DOES THE BUILT ENVIRONMENT INFLUENCE PHYSICAL ACTIVTIY?
EXAMINING THE EVIDENCE

Critical Assessment of the Literature on the Relationships Among Transportation, Land Use, and Physical Activity

SUSAN HANDY

Susan Handy is Associate Professor, Department of Environmental Science and Policy, University of California, Davis.

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EXECUTIVE SUMMARY

Introduction

The purpose of this report is to provide a theoretical framework for discussion and to review and evaluate empirical evidence regarding the relationship between the built environment and physical activity behaviors. The question of interest here is the link between the built environment and physical activity, including both active travel and other physical activity. However, in conceptualizing this link and in designing studies to test it, researchers must think both more specifically and more broadly. First, researchers must more specifically conceptualize the two key variables, the built environment and physical activity. Second, researchers must consider the possibility of a broader conceptual model, one that takes into account other factors that affect physical activity and does not assume that all other factors are exogenous to the relationship between the built environment and physical activity. To assess the progress existing research makes toward meeting these challenges, this report reviews the theory, studies, and findings from two bodies of work—travel behavior research and physical activity research.

Theory

Theory provides the basis for conceptual models, consisting of the behavior of interest and the factors that explain that behavior, the ways in which these variables are defined, and the assumed relationships between them, that researchers use as an essential guide to their efforts. No one theory reviewed here provides a complete framework for understanding the link between the built environment and physical activity. The utility-maximizing framework as applied in travel-behavior research conceptualizes behavior as discrete choices and explanatory factors as the attributes of those choices. Its strength is its focus on the mechanism by which the attributes affect the choice. It does not, however, provide specific guidance on how to think about physical activity behavior as discrete choices or on what attributes might be relevant to those choices. The Theory of Planning Behavior and Social Cognitive Theory, in turn, focus on identifying and defining key psychological and social variables that influence behavior. Their strength is the attention they place on variables such as the attitudes and beliefs of the individual as an explanation for behavior. They do not, however, delineate an explicit mechanism by which those variables influence behavior. Theory on the built environment at this point consists of a loose assembly of ideas about specific characteristics of the built environment that influence behavior in public spaces but is not explicitly a behavior theory.

With further thought, these theories might together add up to complete whole. It is possible for researchers to start with one theory and borrow insights from the others in developing a conceptual model for studying the relationship between the built environment and travel behavior. Researchers using the utility-maximizing framework can look to theory on the built environment to identify potentially important characteristics to include as attributes of the choice of interest and to the Theory of Planned Behavior and Social Cognitive Theory for guidance on attitudes and beliefs that might influence perceptions of attributes and otherwise influence individual assessments of the utility of choices. Researchers using an ecological framework can look to the utility-maximizing framework for insights on the discrete choices that underlie the behavior of interest and may, as a result, consider different conceptualizations of that behavior. These theories all suggest that the relationship between the built environment and

physical activity is not just a simple relationship between these variables and that the study of this relationship should be guided by a more comprehensive conceptual model.

Review of Existing Studies

The fields of travel behavior research and physical activity research have both contributed to the available evidence on the link between the built environment and physical activity. Travel behavior studies have largely focused on automobile travel rather than active travel, but a number of the studies from this literature provide evidence on walking and/or biking. Physical activity studies have focused on total physical activity, with little differentiation of the type or location of that activity, though a few studies focus on walking for exercise and/or transport. In both cases, the interest in the role of the built environment in explaining behavior is relatively recent.

This review examined 22 studies from the travel behavior literature and 28 studies from the physical activity literature. These studies provide convincing evidence of a link between the built environment and physical activity. But these studies together provide less convincing evidence of what characteristics of the built environment are most strongly associated with physical activity and they do not firmly establish a causal relationship or eliminate the possibility of spurious relationships. Nevertheless, certain patterns emerge from this review that tend to suggest specific relationships between the built environment and physical activity, including:

- Accessibility, measured in various ways, emerges most clearly from both literatures as a strong correlate of away-from-home physical activity.
- The importance of design variables in explaining active travel or physical activity was somewhat more ambiguous, in both literatures.
- Design may prove more important for other physical activity than for active travel and distance more important than design for active travel.
- Individual and interpersonal factors are potentially more important than the built environment in explaining physical activity.
- Supportive built environment is not enough on its own to ensure physical activity but it does facilitate physical activity.

Although the studies reviewed show significant correlations between certain characteristics of the built environment and certain types of physical activity, the use of cross-sectional designs leaves many unanswered questions about the causal mechanisms involved. In particular, the possibility of "self-selection," in which preferences for physical activity influence residential location choice, and other potential relationships between longer-term and shorter-term decisions must be addressed. More comprehensive conceptual models and more sophisticated research designs can help to address questions of time-order, spuriousness relationships, and causal mechanisms and shed further light on the causal relationships between the built environment and physical activity.

Recommendations

Considerable progress has been made in showing the significance of a connection between the built environment and physical activity, but evidence on what aspects of the built environment affect what types of physical activity to what degree is slim as is evidence on the nature of causal relationships. If the goal is to determine what land use, transportation, and design policies will lead to increases in physical activity, researchers have a long way to go. Rather than more studies that confirm a correlation between the built environment and physical activity, we need studies that help show which characteristics of the built environment affect what types of physical activity to what degree and we need studies that begin to sort out the causal relationships among a broader set of factors. Recommended considerations for future research include:

Conceptualizing the Key Variables

- Build a theoretical basis for identifying characteristics of the built environment that may influence physical activity based on the existing urban design literature and travel behavior theory, as well as further qualitative research. Move away from the use of proxy variables such as density and focus instead on characteristics of the built environment that directly affect behavior.
- Explore the relationship between perceived and objective characteristics of the built environment and incorporate this relationship into studies of the link between the built environment and physical activity.
- Match specific characteristics of the built environment at specific scales to specific types of physical activity in specific settings and examine relationships ignored so far by researchers, such as the role of regional-scale characteristics on physical activity.

Conceptual Models and Study Design

- Employ a more comprehensive conceptual model, one that accounts for bi-directional relationships between choices about residential location, auto ownership, the built environment, and physical activity, and for the role of preferences and perceptions in all these choices.
- Move toward the use of quasi-experimental designs, either by measuring changes in physical activity associated with changes in residential location or by taking advantage of planned changes to the built environment, whether small changes such as the installation of traffic calming devices or significant redevelopment projects.

INTRODUCTION

Purpose of Paper

The purpose of this report is to provide a framework for discussion and to review and evaluate empirical evidence regarding the relationship between the built environment and physical activity behaviors. The context for this work is a growing concern over decreasing levels of physical activity in the United States and elsewhere and the various health implications of this trend. In the search for strategies to increase physical activity, public health officials have come to a realization that communities are built to accommodate the car with relatively little attention to the pedestrian or the bicyclist. At the same time, transportation planners have turned to land use policies as a potential strategy for reducing automobile dependence and the various economic, environmental, and social problems associated with this dependence. The concerns of the two fields overlap on the topic of active travel—walking and biking to destinations—and officials from both fields hope to answer this question: what land use, transportation, and design policies will help to increase active travel?

This report reviews the theory, studies, and findings from two bodies of work: travel behavior research and physical activity research. Coming from different directions, researchers in both areas hope to increase our understanding of the link between the built environment and active travel, a subset of the larger realm of travel of interest to travel behavior researchers and a subset of the larger realm of physical activity of interest to physical activity researchers. In both areas, however, the theory and measures used by researchers reflect the traditional focus of each field: automobile use for travel behavior research and personal and social factors for physical activity research. In both cases, the interest in the role of the built environment in explaining active travel is relatively new, but comes at a critical time. Researchers can contribute to the current policy debates by providing empirical evidence crucial to the development and justification of effective policies for increasing active travel.

The development of this report involved three stages of work, although the process was not entirely linear. In the first stage, I gathered relevant materials, including published literature reviews, relevant quantitative studies, theoretical discussions, and others. In the second stage, I read these materials and identified salient points. In the third stage, I analyzed and synthesized salient points, focusing in particular on quantitative studies of the link between the built environment and active travel or other physical activity from both literatures. Finding an end point for each of these stages was one of the more challenging aspects of the task, particularly as new studies or commentary on the topic seem to appear daily. This final report represents the state of knowledge at one point in time, and it is possible that new contributions to these literatures may suggest new twists. In the remainder of this chapter, I define key terms and lay out the research challenges that the report will address.

Definitions of Key Terms

Exactly what is meant here by the "built environment" or by "active travel" or by "physical activity" more generally needs some clarification. Not every writer defines these terms in the same way, as quickly becomes obvious in a review of the literature. I offer here my own way of thinking about these terms, as a framework for the critique that follows.

Built Environment

I define the built environment as consisting of three general components: land use patterns, the transportation system, and design. Together these components characterize the opportunities available to residents for travel and for physical activity.

"Land use patterns" refers to the spatial distribution of human activities, in other words, what kinds of activities are located where. These patterns are usually depicted in a two-dimensional way through land use maps and may be more or less detailed, distinguishing land uses in an aggregate way by districts within a region or in a disaggregate way using parcel-by-parcel differentiation. Land use patterns determine the relative proximity of activities of different types, including specific kinds of public and private facilities.

The "transportation system" refers to the physical infrastructure and the services that make up the transportation system and that provide the spatial links—or "connectivity"—between activities. Specific activity locations may be linked more or less directly; in this way, the transportation system mediates land use patterns to determine the travel distances between one place and another. The quality of the links must also be considered—not just what distance, but also what speed, how safe, how comfortable, how pleasant they are.

"Design" refers to the aesthetic qualities of the built environment and overlays both land use patterns and the transportation system, particularly in terms of the design of buildings and the design of streetscapes, respectively. Design comprises the visual details of the built environment, the styles, textures, color, and ornamentation of physical structures. Broadly defined, design includes the interior design of buildings as well as the character of private and public spaces outdoors.

The "physical environment" refers not just to the built environment but also to the natural landscape and to human use of public spaces. The natural landscape includes trees and other landscaping, foliage, and greenery. It can be a minor component of the environment or a dominant one, exerting more influence over the character and feel of a place than buildings and streets. Human use of public spaces adds to or detracts from the quality of the environment, through the presence or absence of people and through the residue of their presence (e.g., trash or graffiti). Although I will mostly use the term "built environment" through this report, most of the discussion applies also to the larger concept of the physical environment, and researchers often use the term "built environment" to refer to the larger concept.

Scale also plays a role in defining the built environment. The built environment is often evaluated or measured at the building, street/block level, the neighborhood level, the district level, or the regional level. At each spatial scale, different characteristics are more or less relevant, and the influence of the built environment on physical activity at one spatial scale may depend on the influence of the built environment at another spatial scale.

Physical Activity

"Physical activity" can be broadly defined as any sort of movement of the body. For the purposes of this paper, it is categorized according to purpose, whether for travel or not. In addition, it is useful to consider the location of the physical activity, or what researchers call "behavioral settings:" home, work or school, the neighborhood, facilities of various types. In each setting, physical activity can take place inside or outside buildings.

What might be called "active travel" refers to travel from one point to another by non-motorized means, usually walking or biking, though rollerblading, skateboarding, and non-motorized wheelchair use would also count. Active travel is not simply a loop from starting point back to starting point, but rather involves a destination, a place where the traveler stops for some activity. Active travel might also be called "destination-oriented physical activity," although it can be differentiated by the type of activity at the origin as well as at the destination: travel from home to work, travel from home to destinations other than work, travel from work to destinations other than home, and so on. Travel is often much more complicated than that, consisting of complex chains of trips from one destination to another, but most of the research reviewed below focuses on one of these specific combinations. Active travel is often referred to as "nonmotorized travel."

What I've labeled here "other physical activity" refers to all physical activity that is not considered active travel. This includes activity for the purpose of leisure or sport and what might be called inadvertent exercise—activity as a part of work or chores. Other physical activity can take place anywhere—in or around the home, in or around work, formal recreational or exercise facilities, streets and other public spaces. The distinctions between active travel and other physical activity are not always clear, however, as for example when a person goes for a walk for the purpose of exercise but happens to stop somewhere along the way. In these cases, the observable behavior may not clearly reveal the motivation for the behavior.

Research Challenges

The question of interest here is the link between the built environment (or more broadly, the physical environment) and physical activity, including both active travel (of interest to both transportation planners and public health officials) and other physical activity (of interest to public health officials). However, in conceptualizing this link and in designing studies to test it, researchers must think both more specifically and more broadly.

First, researchers must more specifically conceptualize the two key variables, the built environment and physical activity. These variables have multiple dimensions, as defined above and summarized in Table 1-1, and researchers must consider which of these dimensions are likely to be linked, that is, which elements of the built environment as listed in the first column, if any, help to explain levels of physical activity of different types as listed in the third column. Not all of these relationships are as likely as others, and researchers must rely on theory, empirical evidence, and intuition in choosing which relationships to target for study. In addition, researchers must match aspects of the built environment at different scales (column 2) appropriately to types of physical activity by behavioral setting (column 4): not all aspects of the built environment at all scales affect all types of physical activity in all settings.

Second, researchers must consider the possibility of a broader conceptual model, one that takes into account other factors that affect physical activity and does not assume that all other factors are exogenous to the relationship between the built environment and physical activity. Beyond socioeconomic characteristics, widely known to affect both travel behavior and physical activity behavior, attitudes and preferences are likely to play a role, for example. If so, then the possibility that preferences for physical activity influence the choice of where to live and thus the characteristics of the built environment found in the area near home might also be considered. The direction of causality between these factors is also an important question for exploration, not

only at one point in time but as the factors influence each other over time. More complicated conceptual models then demand more sophisticated research designs.

In addition to summarizing the available empirical evidence, this review thus focuses on these two research challenges: finding appropriate ways to conceptualize the two key variables, and deciding upon an appropriate conceptual model along with appropriate research designs to test it. The theories reviewed in Chapter 2 provide a helpful starting point for both challenges. The empirical studies reviewed in Chapter 3 mostly use the most basic conceptual model but apply a wide variety of approaches to conceptualizing and operationalizing the two key variables, the built environment and physical activity. Chapter 4 discusses possibilities for a broader conceptual model, one that brings more variables into the model and accounts for their potential endogeneity, and reviews both the findings from and research designs used in a handful of studies that make steps in this direction. Researchers are making progress in meeting both challenges, which are often exacerbated by the limitations of available data sources, and I conclude the report with a critical assessment of the research to date and with recommendations for further improvements in conceptualization and research design.

THEORETICAL DISCUSSION

Role of Theory

In scientific research, the term "theory" refers to a set of general laws, well established by empirical research and useful in producing accurate predictions and plausible explanations. A particular theory provides a particular view of the world that helps a researcher both generate hypotheses and interpret results. It influences empirical research by influencing the subjects, variables, and relationships a researcher chooses to study, and it provides the foundation for conceptual models, consisting of the behavior of interest and the factors that explain that behavior, the ways in which these variables are defined, and the assumed relationships between them. These conceptual models provide an essential guide to the research effort, including the research design, the measurement of variables, and the analysis that follows. Theory is thus a starting point for meeting both of the research challenges posed at the end of the previous section: thinking more specifically about the conceptualization of the key variables, and thinking more broadly about a more comprehensive conceptual model.

This section reviews a number of theories from different disciplines that might help us meet both challenges. I start with the theory of travel behavior that has dominated research in this field for going on three decades and discuss ways that travel behavior researchers have either simplified or extended this theory over time. I then review extensions to utility-maximizing theory from inside and outside the field that might prove helpful in exploring the relationship between the built environment and travel behavior. Finally, I look at theories from beyond the utility-maximizing framework, including the theory of planned behavior and social-cognitive theory, the latter widely used in physical activity research. This review reveals important commonalities as well as differences with respect to what these theories suggest about the relationship between the built environment and physical activity. These theories offer potentially complementary insights into the development of conceptual models for the study of this relationship.

Utility Maximizing Theory

The goal of travel behavior researchers, particularly those based in the engineering discipline, has traditionally been improved accuracy in forecasting. For the first few decades of this field, researchers developed aggregate, ad hoc models that were reasonably successful in replicating current patterns of travel at the metropolitan level. In the late 1960s and early 1970s, researchers began to argue for disaggregate models of individual choice, based on behavioral theory, that would more accurately represent cause and effect and thus produce more accurate forecasts of the implications of changes to the transportation system. Although others helped to articulate a disaggregate approach (Kutter 1973), Dan McFadden is widely credited with bringing a utility-maximizing framework from economics and psychology to travel behavior research. McFadden argued in 1974:

> Travel demand forecasting has long been the province of transportation engineers, who have built up over the years considerable empirical wisdom and a repertory of largely ad hoc models which have proved successful in various applications. The contribution of psychologists and economists to forecasting methodology has been limited; despite a surge of recent interest, there still does not exist a solid foundation in behavioral theory for demand forecasting practices. (McFadden 1974)

The work of McFadden and others (Train 1986; Ben-Akiva and Lerman 1991) solidified the position of the concept of utility maximization at the core of travel behavior theory. The development of this theory started with the general proposition from economics that "people make decisions to advance their self-interest" (McFadden 2002). The general model of consumer behavior suggests that individuals make decisions that maximize their utility subject to budget constraints and that their demand for different goods depends on prices of all goods, income, and tastes. What differentiated travel behavior theory from consumer choice theory is that transportation choices are discrete (e.g., where to go, when to go, which mode to use) rather than continuous (e.g., how much of a good to buy). For continuous choices, in which small marginal adjustments are possible, researchers could assume common tastes across all individuals; for discrete choices, in which a small change in price either leads to no change or a significant change, unobserved variations in tastes were an important consideration (Domencich and McFadden 1975). To accommodate taste variations, McFadden and others formulated a function for utility that included mean utility, reflecting representative tastes, plus a stochastic or "random" component, reflecting unobservable variations in taste and unobserved attributes of the choices.

This approach led to the use of the multinomial logit model for analysis of discrete choices. In this model, the probability of a particular choice is a function of the utility of that choice relative to the utility of all choices. Utility is assumed to be a linear function of a series of attributes of the choice, each with a coefficient that reflects the relative importance of that attribute. In travel behavior research, the model is usually estimated based on observed choices for a sample of the population. The utility function usually includes socioeconomic characteristics as well as attributes of the choices to account for differences in tastes across the sample. In more recent applications of this model, the coefficients of the attributes in the model are treated as random variables, varying either for different segments of the population or

continuously over the population, to reflect variations in taste for the observed attributes (Bhat and Koppelman 1999).[1]

This approach provided the foundation for a significant improvement over previous forecasting models, which lacked a foundation in behavioral theory. As argued by Domencich and McFadden (1975):

> We define a behavioral model as one which *represents the decisions that consumers make when confronted with alternative choices*… In other words, the model must attempt to describe the causal relationships between socioeconomic and transport system characteristics, on the one hand, and trip-making on the other. It is necessary for the model to explain why travel decisions vary as conditions change… In short, only by explaining the causal relationships can the model be used to forecast the effects of future changes in the performance of the transportation system. Otherwise, the model will simply replicate the effects of the transportation system that existed when the model was originally calibrated.

