland, WA), as seen in Tables 2 and 3. The geographic focus of transportation and planning literatures remains in urban areas (Tables 2 and 3), rural areas remain largely understudied in the transportation literature, with some exceptions (43). Factors associated with nonmotorized transport among rural residents are unknown but likely differ from relevant factors in urban and suburban environments. Developing and standardizing environmental indices of walkability and bikeability will help in this process.

Many of the neighborhood comparison studies lacked individual socioeconomic and ethnic diversity information or did not include analysis of these factors. Often the sociodemographic characteristics of the neighborhoods and samples were not reported, but these can be highly influential factors in nonmotorized transport behavior (14,22,58). Low-income individuals may be more likely to walk for transport purposes than higher income individuals (59), and gender differences in walking for transport may exist (60). Physical activity researchers can infuse the long tradition of assessing sociodemographic influences into measurement of nonmotorized transport and related physical activity. The possibility that land use has differential effects on people with varying characteristics (e.g., ethnicity, age, socioeconomic status, disability status) rarely has been explored, so increasing the diversity of the neighborhoods and samples investigated should be a high priority for researchers in health fields. Children may be less likely than adults to walk and bike for transport (with the notable exception of transport to and from school), and different aspects of the neighborhood environment may influence their physical activity (e.g., proximity of playgrounds [61]). Environmental factors that have a particular influence on older adults' physical activity need to be identified. Curbs with ramps may be a particularly important environmental characteristic for wheelchair users. Similarly, sloping curbs may provide fewer visual impediments for older cyclists and walkers and are increasingly used in some retirement communities.

Data at different levels of aggregation (e.g., individual psychosocial variables vs. neighborhood environmental characteristics) need to be collected to fully understand the correlates of physical activity. Geographical scale can influence the observed relation between the built environment and individuals' transport (62). Future consideration of these factors will require more sophisticated multilevel modeling and analytic methods (e.g., hierarchical linear models) that have begun to be incorporated into transportation research (63). The utility of various statistical approaches for multilevel physical activity research has been discussed (64). Such methods will help to account for the independent and interdependent influences of both individual and neighborhood factors.

In addition to density, connectivity, and land use mix, other potential environmental correlates of nonmotorized transport need to be studied, such as presence and quality of sidewalks;

pedestrian signals and midstreet islands on busy streets; parking cost, location, and availability; and presence of bicycle lanes and trails (42,43). There may be additional physical environmental factors, some of which are presented in Figure 2, that are likely related to recreational physical activity and nonmotorized transport but remain largely unstudied, such as park characteristics, tree canopy, and topography (e.g., street inclines, natural barriers such as waterways). In addition to the built environment, other environmental factors that can be measured objectively may be related to nonmotorized transport and physical activity, including crime and weather. The effect of weather and season has received some attention in transportation research. For instance, rates of cycling to work or school appear to exhibit some seasonal fluctuation (65,66), but among daily weather conditions, including temperature, wind, and rainfall, only the extreme of heavy rain markedly affected commuter cycling (66). We are not aware of any study that has examined the impact of crime on rates of walking/cycling for transport. More comprehensive investigation of nonbuilt environmental influences clearly is required.

Although it is valuable to investigate objective measures of physical environments, it may be useful to collect measures of perceived neighborhood environment as well (e.g., perceived connectivity, aesthetics). It is not clear whether the perceived environment has an independent, synergistic, or shared association with walking and cycling, and it may be most useful to include both objective and subjective modes of environmental assessment. Perceptions of neighborhood may be especially important in evaluating the reasons for residents' choice of community in which to live, as this could better inform the nature and directionality of the relation between neighborhood environment and walking/cycling.

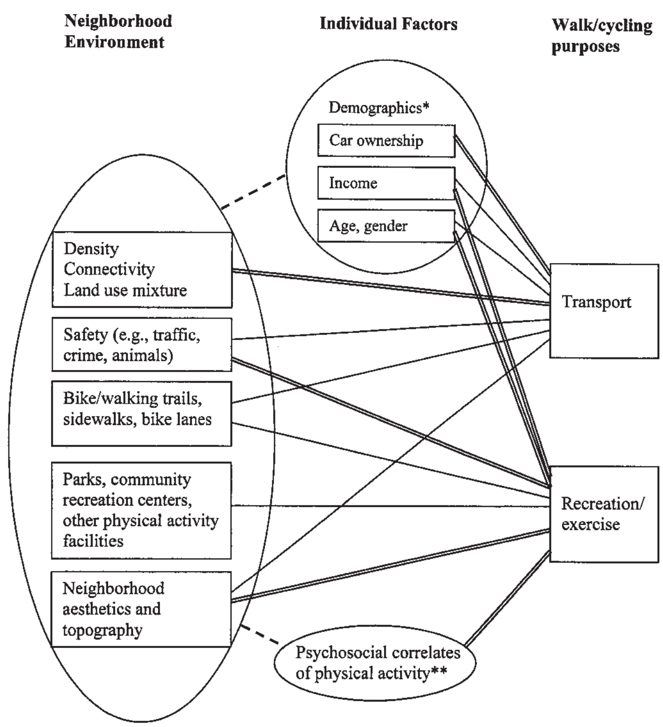

FIGURE 2 A proposed ecological model of neighborhood environment influence on walking and cycling. Double lines denote stronger relations; single lines denote weaker relations; dashed lines denote mediated relations. *Some examples of demographic variables are provided, but should not be considered comprehensive. **Psychosocial correlates of physical activity would include, but are not limited to, such variables as self-efficacy, perceived benefits, perceived barriers, social support, and enjoyment of physical activity.