However, the focus on the goal of forecasting rather than understanding travel behavior tended to limit the variables included in the models as factors influencing the utility of different choices to those that can also be forecast rather than to the larger set of variables that researchers believe might affect travel behavior. McFadden and others recognized the importance of the perceptions and attitudes of individuals, for example, but argued that such factors cannot be forecast and so should be excluded from forecasting models. They also recognized the importance of detailed attributes of alternative travel choices, though even today forecasting models incorporate relatively few attributes. They further recognized the relationships between different short-term travel choices (e.g., choice of mode and choice of destination) and between short-term travel choices and long-term choices about auto ownership, residential location, and job location; such relationships have sometimes been accounted for in more complex models, as discussed in Chapter 4. Thus, although these issues are usually not addressed in travel demand forecasting models, the framework fully supports their consideration.

For example, in travel demand forecasting models, utility maximization generally equates to the minimization of monetary cost and/or travel time. The concept of generalized cost, however, broadens the range of factors incorporated into the model as potentially important determinants of the utility of different options. Generalized cost can be operationalized as a linear sum of attributes, each with a weight reflecting its importance. Besides standard measures of cost, including out-of-pocket monetary costs and travel time, generalized costs can include such factors as "comfort" and "convenience"—anything that contributes to the disutility (or takes away from the utility) of the trip. In application, this concept has been limited to attributes that are relatively easy to measure. Ideally, the attributes included would expand to those that can be accurately and objectively measured, that are intuitive and have some plausible connection to decisions, and that contribute to the explanatory power of statistical models (Goodwin and Hensher 1978).

While the utility-maximizing framework has proved useful in efforts to forecast travel behavior, its usefulness as a framework for understanding physical activity behavior is as yet largely untested. In this framework, the first step is to define the choice of interest, for example, a decision to walk to the store on a particular occasion or a more general decision to walk when

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[1] Thanks to Patricia Mokhtarian for clarifying this point.

possible, and to define the relevant set of possible choices, a task that is not always as straightforward as it seems. For example, for the decision to walk to the store on a particular occasion, the choice might be which mode to use (e.g., with a choice set of walk or drive) or it might be where to walk (e.g., to the store or around the block) or it might be whether to walk or do something else (e.g., hang out at home or drive to the gym). The next step is to define the relevant attributes of the different choices in sufficient detail. For walking, generalized cost broadly defined to include comfort and convenience factors is probably more relevant than travel time or distance alone, and perceived time and cost may be more directly related to travel choices than actual time and cost. The choice to walk is not as simple as it might seem—and may be significantly more complicated than the choice to drive. Choices about other forms of active travel and other kinds of physical activity are likely to be similarly complicated.

The usefulness of travel behavior theory in understanding the choice to use non-motorized modes or to participate in physical activity more generally thus depends on significant changes to the way in which this theory has been applied to the task of forecasting travel behavior, largely for motorized modes. With the necessary changes in its application, this theory provides a useful explanation of the mechanism by which the built environment might influence physical activity, namely through the process of utility maximization. This quality, which is less evident in other theories reviewed below, is perhaps its greatest strength. With respect to the key variables, the utility maximizing framework requires the conceptualization of physical activity behavior as a choice, and it provides a theoretically sound basis for conceptualizing the built environment, as discussed toward the end of this chapter. Finally, this theory suggests the importance of a broader conceptual model, one that considers the relationships between different choices and the possibility that choices are conditional on each other, an issue discussed in Chapter 4.

Extensions of Utility Maximizing Theory

Choice theory based on the concept of utility maximization has been extended by travel behavior researchers and others in ways important to fully understanding travel behavior. One early extension was an emphasis on the demand for travel as derived from the demand for activities, called the activity-based approach. A complementary yet seemingly contradictory extension is a focus on the positive utility of travel, that is, the benefits of travel itself, above and beyond the benefits of the activity that travel to a destination enables. Both of these extensions, from within the field of travel behavior research, bear on the development of conceptual models for studying the link between the built environment and physical activity. Extensions from outside the field of travel behavior research also offer potentially important theoretical insights into the link between the built environment and physical activity; these extensions include the concepts of experienced utility and variety seeking.

Activity-Based Approach

The activity-based approach to travel behavior research emerged not long after the adoption of a utility-maximizing framework. Although the activity-based approach first offered an alternative to a strict utility-maximizing framework, in application the two have mostly merged. In developing the activity-based approach, researchers offered several important extensions to (or criticisms of) the utility-maximizing framework: the relevance of uncertainty, the importance of

habit and thresholds, the role of constraints, and the influence of levels of adequate information and knowledge (Goodwin and Hensher 1978). As Goodwin and Hensher (1978) noted, "The point is that rationality is a more complex concept than it has often been given credit for."

The activity-based approach takes as its starting point the assumption that the demand for travel is derived from the demand for activities. This assumption led to a change in focus for researchers, from understanding choices about travel to understanding choices about activities. The relationship between these choices works both ways: the choice of activities determines the demand for travel, but expected costs of travel may influence the choice of activities: "The idea of transport as a derived demand implies a simple trade-off between the advantages or benefits to be derived from being at a destination and the disadvantages or costs involved in traveling to that destination" (Goodwin and Hensher 1978). The derived nature of travel demand had been acknowledged by McFadden (1974) as well: "Travel is not normally an end objective of the consumer, but rather a concomitant of other activities such as work, shopping, and recreation." As a result, to understand travel patterns, it is necessary to understand activity patterns.

The shift to a focus on activity choices rather than travel choices meant a new perspective on travel behavior and led researchers to new assumptions about travel behavior (Table 2-1). The new assumptions didn't mean that utility-maximizing framework was dropped—researchers continued to see this framework as useful, but argued that "departures from the simple economic definition of rationality should be explicitly recognized" (Goodwin and Hensher 1978). A body of work from the United Kingdom provided an alternative approach to understanding and analyzing travel behavior, although forecasting was still the primary aim of this work (Jones, Dix et al. 1983). In this work, researchers analyzed travel in a holistic way, looking at patterns of activities over the day and the interactions between household members to explain the resulting pattern of travel using a tool called the Household Activity Travel Simulator (HATS). The built environment played a role in this analysis by determining opportunities for and constraints on activity participation and travel. The HATS approach has not been widely used since then. Instead, researchers have fallen back on statistical modeling of choices using the utility-maximizing framework, although the range of choices analyzed now includes activity episode participation and activity episode generation and scheduling, among others (Bhat and Koppelman 1999). Concern with the role of the built environment in explaining travel behavior in this body of work is relatively recent.

This activity-based approach points to several potentially important considerations in applying the utility-maximizing framework to the study of physical activity. One possibility is to distinguish between travel that is derived from the demand for activities and travel that represents an activity in its own right. In the latter case, the choice to walk is not defined as a choice between different travel modes but is instead defined as a choice between different activities. The role of habits, lack of information, and other constraints emphasized in this framework may be particularly important for understanding active travel and other physical activity and should be accounted for in the model. For example, if the choice to walk becomes habitual over time, then the relevant choice to model may not be a daily choice to walk but instead the initial choice to walk or continuing walking. The recent attention to activity scheduling may prove especially helpful in understanding time constraints that limit an individual's ability to choose active travel over motorized travel or to fit other physical activity into her day. The choice to walk may be best conceptualized as a choice as to how to allocated one's time.

Positive Utility of Travel

Recent work by Mokhtarian and Salomon (Salomon and Mokhtarian 1998; Mokhtarian and Salomon 2001; Mokhtarian, Salomon et al. 2001) questions the standard assumption of travel as purely a derived demand. In their work, they provide theoretical arguments and empirical evidence for the notion that travel is sometimes valued as an end in its own right, not simply as a means to a destination. In other words, time spent traveling offers a positive contribution to utility, at least for some people on some occasions. This positive utility can lead to additional travel, as when a family goes on a Sunday drive in the country, or when a commuter chooses a longer route home. In their work, they distinguish between the positive utility of traveling itself, the positive utility of activities one can participate in while traveling (e.g., watching the scenery, listening to the radio, or mentally transitioning between home and work), and the value of the activities one reaches at the end of the trip.

　　The positive utility of travel may be important in understanding the choice to use nonmotorized modes. The standard application of the utility-maximizing model in travel behavior research assumes that travelers will minimize travel time in order to maximize utility. If so, then active travel, particularly walking, will compete with driving only in specific situations where it is faster than driving, such as in a congested city center. But if walking has a higher positive utility than driving in other respects, then the greater travel time is at least partially offset. The enjoyment of walking itself (e.g., the feeling of movement, the exercise of muscles), the enjoyment of activities while walking (e.g., studying the scenery, breathing the fresh air), and the health benefits of walking might add significantly to the utility of the walking choice. These possibilities suggest a further expansion of the factors included in the model as attributes of utility.

Other "Irrationalities"

That individuals do not always act in seemingly rational ways to maximize their utility has been demonstrated by Kahneman and others. This is not to say that individuals are irrational, rather that their rationality is not always so simple. For one thing, "remembered utility," the retrospective evaluation of the outcome of a choice, influences future decisions. If these retrospective evaluations are inaccurate, they may lead to choices that do not maximize utility (Kahneman, Wakker et al. 1997). In another twist, experiments have shown that individuals "…are willing to sacrifice real-time enjoyment for the sake of variety" (Ratner, Kahn et al. 1999). Instead of selecting the option that maximizes utility at the moment, individuals sometimes choose a less-preferred alternative for the sake of variety. What they gain is a more favorable memory of the sequence of choices.

　　These seeming irrationalities may help to explain the link between the built environment and physical activity. For example, memories of a bad walking experience may discourage an individual from choosing walking again, while memories of a good experience may encourage the walking choice. If memories are inaccurate, on the other hand, individuals will choose walking more or less than they would if their memories were accurate. On the other hand, a desire for variety may lead to the choice of walking even though it is less preferred. In this case, the walking experience leads to a revision of remembered utility for walking and may increase the likelihood of choosing walking in the future. Both of these possibilities point to the importance of considering the relationship between choices at different points of time and

suggest a more complex conceptual model for understanding the link between the built environment and physical activity.

Other Behavioral Theories

Health behavior research, including physical activity research, has drawn largely on theories based in the field of psychology. These theories provide useful frameworks for understanding physical activity, including active travel, and might also be useful for understanding travel behavior more generally. These theories can be grouped into two categories, one surrounding the theory of planned behavior, and one surrounding social cognitive theory and its extension to ecological models. Theories in both categories share important similarities in their focus on cognitive processes, and many of the key concepts are similar. They differ from the utility-maximizing framework in that they are more explicit about the specific variables that explain behavior and less explicit about the mechanism by which these variables act on behavior.

The Theory of Planned Behavior

The Theory of Planned Behavior, developed by Ajzen as an extension of the earlier Theory of Reasoned Action developed by Ajzen and Fishbein (Ajzen 1988; Ajzen 1991; Montano and Kasprzyk 2002), focuses on the role of beliefs in explaining behavior. According to Azjen (1991), "It is at the level of beliefs that we can learn about the unique factors that induce one person to engage in the behavior of interest and to prompt another to follow a different course of action."

Azjen distinguishes between behavior beliefs, normative beliefs, and control beliefs, which respectively influence attitudes, subjective norms, and perceived behavioral control. Behavioral beliefs are beliefs about the likelihood of possible outcomes of a behavior; attitudes about a behavior depend on behavioral beliefs about each possible outcome weighted by an individual's evaluation of those outcomes, whether positive or negative. Normative beliefs are beliefs about whether important referent individuals (e.g., a friend, partner, parent, or boss) approve or disapprove of performing the behavior; subjective norms about a behavior depend on normative beliefs for different referent individuals weighted by an individual's motivation to comply with those referent individuals. Control beliefs are beliefs about the likelihood of possible factors that would facilitate or constrain a behavior; perceived behavioral control about a behavior depends on control beliefs for different factors weighted by the perceived power of each factor to facilitate or inhibit the behavior. These factors determine behavioral intention, which together with perceived behavioral control then determine behavior (Figure 2-1).

This theory has proved useful as a framework for conceptualizing, measuring, and identifying factors that determine behavior (Montano and Kasprzyk 2002). By focusing on beliefs, this theory does not posit a significant role for the built environment in explaining physical activity. Where characteristics of the built environment might come into play is in control beliefs, the beliefs an individual holds about the likelihood of possible factors that facilitate or constrain a behavior. For walking, such factors might include the presence or absence of sidewalks or the presence or absence of automobile traffic. In this theory, it is an individual's beliefs—or perceptions—about the existence of these factors, rather than the objective existence of these factors, that explain behavior. The theory also emphasizes attitudes and social norms, factors that are virtually absent from the utility-maximizing framework used in

travel behavior research. Social norms may play an important role in the choice of alternatives to the automobile, not just walking and biking but also transit.

Social Cognitive Theory and Ecological Models

Social cognitive theory, developed by Bandura, explains behavior in terms of reciprocal relationships between the characteristics of a person, the behavior of a person, and the environment in which the behavior is performed (Bandura 1986; Baranowski, Perry et al. 2002) (Figure 2-2). Called "reciprocal determinism," this concept suggests that a simple linear relationship in which characteristics of the person and the environment determine behavior is inadequate. Behavior also influences the environment and the person, and the person and the environment influence each other. This concept does not mean perfect symmetry in the strength of the influences between each pair of components, nor does it mean that the interactions happen simultaneously (Bandura 1986). Bandura (1986) thus reassures researchers that they can examine specific two-way relationships "without having to mount a Herculean effort to study every possible interactant at the same time."

This theory also contributes other concepts potentially important to understanding physical activity behavior (Baranowski, Perry et al. 2002). One important distinction in this theory is between environments, the objective factors external to a person that can affect her behavior, and situations, the mental representation or perceptions of the environment that may affect her behavior. Outcome expectations also play an important role in this theory: individuals learn that outcomes occur as a result of their behavior, then expect them to occur again. This learning can occur through one's own experience in similar situations and the rewards accrued, from observing others in similar situations and seeing what rewards they accrue, from hearing about situations from others, and from one's own emotional and physical responses to the behavior.

The concept of self-efficacy, developed by Bandura, is seen as tremendously important in efforts to understand health behavior. Self-efficacy refers to "the confidence that a person feels about performing a particular activity, including confidence in overcoming the barriers to performing that behavior" (Baranowski, Perry et al. 2002). Bandura (1986) explains this concept as "… people's sense of personal efficacy to exercise some control over events that affects their lives." According to Bandura, perceived self-efficacy is a significant determinant of performance and operates partially independently of underlying skills. In other words, whether one believes she can do something can matter as much as or even more than whether she actually can. An individual can come to know about her own efficacy through what she has attained in prior performances, observing what others have attained through their performances ("vicarious" learning), verbal persuasion and other social influences that convince her that she possesses the necessary capabilities, and through physical responses from which she judges her capabilities.

Social cognitive theory provided a basis for the development of ecological models now increasingly used in physical activity research. Ecological models differ from social cognitive theory in their emphasis on the role of the physical environment, not just the social environment (King, Stokols et al. 2002; Sallis and Owen 2002). These models are explicitly multilevel: typically, they distinguish between the intrapersonal level, the interpersonal level, and the community level of influence, although some versions make further distinctions between levels. The concept of self-efficacy plays an important role at the intrapersonal level. The interpersonal level focuses on the social environment, including the concept of social norms. The community

level refers to the physical environment, from the micro-scale (e.g., the home), to the meso-scale (e.g., the neighborhood), to the macro-scale (e.g., the region and beyond) (King, Stokols et al. 2002). Thus, ecological models emphasize the role of multiple levels of factors in health behavior and the role of multiple types of environmental influences. In addition, Sallis and Owens (2002) note that behavior-specific models are useful, in that different factors influence different behaviors to different degrees. The concept of behavioral settings, the "social and physical situations in which behaviors take place," are also important in understanding the influence of the environment on behavior. The ecological model is seen as an essential guide to the design of effective multilevel interventions to increase physical activity.

Theory on the Built Environment

Although the theories reviewed above provide important frameworks for understanding active travel and other physical behavior, they say little to nothing about specific elements of the built environment (or physical environment more generally) that might influence that behavior (Sallis and Owen 2002) and thus provide little guidance on how to conceptualize this key variable. As I defined it in Chapter 1, the built environment consists of three dimensions: land use patterns, the transportation system, and design. In my definition, land use patterns and the transportation system are functional dimensions of the built environment, while design is an aesthetic dimension that overlays functional aspects of the built environment. Similar definitions are used by Frank, Engelke et al. (2003). Pikora et al. (2003) define four environmental factors. Their "destination" factor is similar to my land use dimension, their "functional" factor is similar to my transportation dimension, and their "aesthetic factor" is similar to my design dimension; they also include a "safety" factor that mostly reflects characteristics of the transportation system.

However, the lack of an agreed-upon conceptualization of "built environment" is apparent in the inconsistent approach to defining and measuring dimensions of the built environment in the empirical studies summarized in Chapter 3. Many studies focus on just one or two of the dimensions I have defined, and these dimensions have been measured in many different ways, largely due to the lack of a guiding theory. Measures of design are most closely tied to theory, whether theory from environmental psychology or urban design (King, Stokols et al. 2002), but design is less often included in studies than land use or transportation. Land use and transportation are more routinely measured, but these measures are based more on intuition or available data than behavioral theory about what aspects of land use and transportation influence physical activity behavior. In this chapter, I offer my own thoughts on a framework for conceptualizing and measuring the built environment.

Design Dimension

Reviews of the environmental psychology and urban design literatures provide some insights into specific aspects of design that might be associated with walking, though little guidance on how to measure these qualities. The fact that so few of the studies summarized in Chapter 3 include measures of design may reflect the challenge associated with quantifying what are rather abstract and subjective qualities of the built environment.

King, Stokols et al. (2002) conclude from their review of these literatures that environmental factors that constrain or decrease physical activity include environmental stressors (e.g., crowding, noise, traffic congestion, community violence and crime), physical features that

reduce sense of defensible space, incivilities that increase neighborhood disorder, high levels of information overload and distraction, and excessive participation in sedentary activities such as Internet use. Similarly, environmental factors that promote physical activity include restorative or stress-reducing features (e.g., water, foliage, vistas, aesthetic elements), prevalence of recreational facilities (e.g., parks, gyms, playing fields, bike trails), high levels of social capital or cohesion among community members, physical features that enhance imageability and legibility, and community-based electronic networks that disseminate information about the health benefits of physical activity.

I have previously reviewed the urban design literature and summarized the aspects of design that might work to encourage or discourage walking according to these theories (Handy 1996c). These characteristics can be divided into those relating to house or building design and those relating to street design. With respect to house design, a common theme in the urban design literature is that better links between the private space of buildings and the public space of the street encourage more street activity and make for a more interesting environment. Design characteristics such as front porches are important as a transition from public to private space (Schumacher 1986), while housing characteristics such as walls, long distances, different levels, and orientation away from the street tend to prevent people from hearing and seeing each other (Gehl 1986). Building types in terms of height, continuity, and solidity may also affect street life (Appleyard 1981). Rappaport (1987) stressed the importance of "adequate complexity levels and adequate interest" in supporting activity in public areas. The urban design literature also suggests that characteristics of the street are an important determinant of street activity. Traffic levels are a particularly important factor, with greater traffic making for a less inviting street environment (Appleyard 1981; Gehl 1986). Characteristics such as slope, width, setbacks, vegetation, barriers, parking, services, and amenities (views and lighting) might also affect street life (Appleyard 1981). The amount of street activity itself may be important because it is self-reinforcing: street life encourages more street life.

In addition to these objective characteristics, the urban design literature provides a long list of street characteristics that can be synthesized into eight perceptual qualities, as listed in Table 2-2, assumed to influence the quality of that street as a place for walking (Winston, Handy et al. 2004). In a current study, Reid Ewing, Ross Brownson, and I are developing objective measures of these qualities for use as independent variables in studies of walking behavior. We hypothesize that together with physical characteristics (such as sidewalks, street widths, etc.) and individual reactions to the environment in terms of perceived sense of safety, sense of comfort, and sense of interest, these perceptual urban design qualities influence the perceived quality of the walking environment and thus walking behavior.

Land Use and Transportation Dimensions

The fact that measures of land use and transportation vary so widely in the studies summarized in Chapter 3 at least in part reflects the lack of an obvious theory on which to define these variables and their measurement. However, travel behavior theory offers a potentially useful framework for developing such measures, and the concept of accessibility, which has been important in travel behavior research, is helpful as well.

Utility maximizing theory says that an individual will select the option, from the available set of options, that provides the greatest net benefits to that individual. This theory indicates that both the set of options available and the characteristics of those options will

influence behavior. When applied to the question of the link between the built environment and physical activity, this theory thus suggests that the built environment should be measured in terms of the set of options and the characteristics of the options for physical activity it provides (Handy 1996b). From this perspective, it is not simply whether a neighborhood is new or old or high-density or low-density that influence physical activity—it is the set of options for physical activity inherent in the built environment of the neighborhood that influence physical activity. In other words, the built environment should be conceptualized and measured in terms of the options for physical activity that it provides.

In models of destination choice formulated using the utility maximizing framework, the characteristics of the available choices are represented by the distance to potential destinations and by the size of destinations; in joint models of destination and mode choice, differences in travel times by mode are also accounted for. In this way, these models describe opportunities in terms of both the kinds of activities found in different locations and the quality of the links between activity locations, in other words, the combined effect of land use patterns and the transportation system. This combined effect equates to concept of accessibility, defined as reflecting both the ease of reaching potential destinations (an "impedance" factor) and the nature of the opportunities for activity found there (an "attractiveness" factor). Thus, as I have argued in the past (Handy 1996b), the concept of accessibility provides a theoretically-sound approach to conceptualizing the built environment for the purposes of studying its impact on travel behavior.

Extending the concept of accessibility to the study of the link between the built environment and physical activity requires attention to specific aspects of land use and of the transportation system that are relevant to different types of physical activity. For active travel, the destination provides a reason for physical activity but is not usually the site of physical activity; the measure should include any destinations to which individuals could be expected to walk or bike, such as a cafe, post office, or shop. For most out-of-home exercise or recreation, the destination is the site of physical activity; in this case, the measure might include destinations such parks, gyms, swimming pools, and other facilities. For walking or biking for exercise, the transportation system is the destination, so to speak, so that the characteristics of the destination and the characteristics of the transportation system are one and the same. In all cases, measures of the transportation system must be differentiated by mode, as the ease of reaching destinations varies depending on the mode of travel.

Measures of accessibility can take many different forms (Handy and Niemeier 1997). Using some formulations, it is possible to include a wide variety of characteristics of both land use patterns and the transportation system in one composite measure by expanding the concepts of "impedance" and "attractiveness" beyond travel time and size of destination, respectively. Another approach is to separately measure the wide variety of characteristics that contribute to accessibility (Handy and Clifton 2001a). The composite approach has the advantage of eliminating problems of mutlicolinearity between more detailed characteristics of the built environment (Cervero and Duncan 2003). The separate-measures approach has the advantage of enabling an assessment of the relative importance of specific characteristics of the built environment in explaining physical activity. In either approach, it is also possible to incorporate aspects of design as well as of land use and transportation. The concept of generalized cost, for example, can be broadened to encompass the kinds of aesthetic qualities emphasized in the urban design literature.

Conclusions

Theory provides the basis for conceptual models, consisting of the behavior of interest and the factors that explain that behavior, the ways in which these variables are defined, and the assumed relationships between them, that researchers use as an essential guide to their efforts. No one theory reviewed here provides a complete framework for understanding the link between the built environment and physical activity. The utility-maximizing framework as applied in travel-behavior research conceptualizes behavior as discrete choices and explanatory factors as the attributes of those choices. Its strength is its focus on the mechanism by which the attributes affect the choice. It does not, however, provide specific guidance on how to think about physical activity behavior as discrete choices or on what attributes might be relevant to those choices. The Theory of Planning Behavior and Social Cognitive Theory, in turn, focus on identifying and defining key psychological and social variables that influence behavior. Their strength is the attention they place on variables such as the attitudes and beliefs of the individual as an explanation for behavior. They do not, however, delineate an explicit mechanism by which those variables influence behavior. Theory on the built environment at this point consists of a loose assembly of ideas about specific characteristics of the built environment that influence behavior in public spaces but is not explicitly a behavior theory.

With further thought, these theories might together add up to complete whole. It is possible for researchers to start with one theory and borrow insights from the others in developing a conceptual model for studying the relationship between the built environment and travel behavior. Researchers using the utility-maximizing framework can look to theory on the built environment to identify potentially important characteristics to include as attributes of the choice of interest and to the Theory of Planned Behavior and Social Cognitive Theory for guidance on attitudes and beliefs that might influence perceptions of attributes and otherwise influence individual assessments of the utility of choices. Researchers using an ecological framework can look to the utility-maximizing framework for insights on the discrete choices that underlie the behavior of interest and may, as a result, consider different conceptualizations of that behavior. Ideas and insights for researchers from each theory reviewed here are listed in Table 2-3 as a starting point.

Both the utility-maximizing framework and the other behavioral theories suggest that the relationship between the built environment and physical activity is not just a simple relationship between these variables, with all other factors exogenous to the model, and that the study of this relationship should be guided by a more complex conceptual model. Two common sets of questions emerge from these theories, although each theory describes the questions in its own terms, that merit consideration in future research:

- Questions about the direction of causality raised by the idea of reciprocal determinism from Social Cognitive Theory and the concern with a possible link between short-term and long-term choices from utility maximizing theory. In both cases, theories suggest the need for a conceptual model that accounts for the role of preferences and for bi-directional relationships between preferences, the built environment, and behavior. Researchers have begun to address these questions, as discussed in Chapter 4.
- Questions about the role of past experience in explaining current behavior, raised by the attention to habit in activity-based research, the idea of "remembered utility" from utility-maximizing theory, the notion of behavioral beliefs from the Theory of Planned Behavior, and

the concept of outcome expectations from Social Cognitive Theory. These questions have not been explicitly addressed in either the travel behavior or physical activity literatures, reviewed in Chapter 3.

REVIEW OF EXISTING STUDIES

Introduction

The fields of travel behavior research and physical activity research have both contributed to the available evidence on the link between the built environment and physical activity. Travel behavior studies have largely focused on automobile travel rather than active travel, but a number of the studies from this literature provide evidence on walking and/or biking. Physical activity studies have focused on total physical activity, with little differentiation of the type or location of that activity, though a few studies focus on walking for exercise and/or transport. In both cases, interest in the role of the built environment in explaining behavior is relatively recent, and in both cases, researchers are still struggling to develop appropriate conceptual models for studying the link between the built environment and travel behavior, including the conceptualization of the key variables and the incorporation of more complex relationships and a broader set of factors into the model.

In searching for studies to include in this review, I relied heavily on recently published reviews of either the travel behavior literature, the physical activity literature, or both (Frank and Engelke 2000; Humpel, Owen et al. 2002; Kahn, Ramsey et al. 2002; Task Force on Community Preventive Services 2002; Saelens, Sallis et al. 2003b). To the studies listed in these reviews, I added studies published after the writing of these reviews, recommended by committee members, cited in other studies, and otherwise available in my files. The review of the travel behavior literature by Saelens et al. included 12 studies that provided evidence of walking and cycling rates as an outcome variable; to this list I added 10 studies, 6 of which seem to have been published after the writing of the review, 1 that is significantly older than the others and may not have turned up in that search, 1 that looked at trips by alternative modes (including transit), and 2 that focused on pedestrian counts at specific sites rather than walking rates for residents, for a total of 22 studies. The review of the physical activity literature by Humpel et al. included 19 quantitative studies of the link between the physical environment and physical activity; I deleted 4 studies from this list that I felt were not relevant to this review and added 13 studies published since 2000 (including 6 published in 2003) for a total of 28 studies. In addition to these studies, summarized in Tables A1 and A2 in the Appendix, I also reviewed descriptive and qualitative studies and a small number of reviews and studies of the impacts of interventions in the built environment on physical activity; the latter are discussed in Chapter 4. I have undoubtedly missed some relevant studies, though I believe I have captured most of them.

It should be noted that all the studies reviewed here but the handful of available intervention studies fall into the category of "least suitable" for assessing the effectiveness of potential interventions according to the criteria used by the Task Force on Community Preventive Services: cross-sectional studies measure exposure and outcome in a single group at the same point in time, creating a potential for significant threats to validity (Briss, Fielding et al. 2000). Beyond this general limitation, none of the studies is without further flaws, at least with respect to the question of the link between the built environment and physical activity (a question

not all were explicitly designed to answer). A detailed evaluation of the quality of execution of each study, using a framework such as that used by the Task Force, was beyond the scope of this review. Instead, I subjectively and unscientifically separated studies into two tiers. Tier 1 studies are correlative rather than comparative (a distinction explained below) and control for at least basic socio-demographic factors. In addition, the measures of the built environment and physical activity used in Tier 1 studies are ones I deem more directly relevant to this review. Among the 22 studies from the travel behavior literature, 7 made it into Tier 1; many of the Tier 2 studies are comparative rather than correlative and several do not control for sociodemographic factors. Among the 28 studies from the physical activity literature, 13 made it into Tier 1; measures of the built environment were problematic in many of the Tier 2 studies. In summarizing the results of the studies reviewed here, I looked at patterns across all studies but gave somewhat greater weight to the findings from Tier 1 studies. In discussing the results, I emphasize specific findings from Tier 1 studies. Studies are grouped by tier in Tables A1 and A2, and the results of Tier 1 studies are highlighted in Tables 3-4 and 3-7, below.

In this chapter, I begin with studies from the travel behavior literature and then turn to the physical activity literature. Within each section, I provide an overview of conceptualization and study design, including the definition of active travel or physical activity variables, built environment variables, and control variables, and a summary of findings on the associations between the built environment and active travel and other physical activity. In each section, I also mention studies other than those formally reviewed that also provide insights into the link between the built environment and physical activity. I end with a summary of the findings across the two literatures and identify apparent patterns in the results produced by these studies. Besides summarizing the findings from the available studies, this chapter focuses primarily on the challenge of conceptualizing and measuring the key variables, the built environment and physical activity. In the next chapter, I focus on the question of "self-selection" and the need for more comprehensive and complex conceptual models that recognize the endogeneity of other factors and in turn create a need for more sophisticated research designs. In the final chapter, I critique various aspects of this body of work as a whole and offer recommendations for future research.

Travel Behavior Literature

Numerous studies from the field of urban planning have examined the link between the built environment and automobile use (Ewing and Cervero 2001), but fewer have focused on the link between the built environment and walking or biking (Saelens, Sallis et al. 2003b). The available studies have come in two waves, a first wave of studies in the 1970s and early 1980s associated with the development of travel behavior theory and improved forecasting models, and a second wave that began in the 1990s in response to a growing interest in the use of land use policies to manage transportation demand. Several authors have provided insightful overviews of the literature on the link between the built environment and travel behavior (Hanson 1979; Handy 1992; Handy 1996a; Crane 2000; Ewing and Cervero 2001; Handy, Boarnet et al. 2002; Frank, Engelke et al. 2003; Saelens, Sallis et al. 2003b).

Conceptualization and Study Design

Not surprisingly, almost all of the studies reviewed in this section focus on active travel, rather than walking or biking for exercise or recreation. More surprisingly, all but 7 of the 22 studies reviewed here did not explicitly draw on travel behavior theory as a basis for the research design. Instead, most studies are driven by questions that emerge from current trends and policy proposals, with most focusing on the new urbanism movement and calls for more traditional design in suburban areas. After reviewing previous empirical findings, these studies offer questions and hypotheses that are largely intuitive, but they stop short of discussing how the built environment factors into the decision making process. Cervero and Radisch (1996), Kitamura et al. (1997), (Kockelman 1997), Greenwald and Boarnet (2001), Bagley and Mokhtarian (2002), and Cervero and Duncan (2003) are the exceptions in making use of the utility-maximizing concept to frame their analyses and in estimating logit models as a way of testing the significance of built environment variables in explaining active travel choices. In another study, I offer a conceptual model for walking that focuses on individual motivations and limitations and on characteristics of the built environment that encourage or discourage walking (Handy 1996c).

All but one of these studies uses a cross-sectional design, examining levels of active travel at one point in time for residents of neighborhoods that differ in their characteristics of the built environment. The reliance on available sources of travel data in most of these studies explains the reliance on cross-sectional design. Only Krizek (2000; 2003), who uses the Puget Sound Transportation Panel, one of the few panel surveys of daily household travel available, provides a longitudinal analysis of changes in active travel associated with the change in built environment that results when a resident moves from one neighborhood to another. For those studies that collect travel data using an original survey (Cervero and Radisch 1996; Handy 1996c; Kitamura, Mokhtarian et al. 1997; Handy, Clifton et al. 1998; Black, Collins et al. 2001; Handy and Clifton 2001b; Bagley and Mokhtarian 2002), the time, cost, and complexity of conducting a panel survey or even multiple cross-sectional surveys may be prohibitive. Studies by Hess et al. (1999) and Moudon et al. (1997) differ from these others in their use of observational techniques to collect data on the number of pedestrians at specific locations.

The studies are of two basic types: comparative or correlative (Table 3-1). Comparative studies use a simple classification scheme for the explanatory variable. As described below, neighborhoods are generally categorized into one of two types. These studies usually focus on a limited number of neighborhoods, though some studies classify neighborhoods throughout the region. The analysis then consists of a comparison of the dependent variable across the neighborhoods. Studies that use aggregate data (e.g., an average value for the neighborhood) do not provide statistical tests of the significance of the differences between neighborhoods. Studies that use disaggregate data (e.g., values for individual households) generally use t-tests or analysis of variance to test the significance of the differences between neighborhoods. Correlative studies, on the other hand, use continuous measures of the built environment and/or multiple categorical measures as explanatory variables and tend to look at a larger number of neighborhoods or at the region as a whole. Most of these studies estimate regression models for continuous measures of active travel, but a subset instead estimate logit models for the choice of active travel modes, and one study uses simultaneous equations modeling to address endogeneity bias (Bagley and Mokhtarian 2002), as discussed in Chapter 4. The more sophisticated approaches provide a stronger basis for inferring causality between the built environment and active travel.

The split of studies into these two types can be explained by the nature of the available data and by the relative homogeneity of the built environment within a particular neighborhood. Studies that use data from regional travel diary surveys have data for a sample of households spread throughout the metropolitan region, with at most a few households within any particular neighborhood. They tend to rely on existing data to create measures of the built environment measured at the level of the neighborhood. Studies that use original surveys to collect data on travel behavior in selected neighborhoods have the opportunity to collect more detailed data on the built environment in these neighborhoods, although the differences in characteristics of the built environment within the neighborhood may be relatively slight. These studies either compare neighborhoods by type or use household-level measures of the built environment, either perceptions or objective measures. More recent studies tend to fall into the correlative category, reflecting the greater power of this approach to discern the relationships between the built environment and active travel. So far, no regionwide studies use household-level rather than neighborhood-level measures of the built environment, although geographic information systems (GIS) now enable such an approach.

Active Travel Measures Measures of active travel, the dependent variables, differ between these studies. The studies are about evenly split between those that look at walking trips (Cervero and Gorham 1995; Frank and Pivo 1995; Handy 1996b; McNally and Kulkarni 1997; Handy, Clifton et al. 1998; Black, Collins et al. 2001; Greenwald and Boarnet 2001; McCormack, Rutherford et al. 2001; Krizek 2003) and those that look at non-motorized trips, including both walking and biking (Hanson and Schwab 1987; Parsons Brinckerhoff Quade & Douglas 1993; Ewing, Haliyur et al. 1995; Cervero 1996; Kitamura, Mokhtarian et al. 1997; Kockelman 1997; Bagley and Mokhtarian 2002). Three studies look at walking and biking trips separately (Friedman, Gordon et al. 1994; Cervero and Duncan 2003; United States Environmental Protection Agency 2003). Two studies look at non-automobile modes, including transit, walking, and biking (Cervero and Radisch 1996; Krizek 2000); because transit use generally involves a notable amount of walking or biking, these studies have also been included here.

Most studies use either the number of walking (or nonmotorized) trips per person or household or the share of trips made by walking (or nonmotorized modes). A few studies estimate logit models of mode choice; in this case, the dependent variable is the probability of choosing walking or choosing a non-motorized mode (Cervero 1996; Cervero and Radisch 1996; Kockelman 1997; Cervero and Duncan 2003; United States Environmental Protection Agency 2003). The studies by Moudon et al. and Hess et al. count the number of pedestrians at different locations, rather than measuring walking trips by residents (Moudon, Hess et al. 1997; Hess, Moudon et al. 1999). As shown in Table 3-2, these studies also differ in the purpose of trips they examine: trips from home to work (5 studies), to shopping (7 studies), to school (1 study), and all trips (19 studies). The emphasis on home-based trips is consistent with an interest in the impact of residential neighborhood design on travel behavior. In two studies, I look at strolling trips from home as well as walks to the store (Handy 1996c; Handy 1996b; Handy, Clifton et al. 1998).

Built Environment Measures Measures of the built environment, the explanatory variables, also vary significantly from study to study but fall into five general categories (Table 3-3). Most correlative studies use more than one measure of the built environment, while the comparative studies use a classification of neighborhood type.

Several studies focus on measures of land use, particularly population and/or employment density (Parsons Brinckerhoff Quade & Douglas 1993; Frank and Pivo 1995; Greenwald and Boarnet 2001; United States Environmental Protection Agency 2003). Another measure of land use used by a number of studies is land-use mix (Frank and Pivo 1995; Kockelman 1997). Cervero and Duncan (2003) combine a measure of mixed-use entropy with a index of the balance between employed residents and total jobs and between employed residents and retail/service jobs to create a land-use diversity factor. Although most studies look at density or land-use mix in the neighborhood, or the origin of the trip, several distinguish between density and land use mix for the origin and for the destination area (Frank and Pivo 1995; Kockelman 1997; Cervero and Duncan 2003). Kockelman (1997) also specifies a measure of the balance of land uses, using an entropy measure. Kitamura et al. (1997) use a simple indicator of mixed-use or not and high density or not. Cervero (1996) uses indicators of single-family housing within 300 feet and multifamily housing of various densities within 300 feet as an indicator of land use in the neighborhood.