Consistent with ecological models of behavior, researchers are encouraged to maximize their ability to explain individual variation in physical activity by simultaneously examining psychosocial correlates of physical activity and environmental variables. The examination of psychosocial physical activity correlates may add to the understanding of how "derived" walking and cycling are for transport (44). It may also be fruitful to examine interactions of environmental and psychosocial variables as well, in addition to the interaction between environmental and sociodemographic variables known to influence physical activity. Figure 2, although not comprehensive, proposes a model for next possible steps in the evaluation of environmental and psychosocial variables involved with physical activity and their interaction. For instance, it is possible that the collective psychosocial factors of social support, self-efficacy, and positive beliefs about physical activity are more closely related to the behavior in the presence of a more walkable physical environment. Alternatively, individual environmental characteristics related to walkability may interact with specific psychosocial correlates to promote greater walking/cycling. For instance, an individual who perceives a high benefit to being physically active may be more likely to be influenced by street connectivity than a neighbor next door who has less positive beliefs about physical activity.

Evaluation of environmental and psychosocial interactions can also inform physical activity interventions. Educational and behavioral interventions in low-walkable environments may need to provide strategies to compensate for the lack of nearby resources or encourage participants to go to other environments to be physically active. Individual-focused interventions in more walkable neighborhoods may need to educate people about local physical activity resources and encourage them to use those resources. On the basis of current estimates of average walking/cycling rates from transportation and urban design research, even residents in the most walkable neighborhoods do not all attain a level of physical activity consistent with health benefits (1). This highlights the continued importance of investigating psychosocial factors and interventions and the interaction between psychosocial and environmental factors. Other researchers have proposed complex models of integrating health promotion and transport policy (67) to perhaps target communities with environmental risk for low physical activity. Intervention and policy studies may also help to determine how environmental effects may or may not be moderated by sociodemographic and psychosocial factors. Investigators conducting physical activity intervention studies could include measures of neighborhood environments that could be examined as potential moderators of the intervention effects. For example, it is conceivable that a behavior change intervention that teaches goal setting and other skills would be effective in high-walkable neighborhoods or those with more and better recreational facilities. The same intervention may not be effective for people who live in neighborhoods less environmentally "friendly" to physical activity.

CONCLUSION

Transportation and planning research supports the proposition that the physical environment is associated with physical activity in the form of walking/cycling for transport. Because large proportions of people in the United States and other industrialized countries live in the sprawling and exclusively residential environments associated with low levels of walking for transport, land use and design may already be having a substantial, although generally undocumented, impact on public health. A growing number of policy experts, urban planners, and transportation experts are concerned that we have built our communities so it is difficult, and in many cases dangerous, to walk or bike and have thus "engineered" physical activity out of our daily lives (68). Approaches to urban design termed *Smart Growth* and *New Urbanism* have emerged in response to the need to improve air quality, solve traffic congestion, and promote better overall quality of life (16,68,69). There is a public health imperative to evaluate environmental variables and their associations with a wider array of physical activity behaviors within a health framework. The results of such studies can inform efforts to alter the environments in which people live their daily lives so as to promote population shifts in physical activity. It is possible that environmental changes can produce relatively permanent improvements in physical activity, which may help overcome the lack of maintenance of change that is so common in studies of individually oriented interventions (52). Constructs, databases, land use measurement methodologies, and lessons learned can be borrowed from transportation and planning research and, in combination with cross-disciplinary collaboration, be applied in conducting research to improve our understanding of environmental correlates of physical activity and health.

This review of research on transportation-related physical activity complements recent reviews of the correlates of primarily recreational physical activity from the health literature (12,70). Both reviews conclude there is substantial evidence that environmental variables, whether assessed objectively or subjectively, are consistently related to physical activity. Both reviews highlight many unanswered questions in this area, and progress in improving understanding of environmental correlates of physical activity is a high priority, because findings could lead to policy changes that will provide more people with environments that will facilitate active lifestyles. Conducting and applying research on environmental correlates of physical activity will require collaboration among a wider range of professions than previously has been involved in physical activity research. Health researchers need to become more involved in environmental research and policy studies, discussions, and decisions about environmental factors that are influencing physical activity and health.

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