Other studies focus on measures of the transportation system. The Pedestrian Environment Factor used by Parsons Brinkerhoff (1993) is a subjective rating of ease of street crossing, sidewalk continuity, street connectivity, and topography and was measured for zones throughout the region by trained observers. Greenwald and Boarnet use this measure, as well as percent of network that is a grid, median walk distance, and median walk speed (Greenwald and Boarnet 2001). Kitamura et al. (1997) use indicators for the presence of sidewalks and of bike paths. The U.S. Environmental Protection Agency study (2003) uses percent of streets with sidewalks, average sidewalk width, street density, and the pedestrian environment factors. Cervero and Duncan (2003) combine characteristics such as square meters per block within 1 mile and share of dead-ends, three-way, four-way, and five- or more-way intersections within 1 mile into measures of pedestrian and bicycle design at both the origin and the destination of the trip.

An alternative approach is to use measures of accessibility, reflecting both the locations of land uses and characteristics of the transportation system. Some of these studies measure the distance to particular destinations. McCormack and Rutherford et al. (2001) use straight-line distance to the nearest commercial street, while Handy and Clifton et al. (1998) use network distance to the nearest store. Kitamura et al. (1997) use reported distance to the nearest bus stop, rail station, grocery store, gas station, and park. Black et al. (2001) use distance to the school and the square of this distance, to account for a non-linear relationship. Cervero (1996) uses a variety of measures that might be considered accessibility measures: residence in central city, highway/railroad/airport within 300 feet, public transit adequate in neighborhood, distance from home to work.

Other studies focusing on accessibility as an explanatory variable use a cumulative opportunities measure, which counts the number of potential destinations or amount of activity of the specified type within a particular distance. Hanson and Schwab (1987) use home-based accessibility and work-based accessibility, measured based on the sum of the number of establishments within 0.5-km intervals from home weighted by distance. In one study, Cervero (1996) uses the presence of a commercial or non-residential building within 300 feet and the presence of a grocery or drug store between 300 feet and 1 mile. In a more recent study, Cervero and Duncan (2003) measure employment accessibility as the number of jobs within 1 mile of the origin for walking and within 5 miles of the origin for biking. The Parsons Brinkerhoff (1993) study uses transit access to employment, measured as the number of jobs within 30 minutes by

transit. Krizek (2003) uses measures of neighborhood accessibility that combines density, land use mix, and block size, and regional accessibility, based on a gravity measure. Kockelman (1997) uses measures of accessibility by purpose and mode in both the origin zone and the destination zone; for walking for nonwork trips, the measure counts sales and service jobs within 30 minutes by walking.

Few studies include measures of design. Kitamura et al. and Handy et al. both used perceived measures of the environment. Handy et al. (1998)used measures of perception of safety, shade, houses, scenery, traffic, people, stores, walking incentive, and walking comfort. Kitamura et al. (1997) included perceptions of six qualities of the residential neighborhood: no reason to move, street pleasant for walking, cycling pleasant, good local transit service, enough parking, and problems of traffic congestion. The EPA study (2003) uses commercial floor area ratio, that is, the ratio of square footage in buildings to the area of the lot on which the building sits, a characteristic that also be considered a measure of design.

At least one study includes characteristics of the physical environment beyond characteristics of what I've defined here as the built environment. Calling them "constraints/deterrents," Cervero and Duncan (2003) include slope, rainfall on the day of the trip, darkness at the time of the trip, and a variable reflecting the proportion of the households in the area with low-income in their study of the choice to walk or bike. Such characteristics have sometimes been included in studies of physical activity, as described below, but have not been routinely incorporated into studies of active travel. The Pedestrian Environment Factor (PEF) used in studies of Portland does include a rating of topography, however (Parsons Brinckerhoff Quade & Douglas 1993; Greenwald and Boarnet 2001). Such differences reflect the overall inconsistency between studies in the conceptualization of the physical environment.

Nine of the studies classify neighborhoods by type rather than measuring specific characteristics of urban form (see Table 3-2). Although these studies use different labels for the neighborhood categories, they generally differentiate between pre-World War II neighborhoods and post-World War II neighborhoods. These two categories are labeled "traditional" and "suburban" neighborhoods (Friedman, Gordon et al. 1994; Handy 1996b), "transit" and "automobile" neighborhoods (Cervero and Gorham 1995), "traditional development" and "planned unit development" (McNally and Kulkarni 1997), "pedestrian-oriented" and "automobile-oriented" neighborhoods (Cervero and Radisch 1996) and "urban" and "suburban" neighborhoods (Moudon, Hess et al. 1997; Hess, Moudon et al. 1999). Most studies classify neighborhoods based on judgment, confirming the classification by comparing differences in various characteristics; others measure various characteristics first, then classify neighborhoods based on those measures. For example, McNally and Kulkarni (1997) used the ratio of cul-de-sacs to total intersections, the ratio of four-way to total intersections, intersections per acre, the ratio of access points to development perimeter, commercial area to total area, and population density to classify neighborhoods. Krizek (2000) combines measures of density, land use mix, and average block area into a LADUF (less automobile dependent urban form) rating and then classifies neighborhoods as high, medium, or low. Ewing et al. (1995) simply looks at different neighborhoods, describing their characteristics but without labeling them by type. Bagley and Mokhtarian (2002) use measures of both traditional qualities and a suburban qualities to characterize neighborhoods; these factors were derived using principal components analysis from 18 characteristics (Bagley, Mokhtarian et al. 2002).

Control Variables The control variables used in these studies are largely limited to those included in most regional travel diary surveys: household size, workers per household, adults per household, income (household or individual), auto ownership (availability of a vehicle, number of vehicles, vehicles per driver, or only one car), possession of driver's license, gender, employment status, age, and race. Most studies include a subset of this list (see Table A-1 in the Appendix). Some studies add other control variables: household type (Frank and Pivo 1995; Handy 1996b; McCormack, Rutherford et al. 2001), possession of bus pass (Frank and Pivo 1995), professional occupation (Kockelman 1997), number of children (Krizek 2003) or presence of children (Handy, Clifton et al. 1998; Greenwald and Boarnet 2001), having a pet that needs walking (Handy, Clifton et al. 1998), number of years living in the region (Kitamura, Mokhtarian et al. 1997), education level (Kitamura, Mokhtarian et al. 1997), whether living in single-family home (Kitamura, Mokhtarian et al. 1997), and whether a full-time homemaker (Black, Collins et al. 2001). Greenwald and Boarnet (2001) included the square of income to reflect possible non-linear relationships. The comparative studies do not directly account for control variables, but generally try to match neighborhoods by income (Cervero and Gorham 1995; Handy 1996b) or use multivariate analysis of variance techniques to compare the differences between neighborhood to the differences between categories for other variables, such as household type (Handy 1996b) or income level (McNally and Kulkarni 1997).

The studies by Kitamura et al. (1997)and Bagley and Mokhtarian (2002) are the only ones reviewed here that incorporates attitudinal factors as control variables. The survey used in both of these studies included 39 attitudinal statements, for which respondents indicated their degree of agreement or disagreement on a five point scale. Using factor analysis, they reduced these 39 items to eight attitudinal factors reflecting both feelings about transportation and more general lifestyle preferences: pro-environment, pro-transit/ridesharing, suburbanite, automotive mobility, time pressure, urban villager, TCM (transportation control measure), and workaholic. Handy et al. (1998) include a measure of the frequency of strolling in the model of the frequency of walking to the store; this variable can be interpreted as a measure of the propensity to walk.

Associations

The vast differences in these studies in study design, dependent variables, explanatory variables, and control variables mean that any attempt to summarize across studies is rather suspect. Nevertheless, it is instructive to look at the patterns of findings for different measures of active travel and for different measures of the built environment, for both Tier 1 and Tier 2 studies (Table 3-4). These patterns can be summarized as follows:

- The findings for land use variables are relatively consistent. Population and density measures are significantly correlated with walking and/or biking in most studies that test these measures. In the study by Frank and Pivo (1995), employment density at the origin and population density at both the origin and the destination were significant. In the study by Kockelman (1997), density measures were not significant, but measures of land use mix in the origin and destination zones were. Other measures of land use showed mixed results.
- The findings for measures of the transportation system were not so consistent. Two studies found significant correlations between walking and the pedestrian environment factors. Other variables with a positive effect on walking or nonmotorized travel were the percent of the street network that is a grid and the presence of sidewalks. The presence of bike paths, the

presence of parking problems at the school, sidewalk widths, and street density were not significantly correlated with walking or biking.

- The findings for accessibility measured as the distance to the nearest destination of different types showed negative correlations with walking or nonmotorized travel, as theory would predict, for most studies. Kitamura et al. found insignificant relationships for distance to several specific destinations, but this result might be explained by the use of total travel, rather than travel to these specific destinations, as the dependent variable.

- The findings for other measures of accessibility mostly show positive associations with walking or nonmotorized travel. Again, this result is consistent with theory: higher accessibility means more destinations are nearby, making nonmotorized travel more feasible. In a study by Cervero (1996), the finding that a grocery store or drug store within 300 feet and 1 mile from home is associated with less nonmotorized travel suggests that residents are likely to choose driving for destinations at this distance. The lack of significance of the accessibility measures in the study by Krizek (2003) is not readily explained.

- Design variables are largely insignificant in the few studies that include measures of design. However, the lack of significance of design variables in these studies may reflect inadequate measures of design rather than the insignificance of design to walking. The differences in approach to measuring design and the lack of clear theory on what to measure with respect to design point to a need for further attention to this dimension of the built environment.

- The comparative studies almost all show higher levels of walking and nonmotorized travel in traditional/transit/walkable neighborhoods than in suburban/automobile neighborhoods. Two studies, however, found insignificant differences, though these results depend on the specific neighborhoods chosen and may reflect regional differences in walking as well. Given the wide variability in what exactly constitutes a traditional/transit/walkable neighborhood, these results are hard to interpret.

Other Evidence

A series of studies by the Federal Highway Administration (1992) provides qualitative evidence of elements of the built environment that either promote or discourage bicycling and walking. One study explored factors that influence the decision to bicycle or walk for utilitarian trips (rather than for exercise). This study concluded that long distances, poor traffic safety, and a lack of routes for bicyclists were key impediments to bicycling. Key impediments for walking included long distances, too little time, the hassle of carrying things, and fear of crime; few participants identified inadequate facilities as an impediment to walking. A recent survey of bicyclist and pedestrian attitudes and behaviors asked adults age 16 or older about their satisfaction with the design of their communities as it influences safety: overall, 50 percent were satisfied for bicycle safety and 74 percent were satisfied for pedestrian safety, but somewhat higher shares of respondents who had bicycled or walked recently expressed satisfaction, suggesting that perceptions of safety are associated with bicycling and walking (National Highway Traffic Safety Administration and Bureau of Transportation Statistics 2003).

Consistent with these results, a recent comparison of walking and bicycling between the United States and European countries ties the considerably lower levels of active travel in the United States to poor safety conditions (Pucher and Dijkstra 2003). In 1995, the share of trips by walking and bicycling in Germany was five times the share in the United States and the share in the Netherlands was 6.5 times the share in the United States. Dramatic differences were seen in

all age groups, although the differences were greater for older segments of the population. The differences between the United States and European countries can be attributed to longer trip distances in the United States, low cost, and ease of auto ownership and use, and policies "that make walking and cycling inconvenient, unpleasant, and, above all, unsafe." Rates of injuries and fatalities per trip and per kilometer traveled for bicyclists and pedestrians are many times higher in the United States than in Germany and the Netherlands: pedestrian injury rates per kilometer traveled are 3 and 7 times higher, respectively, and bicycle injury rates are an astounding 15.6 and 62.5 times higher. The authors conclude that the built environment in the United States contributes to a situation where walking and bicycling are "dangerous ways of getting around American cities" and thus helps to explain the low levels of active travel in the United States.

Physical Activity Literature

The physical activity literature can be divided into two basic categories: correlative studies and intervention studies. Correlative studies are cross-sectional, examining the relationships between the dependent variable and explanatory variables at one point in time. Intervention studies involve a pre-test/post-test approach: participants are surveyed prior to and following a planned intervention in order to test the impact of the intervention on physical activity; control groups are generally used in these studies. I review the correlative studies here and the intervention studies in the following chapter. Several authors provide overviews of the literature on the link between the built environment and physical activity (Centers for Disease Control and Prevention 2001; Dunn and Blair 2002; Kahn, Ramsey et al. 2002; Task Force on Community Preventive Services 2002; Saelens, Sallis et al. 2003b).

Conceptualization and Study Design

A total of 28 cross-sectional studies and one prospective study were reviewed for this report. Nearly all studies draw on the Theory of Planned Behavior (e.g., Giles-Corti and Donovan 2002a), Social Cognitive Theory (e.g., King, Castro et al. 2000), or Ecological Models (e.g., Sallis, Johnson et al. 1997) as a basis for research design and the conceptualization of variables. The source of data for these studies is about equally split between large national and state surveys conducted for multiple purposes and original surveys designed and conducted specifically for that study. In several cases, multiple articles are based on the same survey, although different analyses are reported. Most studies rely on reported measures of physical activity and of the built environment. Saelens et al. (2003a) used accelerometers in addition to self-reported measures of physical activity from a mail survey. Six studies used objective measures of the built environment in place of or in addition to perceived measures and three used objective categorization of places, as discussed below. In this literature, the measurement of physical activity is well-established, but the measurement of the built environment is not (Sallis and Owen 2002).

These studies use a wide range of measures of physical activity, falling into the categories of measures of walking, measures of other physical activity, and measures of total physical activity (Table 3-5). Walking is measured dichotomously (yes/no) or continuously (days or minutes per week), and is sometimes measured for all purposes, sometimes specifically for exercise, recreation, or transport. Other measures of walking include walking at recommended

levels, use of walking trails, and increased use of walking trails. Measures of other physical activity tend to focus on the intensity of physical activity, differentiating between moderate and vigorous. Other measures include leisure time physical activity other than walking, participation in recreational activities, use of recreational facilities, and use of a bikeway. The most common measure of total activity is a dichotomous distinction between active and inactive or a measure of meeting recommended levels of activity (yes/no); one study measures total minutes of physical activity in a week (Saelens, Sallis et al. 2003a) and another measures minutes of different types of physical activity in a week (sitting, walking, moderate-intensity activities, vigorous-intensity activities) (De Bourdeaudhuij, Sallis et al. 2003). Studies that use dichotomous variables for physical activity use logistic regression to test the significance of explanatory variables and calculate odds ratios to show the magnitude of significant relationships. It should be noted that logistic regression is identical to the binary logit model used in travel behavior research, although in the physical activity literature the analysis is not conceptualized or interpreted as a discrete choice model.[2] In these studies, the analysis provides a statistical test of the association between the independent and dependent variables and an evaluation of appropriateness of the conceptual model. In contrast, discrete choice models of travel behavior are often used in addition as predictive models of behavior.

The measures of the built environment used in these studies also vary widely and differ considerably from those used in the travel behavior literature (Table 3-6). Most studies use perceived measures, as reported by survey respondents, rather than objective measures, as calculated using GIS or as documented by trained observers. Different types of measures are used within each of these categories. Within the perceived measures category, few studies use measures of land use, with most focusing on measures of accessibility or convenience to facilities or opportunities for exercise or on neighborhood characteristics or on both. Several studies make use of a list of neighborhood characteristics apparently first developed by Sallis et al. (1997) or variations of this list. The most widely used version of the list includes transportation, design, and safety characteristics: sidewalks, heavy traffic, hills, streetlights, dogs unattended, enjoyable scenery, frequently see others exercising, high levels of crime. Several studies include measures of perceived safety, and many included reported measures of access to exercise equipment in the home. In general, the concept of the physical environment in these studies is defined more loosely than it is in the travel behavior literature, encompassing characteristics of the built environment as well as people-related characteristics (such as seeing other people exercising and perceptions of safety) and even the weather.

Six studies used objective measures of the built environment in place of or in addition to perceived measures. Brownson et al. (2000) calculated several measures related to the character of walking trails and the nature of access to them, including the distance to the trail. Similarly, Troped et al. (2001) used GIS to estimate measures of distance to the trail, hills on the way to the trail, and the need to cross a busy street to get there. In three separate articles, Giles-Corti et al. use measures of accessibility to built facilities (sport and recreation centers, gyms, swimming pools, tennis courts, and golf courses) and to natural facilities (attractive open space, beach, river) (Giles-Corti and Donovan 2002a; Giles-Corti and Donovan 2002b; Giles-Corti, Macintyre et al. 2003). They calculated gravity-style accessibility measures for each type of facility, calibrating the distance-decay parameter separately for each and using network distances in the calculation. The accessibility values were then recoded by quartile. These analyses also used measures of the functional environment, including sidewalks and shops visible on the street, and

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[2] Thanks to Patricia Mokhtarian for clarifying this point.

of the appeal of the environment, based on type of street and street trees, as observed by the survey interviewers for the residential location of participants. Craig et al. (2002) used observations of 18 characteristics of the neighborhoods in the study and then used hierarchical linear modeling to create an ecologic score for each neighborhood. Four studies used objective categorizations of places of one sort or another: year when house was built (Berrigan and Toriano 2002), population range of community (Brownson, Housemann et al. 2000), city versus suburb versus small city (Ross 2000), and high-walkability versus low-walkability neighborhood (Saelens, Sallis et al. 2003a).

Many of these studies also include measures of the individual and the interpersonal environment, following the Theory of Planned Behavior and Social Cognitive Theory. Giles-Corti et al. (2002a), for example, include several individual cognitive variables: attitude toward trying, attitude toward the process of trying, subjective norm, frequency of trying in the last three months, perceived behavioral control, behavioral skills used in the last month, intention to try in the next 2 weeks; social environmental variables in this study include club membership, frequency of participation in physical activity by five significant others, and frequency of a significant other doing physical activity with respondent. The study by King et al. (2000), includes health-related variables as well as several psychosocial variables such as perceived barriers, measured on a five-point frequency scale: presence of others who discouraged physical activity, self-consciousness about physical appearance, fear of injury, lack of time, feeling too tired to be physically active, lacking a safe place to exercise, care-giving duties, poor weather, health problems, and lack of energy to exercise. Most studies include standard sociodemographic control variables such as age, gender, race/ethnicity, education level, marital status, employment status, and income.

Associations

Given differences in the measures of physical activity and measures of the built environment used in these studies, comparisons of results are difficult (Table 3-7). Many built environment variables are significant in some studies but not significant in others, most likely reflecting differences in the specific type of physical activity measured and the population and setting studied. Nevertheless, a few notable patterns emerge from a review of the findings. Measures of accessibility have strong positive associations with total physical activity, although the associations with walking and with other forms of physical activity are less certain. On the other hand, perceived neighborhood aesthetics, reported presence of sidewalks, and objective measures of neighborhood characteristics have strong positive associations with walking. These results make sense: if walking takes place mostly in the vicinity of home, then the quality of the walking environment in the neighborhood may be influential; but if total activity depends on more vigorous forms of exercise, then access to facilities for exercising will be important. Other reported neighborhood characteristics do not show consistent associations with walking or total physical activity, although neighborhoods categorized by type generally show statistically significant differences in physical activity. Not surprisingly, distance to a walking trail or bikeway is strongly negatively associated with use of the facility.

Summary

Despite differences in theoretical frameworks, conceptualization, research designs, measurement, and methods (Table 3-8), studies from the travel behavior literature and the physical activity literature provide relatively consistent and convincing evidence of an association between the built environment and physical activity. Saelens et al. (2003b) conclude from their review that studies from the travel behavior literature "demonstrate consistent associations of neighborhood walkability factors with walking and cycling for transport." Humpel et al. (2002) conclude from their review of the physical activity literature, "Physical environment factors have consistent associations with physical activity behavior." These conclusions echo earlier ones by Sallis et al. (1998) who reviewed the physical activity literature: "Findings from numerous cross-sectional studies support the ecological hypothesis that environmental variables and physical activity are correlated." Frank and Engleke (2000) conclude that, "on balance, the literature supports the hypothesis that urban form variables influence levels of walking and bicycling."

But these studies together provide less convincing evidence of what characteristics of the built environment are most strongly associated with physical activity. The largely consistent findings for density and neighborhood type support the hypothesis that the built environment influences active travel, but density and neighborhood type are relatively coarse measures of the built environment. The mixed results for more detailed measures of the built environment suggest that our understanding of what exactly it is about certain places that leads to higher levels of physical activity is limited. As discussed in the following chapter, even the statistically significant relationships found in these studies do not establish a causal relationship, and the possibility of spurious relationships, in which the associations between the built environment and physical activity are explained by independent associations with one or more other variables, must be considered. Nevertheless, certain patterns emerge from this review that tend to suggest specific relationships between the built environment and physical activity.

Accessibility, measured in various ways, emerges most clearly from both literatures as an important condition for physical activity. Within the public health literature, convenient access to exercise facilities is consistently associated with physical activity (Sallis, Bauman et al. 1998; Humpel, Owen et al. 2002). Within the travel behavior literature, distances to potential destinations had strong negative associations with active travel, while cumulative opportunities and gravity measures of accessibility had strong positive associations. It is notable that in studies that tested the significance of both density and accessibility measures, the accessibility measures were significant but the density measures weren't, suggesting the possibility that density serves as a proxy for accessibility (Kockelman 1997; United States Environmental Protection Agency 2003). Humpel et al. (2002) conclude, "Evidence appears to be accumulating for the importance of accessibility of facilities as an important environmental factor related to physical activity."

The importance of design variables in explaining active travel or physical activity were somewhat more ambiguous, in both literatures. Only three studies in the travel behavior literature included measures of design or aesthetics; Handy et al. (1998) found these variables significant, but Kitamura et al. (1997) did not. In the physical activity literature, many studies included measures of neighborhood design of one sort or another, and both reported and objective measures proved significant in predicting walking. But the composite nature of most of these measures leaves open the question of what aspects of design are most important. A handful of studies provide qualitative evidence on design qualities and other characteristics of the built environment that might influence physical activity (Owens 1993; Corti, Donovan et al. 1997;

Moudon, Hess et al. 1997; Handy, Clifton et al. 1998). Design variables may prove more important for physical activity other than active travel and distance more important than design for active travel (Hanson and Schwab 1987; Handy, Clifton et al. 1998).

Within the travel behavior literature, only Kitamura et al. (1997) and Bagley and Mokhtarian (2002) examine the relative importance of attitudes and characteristics of the built environment in explaining active travel, and they conclude that attitudes are more important. Within the physical activity literature, most studies include a variety of individual and interpersonal measures and most of these conclude that such factors are more important than characteristics of the built environment. Based on such findings, Giles-Corti et al. (2002a) conclude that, "access to a supportive physical environment is necessary, but may be insufficient to increase recommended levels of physical activity in the community." Other studies call into question the absolute necessity of a supportive physical environment, however. For individuals highly motivated to walk, the built environment may not have to provide a high level of support: studies by Moudon et al. (1997) and Handy (1996b; 1996c) found surprisingly high levels of walking in suburban areas rated relatively low in terms of walkability. On the other hand, environments with very low walkability may prove insufficient even for relatively motivated individuals, leading to "latent demand" for walking (Moudon, Hess et al. 1997).

Several studies from both literatures point to the role of automobile ownership as a mediating variable in the relationship between the built environment and physical activity: the built environment influences automobile ownership, which in turn influences active travel and other forms of physical activity. Giles-Corti and Donovan (2002a), for example, found that individuals without access to an automobile for personal use were over four times as likely to walk for transportation in the past 2 weeks as individuals who always have access to a car, and even individuals who sometimes have access to a car were 3.5 times as likely to have walked for transportation. Many of the travel behavior studies include automobile ownership (measured as availability of a vehicle, number of vehicles per household, or number of vehicles per driver) as control variables. Several studies report negative associations between walking and automobile ownership (Cervero 1996; Cervero and Radisch 1996; Kockelman 1997; Greenwald and Boarnet 2001), although one study found auto ownership insignificant in explaining walking (Kitamura, Mokhtarian et al. 1997). Analysis by Cervero (1996) supports the possibility of auto ownership as a mediating variable: land use variables were statistically significant in a model of auto ownership levels. A review of the separate literature on automobile ownership would shed further light on this possibility.

THEORY AND EVIDENCE ON CAUSALITY

Introduction

Although the studies reviewed in Chapter 3 show significant correlations between certain characteristics of the built environment and certain types of physical activity, the use of simple conceptual models that assume that a walkable environment has a causal effect on walking levels combined with cross-sectional research designs leaves many unanswered questions about the causal mechanisms involved. In particular, the possibility of "self-selection" must be addressed. It is possible, for example, that individuals who prefer to walk more choose to live in neighborhoods more conducive to walking. Similarly, it is possible that individuals who like to

exercise choose to buy exercise equipment for the home. In both cases, the preference to walk or exercise explains the access to opportunities to walk or exercise that are then associated with higher levels of walking or exercise (Figure 4-1). Access to opportunities still plays a role, though now this variable is endogenous rather than exogenous to the model. This section reviews theoretical perspectives on the issue of causality, offers possibilities for a more comprehensive and complex conceptual model, presents available evidence, and discusses possible research designs to address the question of causality.

Theoretical Perspectives

Travel behavior theory and theories used in physical activity research point to the importance of relationships between longer-term choices or behavior and shorter-term choices or behavior. Work by Domencich and McFadden (1975) and others on travel behavior theory recognized that daily choices about travel are related to choices about auto ownership, residential location, and job location. Bandura (1986) pointed out that interactions between the person, the environment, and the behavior do not happen simultaneously but can play out over time. But while using these theoretical frameworks to study a specific choice or behavior, as the studies reviewed in the previous chapter have done, is relatively straightforward, using them to study the relationships between choices or behaviors over time is not.

     In the field of travel behavior, researchers have sometimes made use of series of linked choice models to address this issue. Ben-Akiva and Atherton (1977), for example, defined long-range decisions as employment location, residential location, and housing type; medium-range decisions as automobile ownership and mode to work; and short-range decisions as nonwork travel (frequency, destination, and mode) (as cited inBen-Akiva and Lerman 1991). In this model, medium-range decisions are conditional on long-run decisions, and short-range decisions are conditional on medium- and long-range decisions. In addition, expected outcomes of short-range decisions can sometimes influence medium- and long-range decisions; to account for this possibility, attributes of short-term decisions are aggregated and included as composite variables in models of medium-term and long-term decisions. At each level, choices can be modeled using the discrete choice framework.

     However, travel behavior theory offers little guidance on what choices are short-term, medium-term, and long-term and how choices at each level are influenced by choices at other levels. It seems logical that frequent choices (e.g., walk to work today) are conditional on occasional choices (e.g., live close to work), but it is possible that occasional choices (e.g., live close to work) are in fact conditional on preferences for frequent choices (e.g., prefer to walk to work). Although travel behavior theory focuses on choices, in practice travel behavior research focuses on observed behavior; researchers equate the observable behavior that results from a choice with the choice itself, when in fact the choice may precede the behavior by some amount of time. Though rarely accounted for in the travel behavior field, the separation between thought-process and behavior is suggested by the concept of intention from the Theory of Planned Behavior. However, this theory does not account for the impact of intention with respect to one behavior on other behaviors, for example, when the intention to walk impacts the choice of where to live. Social Cognitive Theory and ecological models, which also generally focus on one behavior at a time, offer little help.

     The residential location choice literature also provides ambiguous guidance on how long- and short-term decisions interact. The bid rent model from urban economics says that residential

location choice is a trade-off between commute distance and land price: a location near the center of the city means a short commute but high land prices and thus small living spaces, while a location near the edge of the city means low land prices and thus large living spaces but a long commute. Evidence suggests that in the United States preferences for large living spaces win out over preferences for short commutes, at least for most people. In this model, the residential location decision determines the commute distance, but preferences for commuting influence the residential location decision. Residential location choice has also been analyzed with the use of hedonic pricing models. These empirical models explain housing prices through the characteristics of the house and the characteristics of its location. Haider and Miller (2000), for example, found that being within 1.5 km of a subway line was positively associated and being within 5 km of a mall was negatively associated with housing price. Such studies provide at least indirect evidence of the impact of preferences for certain characteristics of the built environment on residential location choice. But few of these studies focus on characteristics of the built environment; instead, most focus on community characteristics such as school quality and crime rates.

Researchers are thus in need of a conceptual model for sorting out the causal relationships that explain the observed correlations between access to opportunities and physical activity. The central question, as I see it, is what exactly we mean by "causality." The answer is not simple: causality means different things with respect to different people in different situations. I offer my own hypotheses here about possible causal relationships for the link between neighborhood type and walking levels as a starting point towards building that framework.

Towards a Conceptual Model

As noted above, an individual's level of preference (or intention or desire) for walking might influence her choice of a place to live, so that her preference for walking and the characteristics of that place together influence her level of walking. This model can play out in two ways. First, an individual with a high preference for walking is more likely to choose a neighborhood that is highly walkable, which then enables higher levels of walking (Model A1 in Figure 4-2). Second, an individual with a low preference for walking may be more likely to choose a neighborhood that is less walkable, which then discourages walking (Model A2).

If an individual's level of preference for walking does not influence her choice of a place to live, a mismatch between her level of preference and the "walkability" of the neighborhood are possible. If factors other than walkability were important in choosing a neighborhood, an individual with a high preference for walking might end up living in a neighborhood with a low level of walkability, which then acts as a constraint on walking (Model B1). Walking preferences may be strong enough that the individual walks despite the poor walking conditions, or the conditions may pre-empt the preference. Conversely, an individual with a low preference for walking might happen to live in a neighborhood with a high level of walkability, which then acts as an encouragement to walking (Model B2). Whether the encouragement is enough depends on how strong the aversion to walking is.

Another possibility is that the walkability of the neighborhood an individual chooses for reasons unrelated to walking impacts her preference for walking over time. A neighborhood with high walkability might lead to higher preference for walking, which then leads to higher levels of walking (Model C1). On the other hand, a neighborhood with low walkability might lead to

lower preference for walking, which then leads to lower levels of walking (Model C2). Putting this possibility together with the first suggests that preferences for walking might influence the choice of neighborhood, and the walkability of the chosen neighborhood might then work to reinforce preferences for walking; the process could lead to either positive or negative reinforcement and either higher or lower levels of walking. A more general model is presented in Figure 4-3.

These hypotheses suggest different causal mechanisms depending on the combination of initial preferences and neighborhood walkability (Table 4-1). For individuals with a high initial preference for walking, the built environment acts as an enabler of walking and a reinforcer of high preferences or as a constraint on walking and a promoter of lower preferences. For individuals with a low initial preference for walking, the built environment acts as an encourager of walking and a promoter of higher preferences or as a discourager of walking and a reinforcer of low preferences. All of these relationships represent causality, though of different types and of different likelihoods. I include my own guesses as to the likelihood that each potential causal mechanism operates at a significant level in Table 4-1. These ratings are based on the premise that it is easier to reinforce existing preferences than change them and that it is difficult to encourage someone to do something they do not have a preference to do. The first combination—high preference for walking with high walkability of neighborhood—is what many researchers have called "self-selection," although the fourth combination is also a form of self-selection.

Evidence on Self-Selection

Though the available evidence on the question of self-selection is limited, the evidence on other potential causal mechanisms is essentially nonexistent. To test for self-selection and other causal mechanisms, researchers need to account for preferences (or intentions or desires) towards walking and they need to consider bi-directional relationships between neighborhood characteristics and preferences. Ideally, researchers would examine relationships over time, to look for associations between preferences and changes in the built environment, the built environment and changes in preferences, and changes in the built environment, changes preferences, and changes in levels of walking. No study published so far does all of these things, though at least two are in the works. In the meantime, I identified four studies that explore the possibility of self-selection, each using a different approach.

A study by Krizek (2003) did not directly test the self-selection question, it provides insights into the possibility. This study used data from the Puget Sound Transportation Panel to test for changes in active travel for participants who moved from one neighborhood to another. His sample consisted of 550 households that had moved between 1989 and 1997. In his models, he examined the relationship between changes in the built environment (measured as neighborhood accessibility and regional accessibility) and changes in travel behavior. However, changes in the built environment were not significant predictors of changes in the use of walking, biking, and transit (although they were significant predictors of vehicle miles of travel). He concludes that these results suggest that household preferences for travel modes remain fixed and are not influenced by changes in the built environment. Another interpretation of the results is that individuals largely self-selected into neighborhoods that match their preferences, before and after they moved, in which case the built environment serves to enable their preferred behavior and reinforce their preferences.

Colleagues and I explored quantitatively and qualitatively the role of preferences for walking in the decision to live in a walkable neighborhood (Handy, Clifton et al. 1998). In a survey of residents of six neighborhoods in Austin, Texas, we found that having stores within walking distance was a more important factor in choosing a neighborhood for the residents of the neighborhood with the highest frequency of walking to stores, although even for these residents it was the sixth most important factor (after qualities such as neighborhood attractiveness, quality of living unit, and proximity to work). Unpublished analysis of the data showed that for the overall sample, respondents who said that having stores within walking distance was very important walked to the store 7.1 times in the previous month, compared to only 2.2 times for residents who said that having stores within walking distance was somewhat important and 1.0 times for residents who said it was not at all important (Table 4-2). In a linear regression model of the frequency of walking to the store, also unpublished, the rating of the importance of having stores within walking distance was significant, accounting for 4% of the explained variation. Focus group results supported the quantitative findings: residents of the neighborhood with the highest frequency of walking to stores consistently mentioned being able to walk to stores as a reason for selecting that neighborhood. This study thus provided strong evidence of self-selection, although the cross-sectional design leaves open the possibility that residents' retrospective reporting of the reasons for selecting a neighborhood are biased by their experiences living there.

Greenwald and Boarnet (2001) examine potential feedback between residential location choice and travel behavior using instrumental variables in an expanded model of walking trips. In general, instrumental variables are used when independent variables are correlated with the error term in a regression model. If residential location choice is influenced by unobserved preferences correlated with attitudes about walking, then variables representing the built environment (as determined by residential location choice) will be correlated with the error term, which accounts for the unobserved preferences and attitudes. The instrumental variables used to address this problem must be highly correlated with the built environment but not significantly correlated with the error term. The researchers used six characteristics of the neighborhood other than transportation characteristics as instrumental variables, all derived from U.S. census data. In models estimated with the instrumental variables, population density and the pedestrian environmental factor (PEF) score remained significant, but the percent of the network that is a rectilinear grid did not; regional population and retail densities remained insignificant. They conclude from their analysis that certain characteristics of the built environment promote walking, even taking into account the possibility of self-selection.

Bagley and Mokhtarian (2002) provide a more sophisticated analysis of the relationships between attitudes, residential location choice, and travel behavior. Using a structural equations modeling approach, they estimated a nine-equation model for residential location (traditional or suburban), attitudes (pro-hi density, pro-driving, and pro-transit), and travel demand (vehicle miles, transit miles, and walk/bike miles) as endogenous variables for a sample of 515 residents of five neighborhoods in the San Francisco Bay Area. This approach provides estimates of both direct effects and indirect effects, taking into account the possibility of multiple directions of causality. The researchers conclude that attitudinal variables had the greatest impact on travel behavior among all of the explanatory variables and that residential location type had little impact on travel behavior, suggesting that "the association commonly observed between land use configuration and travel patterns is not one of direct causality, but due primarily to correlations of each of those variables with others." In other words, observed associations between travel

behavior and neighborhood type are largely explained by the self-selection of residents with certain attitudes into certain kinds of neighborhoods. In addition, the study found no impact of neighborhood type on attitudes, though travel behavior tended to reinforce related attitudes. However, as the researchers note, the cross-sectional nature of the study meant that dynamic changes were not captured in the data and could not be analyzed. However, it does raise the possibility that observed relationships between neighborhood characteristics and levels of walking are spurious (Figure 4-4).

Two current studies employ research designs that capture changes in behavior as well as attitudes and preferences. In a study funded by the California Department of Transportation, Mokhtarian and I are using an innovative quasi-experimental design to sort out the causal relationships between travel preferences, neighborhood design, and travel behavior. In the sampling plan, eight different neighborhoods in the Northern California were selected based on their design characteristics (whether traditional or conventional suburban) and their regional location (within a large metropolitan region or a small city). Within each neighborhood, residents who had moved within the previous year (the "treatment" group) and residents who had not moved (the "control" group) were surveyed in fall 2003. The survey included questions about current travel behavior and travel behavior either before the move or 1 year prior to the survey; questions about characteristics of the current neighborhood, characteristics of the previous neighborhood, and preferences for neighborhood characteristics; questions about travel preferences; and questions about household characteristics. The analysis will involve a structural equations modeling approach. Although this study depends on retrospective reporting of changes in active travel and neighborhood-based physical activity, it should shed new light on the causal relationships underlying the observed correlations between the built environment and physical activity.

In Perth, Australia, a team led by Billie Giles-Corti is undertaking an ambitious 5-year effort named the RESIDE (RESIDential Environments) Project in collaboration with the Department for Planning and Infrastructure, the National Heart Foundation, and the Water Corporation. This project will survey residents before, 1 year after, and 2 years after moving into new communities designed to be more walkable than conventional suburbs. The survey includes questions on neighborhood design, access to facilities for physical activity, and active travel and other physical activity levels. Objective measures of the built environment and of physical activity will also be incorporated into the study. The researchers plan to invite 5,000 households to participate in the study, although the final sample will depend on the participation rate. The association between changes in physical activity and changes in the built environment will be assessed along with the role of attitudes and preferences. This study should provide the strongest evidence yet on the causal relationships between the built environment and physical activity.

Evidence from Intervention Studies

Intervention studies provide a more direct test of causality than cross-sectional studies because they include comparisons of behavior before and after a change in the built environment. They also control for the self-selection possibility because they look at changes in behavior for a fixed residential location. However, few studies of interventions that involve changes to the built environment are available in either the travel behavior or physical activity literatures, and those that are sometimes lack methodological rigor. The studies that are available, however, point to increases in physical activity associated with different types of changes in the built environment.

Travel Behavior Literature

A small group of studies from the travel behavior literature have used a pre-test/post-test design to test the impact of a specific change to the built environment in a relatively limited area (Task Force on Community Preventive Services 2002). In these studies, researchers focused on observed changes in levels of activity in the study area, rather than on reported changes in behavior for the residents who live in those areas. Researchers had no way of randomizing the application of the intervention and did not use a control location to help isolate the impact of the intervention from other effects. Painter (1996) examined the impact of improved lighting on the use of footpaths in London and found an intervention effect ranging from 34% to 101% increases in the use of the footpath depending on the location. MacBeth (1999) looked at the impact of the addition of bike lanes on bicycle traffic and found a 23% increase in traffic. Eubanks-Ahrens (1987) studied the impact of the redesign of two residential streets in Hannover, Germany, into "Woonerven" (designed for shared use by cars and people) on a wide range of physical activities, including ball games, biking, and dancing. In this study, researchers observed 11% to 100% more children on the street and 53% to 206% more incidents of street play after the changes were made to street design.

A recent study of the Safe Routes to School program in California provides a more rigorous assessment of the impact of changes in the built environment on active travel (Boarnet, Day et al. 2003). This study looked at the number of children walking and bicycling to school before and after construction of traffic safety projects at nine schools. The nature of the project varied from school to school but included sidewalk improvements, traffic calming and speed reduction devices, bicycle facilities, traffic control devices, and traffic diversion improvements. In addition to surveying parents of children in grades 3 through 5, researchers made observations of traffic volumes, speeds, and yielding behavior as well as numbers of pedestrians and bicyclists. The results showed strong evidence of success in five schools, weak evidence of success in one school, and no evidence of success in three schools, where success was defined as improvements in safety conditions as well as increases in the numbers of children walking or bicycling to school. The researchers note that their approach is likely to understate the success of the program, given the limited measures of success used and the assessment of impacts only in the near term.

Physical Activity Literature

Although intervention studies are common in the field of public health, interventions that involve changes to the physical environment are relatively rare. A 1998 review of intervention studies by Sallis, Bauman, and Pratt (1998) provides an early assessment of this literature and a framework for considering more recent studies in this category. This review identified seven studies, with interventions ranging from signs to encourage use of stairways, a multifaceted intervention on a military base, a program to increase walking and cycling to work at a large plant in Finland (including the addition of showers and changing rooms), and 14 new publicly-funded leisure centers in Belfast. Although the studies of stairway interventions showed them to be effective, the authors conclude that the studies on the military base, in Finland, and in Belfast all had serious shortcomings.

A more recent review by Kahn et al. (2002), used as a basis for the *Guide to Community Preventive Services*, looked at studies of a wide range of interventions designed to increase

physical activity, including informational, behavioral and social, and environmental and policy interventions. In the last category, 10 studies of efforts to "create or provide access to places and facilities where people can be physically active" were reviewed; most of these interventions involved efforts at worksites rather than in residential neighborhoods and included informational outreach activities. These studies showed a median increase in the percentage of people reporting some leisure-time physical activity of 2.9% and a median increase in the frequency of physical activity of 48.5%. Based on these results, this review strongly recommends the use of such interventions to promote physical activity.

Conclusions

Frank and Engelke (2000) conclude from their review of the available cross-sectional studies that "it is plausible to assert that changes in land use and transportation investment policies will result in shifts to nonmotorized travel for short trips." Such a conclusion presumes that cross-sectional studies provide sufficient evidence of causality. However, five criteria must be considered when deciding whether a causal relationship exists: empirical association, appropriate time order, nonspuriousness, causal mechanisms, and the context in which the effect occurs (Schutt 2004). Cross-sectional studies have established empirical associations between certain aspects of the built environment and certain types of physical activity, as described in Chapter 3. In addition, the growing body of such studies has begun to demonstrate that these associations are found in different places and contexts. However, these studies do not adequately address the other three criteria for causality. The focus of the behavioral theories used in both travel behavior research and physical activity research on explaining a single behavior rather than the relationships between behaviors leaves open the questions of time-order, nonspuriousness, and causal mechanisms. More complex conceptual models and and the application of longitudinal and intervention research designs can help to address these questions and shed further light on the causal relationships between the built environment and physical activity.

CRITICAL EVALUATION AND RECOMMENDATIONS

Introduction

The previous chapters offer a mixed assessment of the state of our understanding of the link between the built environment and physical activity: considerable progress has been made in showing the significance of a connection between the built environment and physical activity, but evidence on what aspects of the built environment affect what types of physical activity to what degree is slim as is evidence on the nature of causal relationships between these variables and others over different scales of time. More progress hasn't been made mostly because the efforts are relatively recent, but the traditional concerns of the fields of travel behavior research and physical activity research have hindered these efforts to some degree, particularly in the field of travel behavior research.

The bulk of funding in travel behavior research has been directed toward producing more accurate forecasts, not toward improving our understanding of travel behavior through basic research. The traditional focus on forecasting has meant little concern with detailed characteristics of the built environment. If researchers can't prove that these characteristics add

considerably to the accuracy of forecasts, then it is hard to justify the investment in data collection it would take to incorporate detailed characteristics of the built environment into the forecasting model. Forecasting efforts have, of course, focused on automobile travel and to some extent transit use, putting walking and biking into the role of side effect. As a result, the theory, data, and analyses used by researchers in this field have not been geared toward walking and biking and don't take into account possible behavioral differences for these modes of travel. This situation is starting to change, but traditions can be hard to overcome.

The field of physical activity research was in some ways better situated to expand its concerns to the role of the built environment in explaining physical activity. This field has a strong tradition of starting with behavioral theory as a basis for the design of research as well as behavioral interventions. The primary goal is to understand behavior in order to find effective ways of changing it. The studies reviewed in the previous chapter show a clear progression from a relatively simplistic conceptualization of the built environment—access to gyms and home exercise equipment—to a more complete conceptualization, including a consideration of perceived versus objective measures of the built environment, and an interest in active travel as a potentially significant component of total physical activity. Still, the research in this field can benefit from the perspectives of travel behavior research.

This final chapter presents an assessment across both fields of the research to date with respect to conceptualization of key variables and the structure of conceptual models and study designs. The chapter concludes with general recommendations for future research.

Conceptualization of Key Variables

One of the primary challenges for researchers is the conceptualization of the two key variables of interest: the built environment and physical activity. The existing research tends to focus on a subset of the possible dimensions of these variables, as outlined in Table 1-1. Studies from travel behavior research focus mostly on the elements of land use and the transportation system at the neighborhood level and their association with walking and/or biking from home to work or nonwork destinations. Studies from the physical activity literature tend to fall into two groups, one group that looks at access to specific exercise facilities and the impact on total physical activity, and a more recent group that looks at all elements of the built environment at the scale of the neighborhood and their association with walking of all types or with total physical activity, regardless of setting.

That leaves lots of unmeasured dimensions of these key variables. One notable gap is a consideration of the built environment at scales larger than the neighborhood. Although there appears to be a movement toward more detailed assessments of the built environment around the homes of survey respondents, limited attention has been given to the effect of district- or region-level characteristics. As Cervero and Radisch note, micro-scale design characteristics may be too micro to matter relative to region-scale characteristics (Cervero and Radisch 1996). Studies that use the concept of accessibility in measuring the built environment may account for the possibility that regional opportunities draw residents away from the neighborhood and the opportunities for physical activity found there. But few studies explicitly account for this possible trade-off. What's needed is some thought to the different types of physical activity in different settings that might substitute for each other, followed by efforts to separately measure these different activities.

The issue of perceived versus objective measures of the built environment merits further attention. The trend appears to be towards the use of objective measures and the development of standardized protocols for carrying out these measurements. One study by Sallis et al. (1997) suggests that objective measures are better predictors of behavior than perceived measures and shows that perceived measures may differ significantly from objective measures. On the other hand, theory suggests that perceptions and beliefs should affect behavior more directly than reality. Even proponents of utility maximizing theory acknowledge the role of perceptions in the decision making process (McFadden 2002). Kirtland et al. (2003) assessed of the consistency of perceived and objective measures of the neighborhood and community environments and found mostly fair and poor consistency, although the results varied by the specific characteristic of the environment and in some cases by the level of activity of the individual. Further research on the relationship between objective measures and perceived measures could prove important in advancing research on the relationship between the built environment and physical activity.

One of the most pervasive and persistent problems in the travel behavior literature is the use of density as a measure of the built environment. Most of these studies note that if destinations are closer, then people are more likely to walk. Higher densities generally mean destinations are closer, because the greater concentration of population can support more businesses within a certain distance. However, higher densities are no guarantee of proximity to any particular activity (other than other people). Density is also correlated with other characteristics of the built environment, including transit service, traffic levels, and the presence of other people on the street. Cervero and Radisch (1996), for example, measured 40 specific characteristics of the built environment that were strongly associated with density. As a result, studies show that density is significantly correlated with active travel. Density is thus a useful measure in predicting travel behavior. But its role in explaining travel behavior is less clear, and its relationship with behavior may be spurious (Frank and Engelke 2000). As Crepeau argues (as cited in Greenwald and Boarnet 2001), using "proxy" variables like density does little to incorporate the built environment into the analysis of the choice process. Most studies tend to rely on readily available measures of the built environment and offer intuitive explanations of why these variables should be associated with active travel. These studies mostly do not explain, however, how these variables factor into the decision making process through, for example, an influence on the utility of the active travel choice. Measures of accessibility, as I argue in Chapter 2, provide more theoretically sound measures of the built environment. Interestingly, such measures have been more consistently used in the physical activity studies reviewed here than in the travel behavior studies.

More attention is also needed to the match between specific characteristics of the built environment and specific types of physical activity. Different aspects of the built environment are likely to affect different types of physical activity to different degrees. As noted in Chapter 3, distance is an important explanatory factor for walking for travel, but is less important for walking for exercise or recreation. Design, on the other hand, seems to be more important for walking for exercise or recreation than it is for walking for travel. In considering which aspects of the built environment may influence behavior, it is thus important to distinguish between walking for travel and walking for exercise or recreation. Within the category of active travel, it is also important to distinguish walking by its destination: different characteristics of the built environment may matter for walking to work than matter for walking to a café. By dissecting total physical activity into specific types of physical activity and focusing on those most likely to

be affected by the built environment, researchers can more decisively determine the nature and extent of connections between the built environment and physical activity.

For both fields, the lack of theory for measures of the built environment has been a significant problem. As Humpel et al. (2002) note, "Currently, even the most relevant theory does not provide sufficiently detailed conceptual tools for differentiating how the separate domains of environmental influences might impact on different physical activity behaviors." The urban design literature can potentially be mined for more ideas about specific design characteristics of the built environment that impact specific types of physical activity, but this literature focuses on activity in public places, rather than physical activity per se and often offers more in the way of abstractions than practical help. As demonstrated by Corti et al. (1997) and Handy et al. (1998), qualitative research can help to identify built environment factors that influence physical activity and should be measured in quantitative studies. Systematic qualitative research could prove useful in validating existing tools for measuring the built environment and those currently being developed. Humpel et al. (2002) call for a "more refined and theoretically anchored set of constructs for characterizing environmental influences on different physical activity barriers."

Conceptual Models and Study Design

Any of the behavior theories reviewed in Chapter 2 can be used to study the link between the built environment and physical activity, though researchers might benefit from stepping outside of their usual frameworks and trying on one of the others for a change. For example, utility-maximizing theory can be applied to decisions about physical activity they way it is applied to decisions about travel behavior. Such an approach would require a slight reconceptualization of the physical activity question. Instead of measuring whether someone gets enough physical activity or not, the researcher would focus on the decision of whether or not to engage in physical activity and the model would include variables that determine the utility of that decision, including variables that represent characteristics of that decision as well as characteristics of the individual. For physical activity, such variables might include positive effects of physical activity, such as relaxation and improved health, as well as negative effects, such as sweating and tiredness. Existing physical activity studies can, with a bit of a stretch, be interpreted within a utility-maximizing framework. But a conscious effort to think about physical activity decisions in the utility-maximizing framework might lead researchers to new ideas about explanatory factors. Similarly, travel behavior researchers could benefit from reconsidering their questions within the perspective of ecological models and other frameworks used in the physical activity literature.

Whichever theory is taken as a starting point, a more comprehensive conceptual model that accounts for the possibility of endogeneity of variables beyond the built environment and physical activity is needed. As discussed in Chapter 4, the observed connection between the built environment and physical activity may, in fact, be explained by a connection between preferences for physical activity and choices about residential location. Automobile ownership, as discussed in Chapter 3, should also be treated as endogenous to the model, in that it might function as an intervening variable between neighborhood characteristics and travel behavior. The interplay between perceived and objective characteristics of the environment might also prove important, as well as the interplay between physical activity and perceived characteristics. These relationships may play out over different time scales, further complicating the picture. An

expanded conceptual model, such as that shown in Figure 5-1, would allow for bi-directional relationships between all of these variables. Testing such a model requires improved research designs, better data, and more sophisticated analysis techniques.

A more comprehensive conceptual model will demand more sophisticated research designs. The reliance on cross-sectional designs is perhaps the most glaring weakness of the existing studies, though it is also one of the most challenging weaknesses to overcome. The reliance on cross-sectional designs can be explained by the nature of the phenomenon of interest. The built environment is relatively fixed in any particular area, changing little or slowly, if at all (in places where it changes more radically, residents are often displaced). Nevertheless, the built environment does change, and these changes can form the basis for quasi-experimental studies of the effects of specific changes in the built environment. Such studies test causal relationships in a way that cross-sectional studies inherently can't. But these studies must be carefully designed, with pre-test/post-test measurement and measurement of control conditions. As Sallis et al. (1998) argue, "This tactic is extremely promising because of the high level of rigor that can be attained and the potential for quickly applying effective programs in the targeted settings." Such studies require multi-year funding, which has been rare in the travel behavior field, and collaboration with researchers and practitioners, which can easily be frustrated by bureaucratic problems. Although researchers are unlikely to have control over changes to the built environment, this approach falls within the tradition of intervention studies in physical activity research.

The built environment also in effect changes for people who move their residence from one location to another. Thus, another promising approach is to examine changes in physical activity for households that move; the move serves as the "treatment" in quasi-experimental design, as described in Chapter 4. This approach requires the identification of households and the measurement of their physical activity before they move, a task that might be achieved through collaborations with real estate developers or utility providers. An alternative approach is to identify households that have recently moved and ask them to report on changes in their physical activity. With either approach, the influence of preferences for physical activity on the choice of residential location must be considered, and control groups should also be included. These studies also require multi-year funding.

Sampling is another challenge for these studies. Because the built environment does not vary significantly within a particular neighborhood, studies need to sample from a relatively large number of neighborhoods to ensure sufficient variation in the built environment. Cervero and Radisch (1996) conclude that at least 30 households in each area in at least 50 areas are needed to adequately test the link between the built environment and travel behavior. Measuring the built environment for individual households rather than for neighborhoods helps to alleviate this problem by accounting for variation in the built environment within the neighborhood, but sampling plans still need to ensure sufficient variation across households and this kind of disaggregate measurement can be extremely costly. The reliance on perceived measures of the built environment typical of physical activity studies is one solution to this problem (in that it saves money and increases variation), but issues about the validity of perceived measures rather than objective measures of the built environment must be considered.

Research Priorities

If the goal is to determine what land use, transportation, and design policies will lead to increases in physical activity, researchers have a long way to go. Rather than more studies that confirm a correlation between the built environment and physical activity, we need studies that help show which characteristics of the built environment affect what types of physical activity to what degree and we need studies that begin to sort out the causal relationships among a broader set of factors. Based on my review of the travel behavior and physical activity literatures, I suggest the following priorities for future research:

Conceptualizing the Key Variables

- Build a theoretical basis for identifying characteristics of the built environment that may influence physical activity based on the existing urban design literature and travel behavior theory, as well as further qualitative research. Move away from the use of proxy variables such as density and focus instead on characteristics of the built environment that directly affect behavior.
- Explore the relationship between perceived and objective characteristics of the built environment and incorporate this relationship into studies of the link between the built environment and physical activity.
- Match specific characteristics of the built environment at specific scales to specific types of physical activity in specific settings and examine relationships ignored so far by researchers, such as the role of regional-scale characteristics on physical activity.

Conceptual Models and Study Design

- Employ a more comprehensive conceptual model, one that accounts for bi-directional relationships between choices about residential location, auto ownership, the built environment, and physical activity, and for the role of preferences and perceptions in all these choices.
- Move toward the use of quasi-experimental designs, either by measuring changes in physical activity associated with changes in residential location or by taking advantage of planned changes to the built environment, whether small changes such as the installation of traffic calming devices or significant redevelopment projects.

Final Thoughts

It is tempting to look for a simple answer to the question, does the built environment influence physical activity? The problem is that there is not one answer to this question but many. Whether the built environment influences physical activity depends on the type of physical activity, the aspect of the built environment, the characteristics of the individual. The simple answer, then, is that it depends, sometimes it does and sometimes it doesn't. The relationships between the built environment and physical activity shown in the studies reviewed here are perhaps not as strong or consistent as many readers would expect. There are two possible explanations for this result. One, the relationships really aren't strong or consistent. Two, we haven't been studying them in the right way. More and better research will help us figure this out.

In the meantime, does the absence of definitive evidence mean that we should not be adopting policies that create what we believe to be environments more conducive to physical activity? I don't think so. One, the available evidence, despite its limitations, shows that a causal link between the built environment and physical activity is a distinct possibility. Two, there are good reasons to build communities that are more walkable, for example, even if we are not sure if it will have a significant impact on the obesity epidemic. Three, there is not necessarily a large cost to doing so, beyond the cost of overcoming inertia and in making changes to existing codes, something that many communities are already doing anyway. And four, there seems to be little risk that building walkable communities will do anyone any harm. We know a lot about how to build drivable communities and we have much to learn about how best to create communities that are walkable as well as drivable. But, as a matter of principle, why shouldn't walkable communities be the norm?

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TABLE 1-1 Summary of Potential Relationships

Physical Environment Elements	Scales	Physical Activity Types	Settings

Land Use
Transportation System
Design
Natural Landscape
Human Use
	Building
	Street/Block
	Neighborhood
	District
	Region
		Active travel
		  Walking
		  Biking
		  Other
		Other physical activity
		  Exercise or recreation
		  Inadvertent
			Home
			Work
			School
			Neighborhood
			Facilities
			Home to Work
			Home to Nonwork
			Work to Nonwork

TABLE 2-1 Traditional Versus Alternative Assumptions

Traditional Assumptions	Alternative Assumptions
The individual can exercise free choice	There are overall and intermediate constraints on behavior
Attributes influencing choice generate (dis)utility in a continuous fashion	The (dis)utility function exhibits discontinuities and rigid constraints on behavior (thresholds)
Individuals choose from a mutually exclusive set of alternatives. That is, they have complete knowledge of all relevant aspects	Uncertainty and lack of knowledge are common influences on behaviour
Perfect substitutability of (dis)utility between attributes influencing choice	In the short run, individuals display habit in repetitive choice situations
There is a zero cost associated with search and learning	There is a positive cost associated with search and learning, and a point is often reached where the utility cost of gathering more information is greater than the anticipated gain

SOURCE: (Goodwin and Hensher 1978)
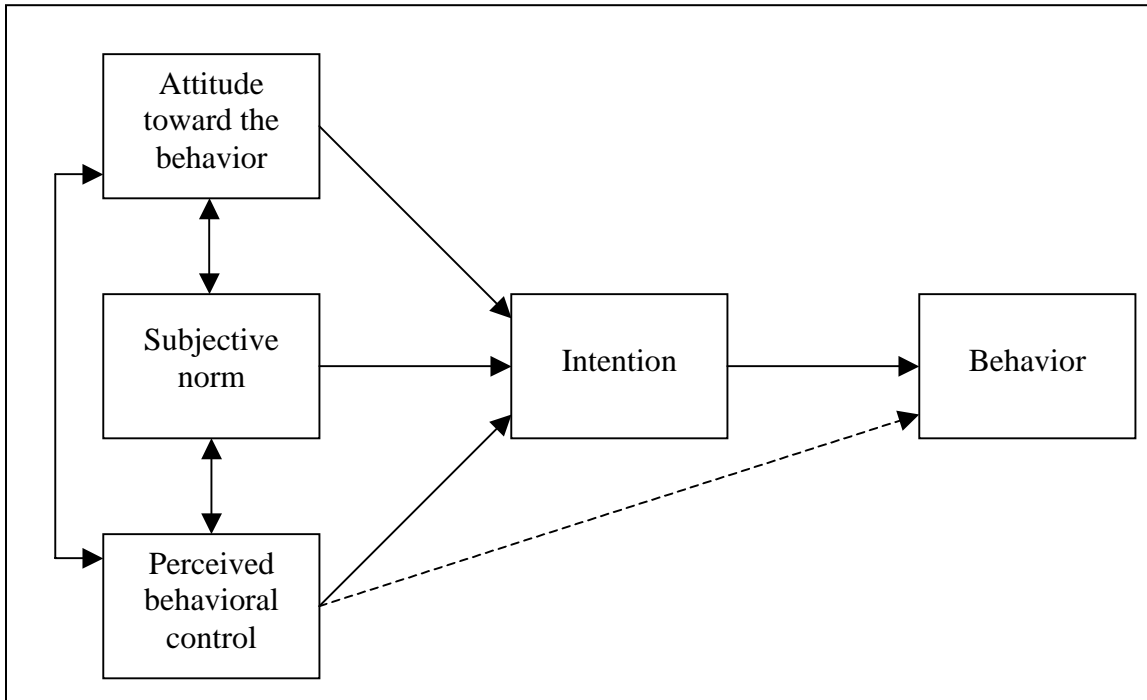
FIGURE 2-1 Theory of planned behavior (adapted from Azjen 1991).
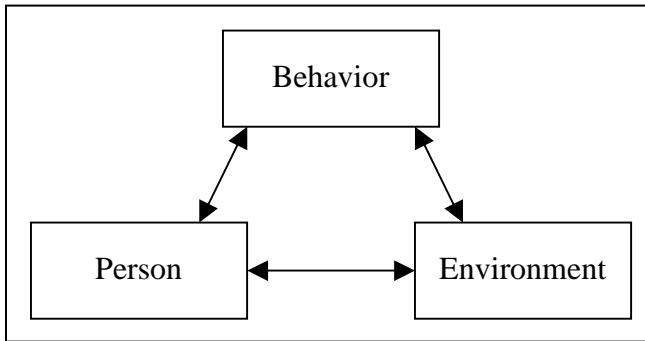
FIGURE 2-2 Reciprocal determinism (adapted from Bandura 1986).

TABLE 2-2 Perceptual Qualities of the Street Environment

Quality	Definition
Legibility	The ease with which the spatial structure of a place can be understood and navigated as a whole
Imageability	The quality of a place that makes it distinct, recognizable, and memorable
Enclosure	The degree to which streets and other public spaces are visually defined by buildings, walls, trees, and other elements
Human Scale	A size, texture, and articulation of physical elements that match the size and proportions of humans and, equally important, the speed at which humans walk
Transparency	The degree to which people can see or perceive what lies beyond the edge of a street or other public space and, more specifically, the degree to which people can see or perceive human activity beyond the edge of a street or other public space
Linkage	Physical and visual connections from building to street, building to building, space to space, or one side of the street to the other
Coherence	A sense of visual order
Complexity	The visual richness of a place

SOURCE: (Winston, Handy et al. 2004)

TABLE 2-3 Insights and Ideas for Research on Physical Activity from Theories Reviewed

Theory	Insights/Ideas
Utility Maximizing Theory	Conceptualize physical activity behavior as a series of discrete choices. Focus on understanding what choices are available for active travel and other physical activity and their characteristics. Consider relationships between long-term choices (residential location, auto ownership) and short-term choices about active travel and other physical activity. Use the concept of accessibility as a way of measuring the opportunities for physical activity provided by the built environment.
Activity-Based Approach	Distinguish between active travel derived from demand for other activities and active travel as activity itself. Consider constraints on behavior, uncertainty, lack of knowledge, habit.
Positive Utility of Travel	Consider benefits of active travel that offset increase in travel time over motorized travel.
Other "Irrationalities"	Consider influence of previous experiences on evaluations of current opportunities for active travel and other physical activity. Account for desire for variety in choice process for active travel and other physical activity.
Theory of Planned Behavior	Account for role of beliefs, attitudes, and intention in explaining active travel and other physical activity behavior. Expand concept of perceived behavioral control to account for characteristics of the built environment that might influence physical activity.
Social-Cognitive Theory	Consider reciprocal relationships between person, environment, and behavior, over various time scales. Account for the role of outcome expectations, similar to concept of remembered utility, in active travel and other physical activity. Account for the role of self-efficacy, similar to concept of perceived behavioral control, in active travel, particularly bicycling, and other physical activity. Distinguish between behavioral settings and focus on characteristics of the built environment specific to the type of active travel or physical activity of interest.
Ecological Model	Account for intrapersonal, interpersonal, and environmental influences in explaining active travel and other physical activity. Consider characteristics of the built environment at various scales, from micro to meso to macro.
Urban Design	Use normative theory to identify design characteristics of the built environment potentially important for explaining active travel and other physical activity. Use normative theory as a basis for the development of measures of potentially important design characteristics of the built environment.

TABLE 3-1 Travel Behavior Studies on Active Travel by Type

	Comparative	Correlative
Regionwide		(Hanson and Schwab 1987; Parsons Brinckerhoff Quade & Douglas 1993; Frank and Pivo 1995; Cervero 1996; Kockelman 1997; Krizek 2000; Greenwald and Boarnet 2001; Cervero and Duncan 2003; Krizek 2003; United States Environmental Protection Agency 2003)
Selected neighborhoods	(Cervero and Gorham 1995; Ewing, Haliyur et al. 1995; Cervero and Radisch 1996; Handy 1996b; McNally and Kulkarni 1997; Moudon, Hess et al. 1997; Hess, Moudon et al. 1999; McCormack, Rutherford et al. 2001)	(Friedman, Gordon et al. 1994; Kitamura, Mokhtarian et al. 1997; Handy, Clifton et al. 1998; Black, Collins et al. 2001; McCormack, Rutherford et al. 2001; Bagley and Mokhtarian 2002)

TABLE 3-2 Studies on Active Travel by Active Travel Type and Built Environment Measure

	Home to work	Home to nonwork	Home to school	Total
Land Use	(Frank and Pivo 1995)	(Cervero and Gorham 1995; Frank and Pivo 1995)	(United States Environmental Protection Agency 2003)	(Parsons Brinckerhoff Quade & Douglas 1993; Kitamura, Mokhtarian et al. 1997; Kockelman 1997; Krizek 2000; Greenwald and Boarnet 2001; Cervero and Duncan 2003; Krizek 2003)
Transportation			(United States Environmental Protection Agency 2003)	(Parsons Brinckerhoff Quade & Douglas 1993; Kitamura, Mokhtarian et al. 1997; Greenwald and Boarnet 2001)
Accessibility	(Hanson and Schwab 1987)	(Handy and Clifton 2001b; McCormack, Rutherford et al. 2001)	(Black, Collins et al. 2001; United States Environmental Protection Agency 2003)	(Hillman, Henderson et al. 1973; Hanson and Schwab 1987; Kitamura, Mokhtarian et al. 1997; Kockelman 1997; McCormack, Rutherford et al. 2001; Cervero and Duncan 2003; Krizek 2003)
Design		(Handy and Clifton 2001b)	(United States Environmental Protection Agency 2003)	(Kitamura, Mokhtarian et al. 1997; Cervero and Duncan 2003)
Neighborhood Type	(Friedman, Gordon et al. 1994; Cervero and Gorham 1995; Cervero and Radisch 1996)	(Friedman, Gordon et al. 1994; Cervero and Radisch 1996; Handy 1996b; McCormack, Rutherford et al. 2001)		(Ewing, Haliyur et al. 1995; McNally and Kulkarni 1997; Moudon, Hess et al. 1997; Hess, Moudon et al. 1999; McCormack, Rutherford et al. 2001; Bagley and Mokhtarian 2002)

TABLE 3-3 Measures of Built Environment in Travel Behavior Studies

Category	Measure	Studies Using Measure
Land Use	Population density	(Parsons Brinckerhoff Quade & Douglas 1993; Frank and Pivo 1995; Greenwald and Boarnet 2001; United States Environmental Protection Agency 2003)
	Employment density	(Parsons Brinckerhoff Quade & Douglas 1993; Frank and Pivo 1995; Greenwald and Boarnet 2001; United States Environmental Protection Agency 2003)
	Retail density	(Greenwald and Boarnet 2001)
	Land use mix	(Frank and Pivo 1995; Kockelman 1997)
	Land use diversity factor	(Cervero and Duncan 2003)
	Land use balance	(Kockelman 1997)
	Rating of land use, density, and urban form	(Krizek 2000)
	Indicator of mixed-use or not	(Kitamura, Mokhtarian et al. 1997)
	Indicator high density or not	(Kitamura, Mokhtarian et al. 1997)
	Amount of single-family housing within 300 feet	(Cervero 1996)
	Ratio of single-family housing to multifamily housing within 300 feet	(Cervero 1996)
	Mid-rise of high-resie multifamily within 300 feet	(Cervero 1996)
Transportation System	Percent of network that is a grid	(Greenwald and Boarnet 2001)
	Street density	(United States Environmental Protection Agency 2003)
	Average block area	(Krizek 2003)
	Median walk distance and median walk speed	(Greenwald and Boarnet 2001)
	Pedestrian Environment Factor	(Parsons Brinckerhoff Quade & Douglas 1993) (United States Environmental Protection Agency 2003)
	Indicator for presence of sidewalks	(Kitamura, Mokhtarian et al. 1997)
	Indicator for presence of bike paths	(Kitamura, Mokhtarian et al. 1997)
	Percent of streets with sidewalks	(United States Environmental Protection Agency 2003)
	Average sidewalk width	(United States Environmental Protection Agency 2003)
	Pedestrian-/Bike-friendly design	(Cervero and Duncan 2003)
Accessibility—distance to nearest destination	Straight-line distance to nearest commercial street	(McCormack, Rutherford et al. 2001)
	Network distance to the nearest store	(Handy, Clifton et al. 1998)
	Reported distance to nearest rail station	(Kitamura, Mokhtarian et al. 1997)
	Reported distance to nearest grocery store	(Kitamura, Mokhtarian et al. 1997)
	Reported distance to nearest gas station	(Kitamura, Mokhtarian et al. 1997)
	Reported distance to nearest park	(Kitamura, Mokhtarian et al. 1997)

	Reported or measured distance to specific destination	(Black, Collins et al. 2001; Cervero and Duncan 2003; United States Environmental Protection Agency 2003)
Accessibility—cumulative opportunities measures and gravity measures	Home-based accessibility	(Hanson and Schwab 1987)
	Work-based accessibility	(Hanson and Schwab 1987)
	Presence of a commercial or non-residential building within 300 feet	(Cervero 1996)
	Presence of presence of a grocery or drug store between 300 feet and 1 mile	(Cervero 1996)
	Transit access to employment	(Parsons Brinckerhoff Quade & Douglas 1993)
	Employment within 1 or 5 miles	(Cervero and Duncan 2003)
	Neighborhood accessibility	(Krizek 2003)
	Regional accessibility	(Krizek 2003)
	Accessibility by mode and purpose for origin and destination	(Kockelman 1997)
Design	Perception of residential areas (safety, shade, houses, scenery, traffic, people)	(Handy, Clifton et al. 1998)
	Perception of commercial areas (stores, walking incentive, walking comfort)	(Handy, Clifton et al. 1998)
	Perception of no reason to move, street pleasant for walking, cycling pleasant, good local transit service, enough parking, problems of traffic congestion	(Kitamura, Mokhtarian et al. 1997)
	Commercial floor-area ratio	(United States Environmental Protection Agency 2003)
Neighborhood type	Traditional neighborhood versus suburban neighborhood	(Friedman, Gordon et al. 1994; Handy 1996b)
	Transit neighborhood versus automobile neighborhood	(Cervero and Gorham 1995)
	Traditional development versus planned-unit development	(McNally and Kulkarni 1997)
	Pedestrian-oriented neighborhood versus automobile-oriented neighborhood	(Cervero and Radisch 1996)
	Urban neighborhood versus suburban neighborhood	(Moudon, Hess et al. 1997; Hess, Moudon et al. 1999)
	LADUF rating: high, medium, low	(Krizek 2000)
	Traditional factor	(Bagley and Mokhtarian 2002)
	Suburban factor	(Bagley and Mokhtarian 2002)

TABLE 3-4 Summary of Findings on Active Travel by Active Travel Type and Built Environment Measure

Category	Measure	To work	To shop	To school	All trips
Land Use	Population density (origin zone and/or destination zone	+	+		++0
	Employment density (origin zone and/or destination zone	+	+		0
	Retail density				+
	Land use mix (origin zone and/or destination zone)	+			+0
	Land use diversity factor (origin and/or destination)				+
	Land use balance (origin and/or destination)				0
	Rating of land use, density, and urban form				+
	Indicator of mixed-use or not				0
	Indicator high density or not				+
	Single-family housing within 300 feet	-			
	Ratio of single-family housing to multifamily housing within 300 feet	-			
	Mid-rise or high-rise multi-family within 300 feet	+			
Transportation System	Percent of network that is a grid				+
	Street density			0	
	Average block area				0
	Median walk distance and median walk speed				-
	Pedestrian Environment Factor				++
	Indicator for presence of sidewalks				+
	Indicator for presence of bike paths				0
	Percent of streets with sidewalks			+	
	Average sidewalk width			0	
	Pedestrian-/Bike-friendly design				0
Accessibility – distance to nearest destination	Straight-line distance to nearest commercial street	-			
	Network distance to the nearest store		-		
	Reported distance to nearest bus stop				-
	Reported distance to nearest rail station				0
	Reported distance to nearest grocery store				0
	Reported distance to nearest gas station				0
	Reported distance to nearest park				-
	Distance to specific destination			--	-
Accessibility – cumulative	Home-based accessibility	+			+
	Work-based accessibility	+			+

	Presence of a commercial or non-residential building within 300 feet	+			
	Presence of presence of a grocery or drug store between 300 feet and 1 mile	-			
	Transit access to employment				+
	Employment within 1 or 5 miles				0
	Neighborhood accessibility				0
	Regional accessibility				0
	Accessibility by mode and purpose for origin and destination				+
Design	Perception of residential areas (safety, shade, houses, scenery, traffic, people)		0		
	Perception of commercial areas (stores, walking incentive, walking comfort)		+		
	Perception of no reason to move, street pleasant for walking, cycling pleasant, good local transit service, enough parking, problems of traffic congestion				0
	Commercial floor-area ratio			0	
Neighborhood type	Traditional neighborhood versus suburban neighborhood	+	++		+0
	Transit neighborhood versus automobile neighborhood	+			
	Traditional development versus planned-unit development	0			
	Urban neighborhood versus suburban neighborhood				+
	Walkable neighborhood versus suburban neighborhood				+
	LADUF rating: high, medium, low				+
	Traditional factor				0
	Suburban factor				0

Key: + positive relationship, – negative relationship, 0 no statistically significant relationship; larger symbols indicated Tier 1 studies

TABLE 3-5 Measures of Physical Activity Used in Physical Activity Studies

Category	Measures	Studies
Walking	Walk for exercise (y/n)	(Ball, Bauman et al. 2001)
	Walk for exercise (minutes per week)	(Hovell, Sallis et al. 1989; Sallis, Hovell et al. 1992; Sallis, Johnson et al. 1997)
	Walk for recreation (y/n)	(Giles-Corti and Donovan 2002b)
	Walk for transport (y/n)	(Giles-Corti and Donovan 2002b)
	Walk for any purpose (y/n)	(Berrigan and Toriano 2002)
	Walk for any purpose (days per week or minutes per week)	(Ross 2000; De Bourdeaudhuij, Sallis et al. 2003)
	Walk at recommended levels (y/n)	(Giles-Corti and Donovan 2002b)(Giles-Corti, Macintyre et al. 2003)
	Used walking trails (y/n)	(Brownson, Housemann et al. 2000)
	Increased use of walking trails (y/n)	(Brownson, Housemann et al. 2000)
Other Physical Activity	Leisure time physical activity other than walking (y/n)	(Berrigan and Toriano 2002)
	Moderate intensity physical activity (minutes per week)	(De Bourdeaudhuij, Sallis et al. 2003; Saelens, Sallis et al. 2003a)
	Vigorous intensity physical activity (minutes per week)	(De Bourdeaudhuij, Sallis et al. 2003; Saelens, Sallis et al. 2003a)
	Vigorous exercise (times per week)	(Sallis, Hovell et al. 1989; Sallis, Hovell et al. 1992; Sallis, Johnson et al. 1997)
	Change in vigorous exercise (by category)	(Sallis, Hovell et al. 1992)
	Level of vigorous activity (4 point scale)	(Rutten, Abel et al. 2001)
	Strength exercise (days per week)	(Sallis, Johnson et al. 1997)
	Participation in recreational activities (hours per week)	(Shaw, Bonen et al. 1991)
	Use of facilities (y/n)	(Giles-Corti and Donovan 2002a)
	Use of bikeway (y/n)	(Troped, Saunders et al. 2001)
Total Physical Activity	Active vs. Inactive	(MacDougall 1997; Centers for Disease Control and Prevention 1999; Booth, Owen et al. 2000; King, Castro et al. 2000; Wilcox, Castro et al. 2000; Stahl, Rutten et al. 2001; Craig, Brownson et al. 2002)
	Meeting recommendations for activity or exercising as recommended (y/n)	(Brownson, Baker et al. 2001; Giles-Corti and Donovan 2002a; Eyler, Matson-Koffman et al. 2003; Parks, Housemann et al. 2003; Powell, Martin et al. 2003a)
	Sedentary vs. Exerciser or does any physical activity vs. does none	(Sallis, Hovell et al. 1990; Eyler, Matson-Koffman et al. 2003)
	Total physical activity (minutes per week)	(Saelens, Sallis et al. 2003a)

TABLE 3-6 Measures of the Built Environment in Physical Activity Studies

Category	Measure	Studies
Perceived Measures		
Land Use	Density of pay and free facilities	(Sallis, Hovell et al. 1990)
	Neighborhood character (residential, mixed, commercial)	(Troped, Saunders et al. 2001)
	Residential density (3 items)	(De Bourdeaudhuij, Sallis et al. 2003)
	Land-use mix—diversity (13 items)	(De Bourdeaudhuij, Sallis et al. 2003)
Accessibility	Access to facilities or places (y/n)	(Booth, Owen et al. 2000; Brownson, Baker et al. 2001; Parks, Housemann et al. 2003)
	Access to local shopping (2 items)	(De Bourdeaudhuij, Sallis et al. 2003)
	Places within walking distance (y/n)	(Eyler, Matson-Koffman et al. 2003)
	Convenience to facilities (y/n or 5 point scales, multiple items)	(Hovell, Sallis et al. 1989; Sallis, Hovell et al. 1989; Shaw, Bonen et al. 1991; Sallis, Hovell et al. 1992; Sallis, Johnson et al. 1997; Ball, Bauman et al. 2001; De Bourdeaudhuij, Sallis et al. 2003)
	Physical activity related opportunities (5 point scales)	(Rutten, Abel et al. 2001; Stahl, Rutten et al. 2001)
	Places to exercise (y/n) or number of places to exercise	(Eyler, Matson-Koffman et al. 2003; Parks, Housemann et al. 2003)
	Places to walk (y/n)	(Powell, Martin et al. 2003)
	Exercise equipment at home (y/n or # items)	(Hovell, Sallis et al. 1989; Sallis, Hovell et al. 1989; Sallis, Hovell et al. 1992; Sallis, Johnson et al. 1997; Booth, Owen et al. 2000; De Bourdeaudhuij, Sallis et al. 2003)
	Worksite environment (10 items)	(De Bourdeaudhuij, Sallis et al. 2003)
	Satisfaction with recreation facilities (5 point scale) or adequacy of facilities (y/n)	(Shaw, Bonen et al. 1991; MacDougall 1997)
	Satisfaction with neighborhood services (2 items)	(De Bourdeaudhuij, Sallis et al. 2003)
	Distance from bikeway, steep hill, busy street to cross	(Troped, Saunders et al. 2001)
	Ease of walking to transit stop (1 item)	(De Bourdeaudhuij, Sallis et al. 2003)
Design	Neighborhood aesthetics (5 point scale or 4 items)	(Ball, Bauman et al. 2001; Giles-Corti and Donovan 2002b; De Bourdeaudhuij, Sallis et al. 2003)
	Satisfaction with living environment (5 point scale) or emotional satisfaction with neighborhood (4 items)	(MacDougall 1997; De Bourdeaudhuij, Sallis et al. 2003)
Safety	Safe for walking (y/n or 5 point scale)	(Booth, Owen et al. 2000; King, Castro et al. 2000; Wilcox, Castro et al. 2000; Troped, Saunders et al. 2001)
	Safe from crime (4 point scale or y/n or 2 items)	(Centers for Disease Control and Prevention 1999; De Bourdeaudhuij, Sallis et al. 2003; Eyler, Matson-Koffman et al. 2003)
	Safe from traffic (2 items)	(De Bourdeaudhuij, Sallis et al. 2003)
Neighborhood Characteristics	Sidewalks (y/n)	(Hovell, Sallis et al. 1989; Sallis, Hovell et al. 1989; Sallis, Hovell et al. 1992; Sallis, Johnson et al. 1997; King, Castro et al. 2000; Wilcox, Castro et al. 2000; Brownson, Baker et al. 2001; Troped, Saunders et al. 2001; Giles-Corti and
	Heavy traffic (y/n)	
	Hills (y/n)	
	Streetlights (y/n)	
	Unattended dogs (y/n)	
	Enjoyable scenery (y/n)	

Category	Measure	Studies
	Frequently see others exercising (y/n)	Donovan 2002b; De Bourdeaudhuij, Sallis et al. 2003; Eyler, Matson-Koffman et al. 2003)
	High levels of crime (y/n)	
	Bike lanes (2 items)	(De Bourdeaudhuij, Sallis et al. 2003)
	Connectivity (2 items)	(De Bourdeaudhuij, Sallis et al. 2003)
Objective Measures		
Transportation	Length of trail	(Brownson, Housemann et al. 2000)
Accessibility	Access to built facilities (gravity measure)	(Giles-Corti and Donovan 2002a; Giles-Corti and Donovan 2002b; Giles-Corti, Macintyre et al. 2003)
	Access to natural facilities (gravity measure)	(Giles-Corti and Donovan 2002a; Giles-Corti and Donovan 2002b; Giles-Corti, Macintyre et al. 2003)
	Distance to trail or bikeway	(Brownson, Housemann et al. 2000; Troped, Saunders et al. 2001)
	Steep hill on way to bikeway	(Troped, Saunders et al. 2001)
	Busy street to cross on way to bikeway	(Troped, Saunders et al. 2001)
Design	Neighborhood characteristics	(Craig, Brownson et al. 2002; Giles-Corti and Donovan 2002a; Giles-Corti and Donovan 2002b; Giles-Corti, Macintyre et al. 2003)
	Trail surface (asphalt vs. chat, woodchips)	(Brownson, Housemann et al. 2000)
Neighborhood Type	Year when home built (age of house)	(Berrigan and Toriano 2002)
	Population of community	(Brownson, Housemann et al. 2000)
	City vs. suburb vs. small city	(Ross 2000)
	High-walkability vs. low-walkability neighborhood	(Saelens, Sallis et al. 2003a)

TABLE 3-7 Summary of Findings on Physical Activity by Physical Activity Type and Built Environment Measure

Category	Measure	Walking	Other Physical Activity	Total Activity
Perceived Measures				
Land Use	Density of pay and free facilities			+
	Neighborhood character (residential, mixed, commercial)		0	
	Residential density (3 items)	00	00	
	Land-use mix – diversity (13 items)	+0	00	
Accessibility	Access to facilities or places (y/n)			+++
	Access to local shopping (2 items)	00	+0	
	Places within walking distance (y/n)	0		0
	Convenience to facilities (y/n or 5 point scales)	+0000	-++0000	
	Physical activity related opportunities (5 point scales)			++
	Places to exercise (y/n) or number of places to exercise			+0
	Places to walk (y/n)			+
	Exercise equipment at home (y/n or #items)	0000	++++00	0
	Worksite environment (10 items)	00	+0	
	Satisfaction with recreation facilities (5 point scale) or adequacy of facilities (y/n)		-	+
	Satisfaction with neighborhood services (2 items)	00	+0	
	Distance from bikeway, steep hill, busy street to cross		-	
	Ease of walking to transit stop (1 item)	+0	00	
Design	Neighborhood aesthetics (5 point scale)	++00	00	
	Satisfaction with living environment (5 point scale) or emotional satisfaction with neighborhood (4 items)	00	+0	0
Safety	Safe for walking (y/n or 5 point scale)	0	0	+00
	Safe from crime (4 point scale or y/n)	00	00	+0
	Safe from traffic (2 items)	00	00	
Neighborhood Characteristics	Sidewalks (y/n)	++++00	000	++000
	Heavy traffic (y/n)	+0	0	+00
	Hills (y/n)	0	0	++0
	Streetlights (y/n or 3 point scale)	0o	0	-000
	Unattended dogs (y/n)	0	0	-+00

Category	Measure	Walking	Other Physical Activity	Total Activity
	Enjoyable scenery (y/n)	0	0	-+++
	Frequently see others exercising (y/n)	0	0$_0$	++
	High levels of crime (y/n)	0	0	00
	Bike lanes (2 items)	00	00	
	Connectivity (2 items)	00	00	
Objective Measures				
Transportation	Trail length	+		
Accessibility	Access to built facilities (gravity measure)	$_+$00	+	-
	Access to natural facilities (gravity measure)	-++$_0$	+	0
	Distance to trail or bikeway	-	-	
	Steep hill on way to bikeway		-	
	Busy street to cross on way to bikeway		0	
Design	Neighborhood characteristics	++$_{++}$		+
	Trail surface (asphalt vs. chat, woodchips)	+		
Neighborhood Type	Age of house	+	0	
	Population of community	+ /-		
	City (vs. suburb or small city)	+	0	
	High-walkability vs. low-walkability neighborhood		+	+

Key: + positive relationship, - negative relationship, 0 no statistically significant relationship; larger symbols indicated Tier 1 studies

TABLE 3-8 Comparison of Typical Characteristics of Studies from Travel Behavior Literature and Physical Activity Literature

	Travel Behavior Literature	Physical Activity Literature
Theory	None Utility-Maximizing Theory	Ecological Model Social Cognitive Theory Theory of Planning Behavior
Study Designs	Cross-sectional	Cross-sectional
Physical Activity Measures	Walking, Walking/Biking, Non-motorized travel: frequency, share, choice	Walking, other physical activity, total physical activity: yes/no, as recommended, time, frequency
Source for Physical Activity Measures	Diary surveys	Self-report
Built Environment Measures	Objective	Perceived Objective
Control Variables	Sociodemographic characteristics	Sociodemographic characteristics Individual and interpersonal variables
Associations Found	Accessibility Neighborhood type	Accessibility Neighborhood characteristics

Assumed Causal Models

```
┌──────────────┐              ┌──────────────┐
│ Walkable     │              │ Walking      │
│ Environment  │─────────────▶│ Levels       │
└──────────────┘              └──────────────┘

┌──────────────┐              ┌──────────────┐
│ Home         │              │ Physical     │
│ Exercise     │─────────────▶│ Activity     │
│ Equipment    │              │ Levels       │
└──────────────┘              └──────────────┘
```

Possible Alternative Causal Models

```
                              ┌──────────────┐
                              │ Walkable     │
┌──────────────┐             ┌│ Environment  │            ┌──────────────┐
│ Preference   │─────────────▶└──────────────┘───────────▶│ Walking      │
│ for Walking  │──────────────────────────────────────────▶│ Levels       │
└──────────────┘                                           └──────────────┘

                              ┌──────────────┐
                              │ Home         │
┌──────────────┐             ┌│ Exercise     │            ┌──────────────┐
│ Preference   │─────────────▶│ Equipment    │───────────▶│ Physical     │
│ for          │              └──────────────┘             │ Activity     │
│ Exercise     │──────────────────────────────────────────▶│ Levels       │
└──────────────┘                                           └──────────────┘
```
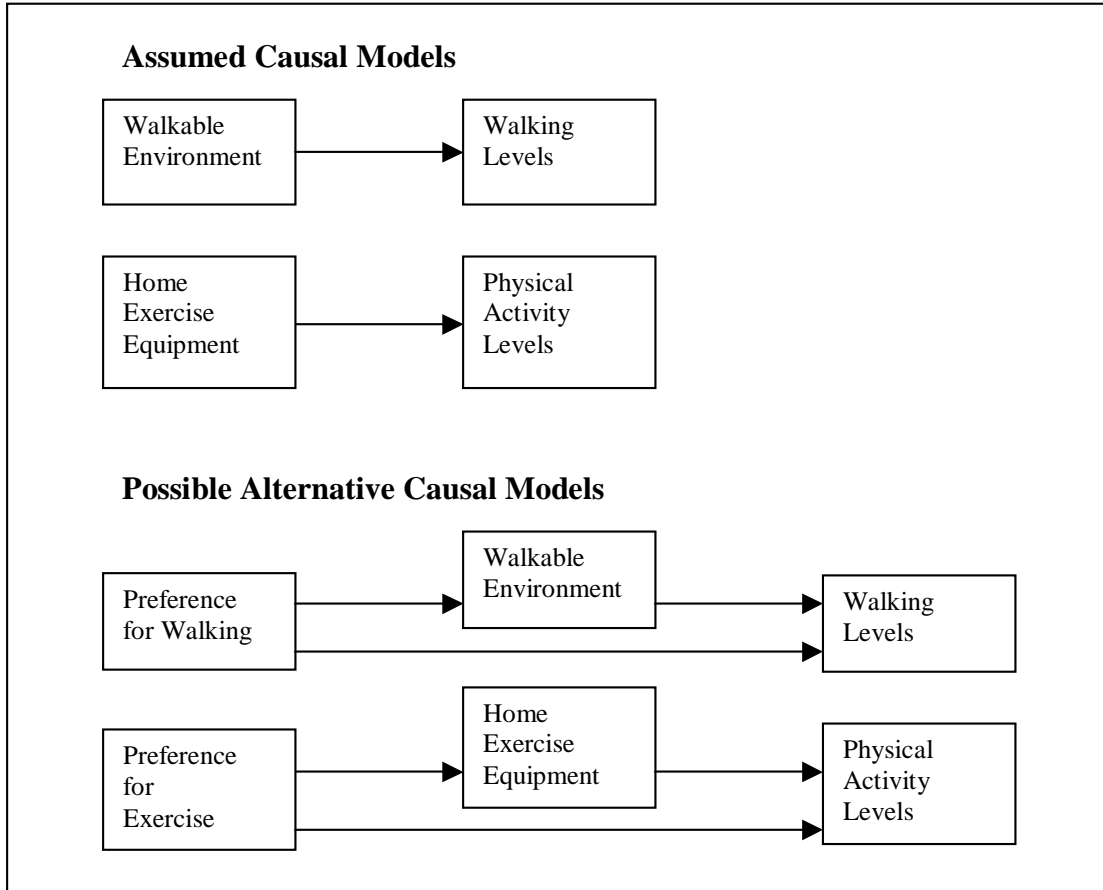
FIGURE 4-1 Assumed causal models vs. possible alternative causal models.
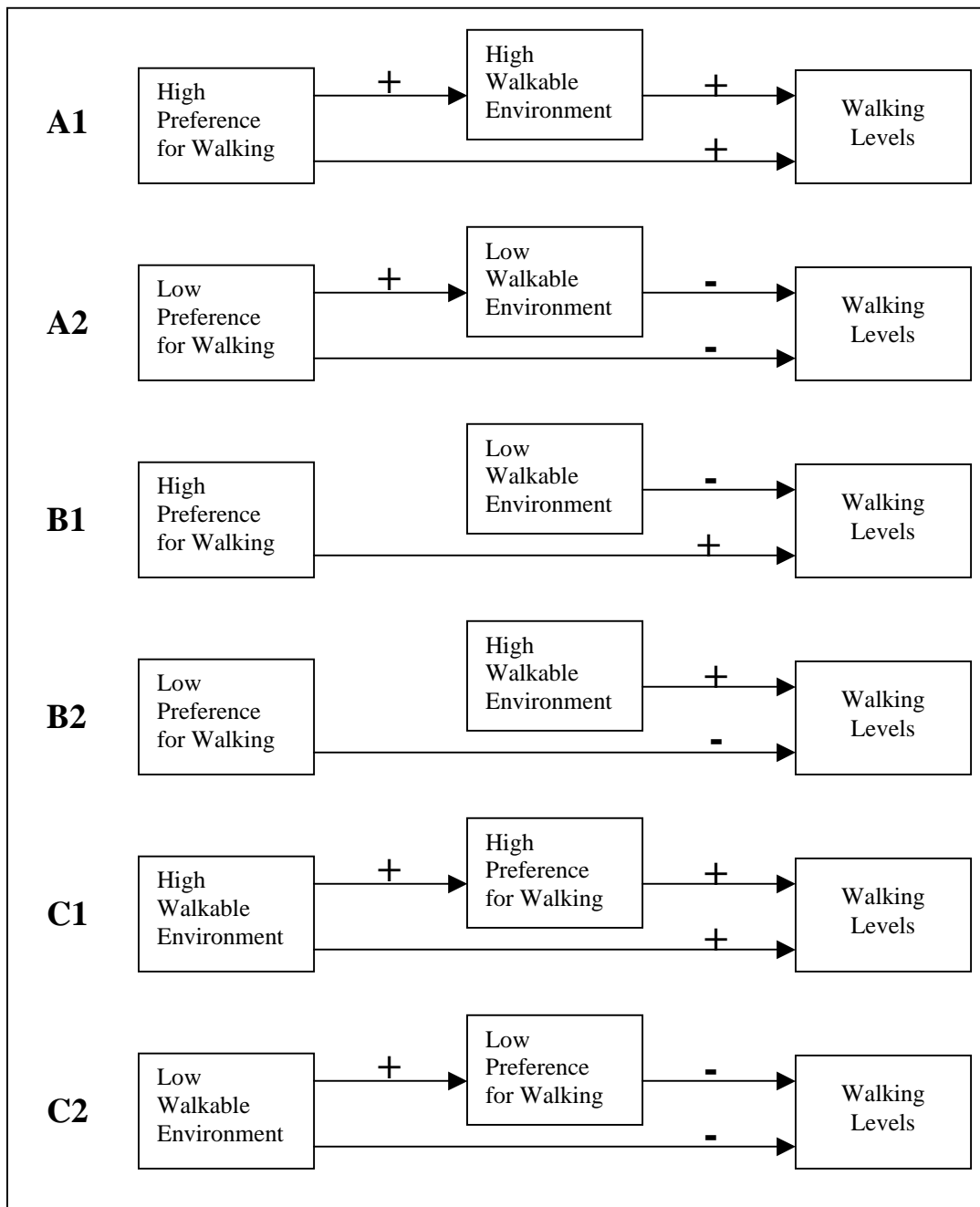
FIGURE 4-2 Hypothesized relationships.
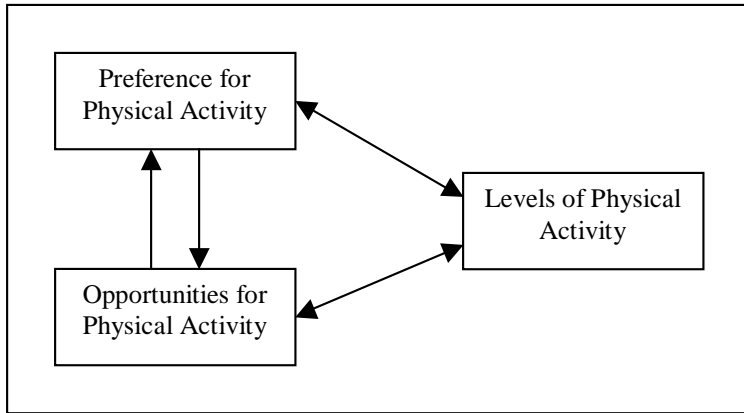
FIGURE 4-3 Generalized model.

TABLE 4-1 Causal Roles of Built Environment

Initial Preferences for Walking	Walkability of Neighborhood	Causal Roles of Built Environment	Likelihood?
High	High	Enabler of walking Reinforcer of preferences	High High
High	Low	Constraint on walking Promoter of lower preferences	High Moderate
Low	High	Encourager of walking Promoter of higher preferences	Low Moderate
Low	Low	Discourager of walking Reinforcer of preferences	High High

TABLE 4-2 Average Walks to Store by Importance of Being Within Walking Distance in Decision to Live in Current Neighborhood

Importance of "stores within walking distance"	Average walking trips to store in last 30 days	N
1 = Not at all important	0.92	317
2	1.02	260
3	2.19	370
4	4.41	212
5 = Extremely Important	7.10	141
All respondents	2.54	1300
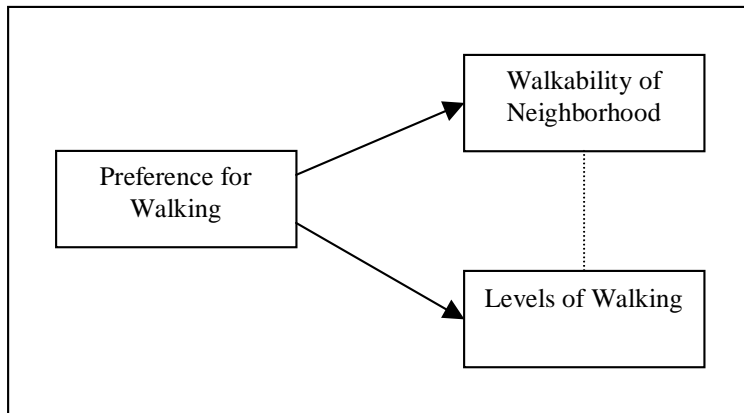
FIGURE 4-4 Potential spurious relationship.
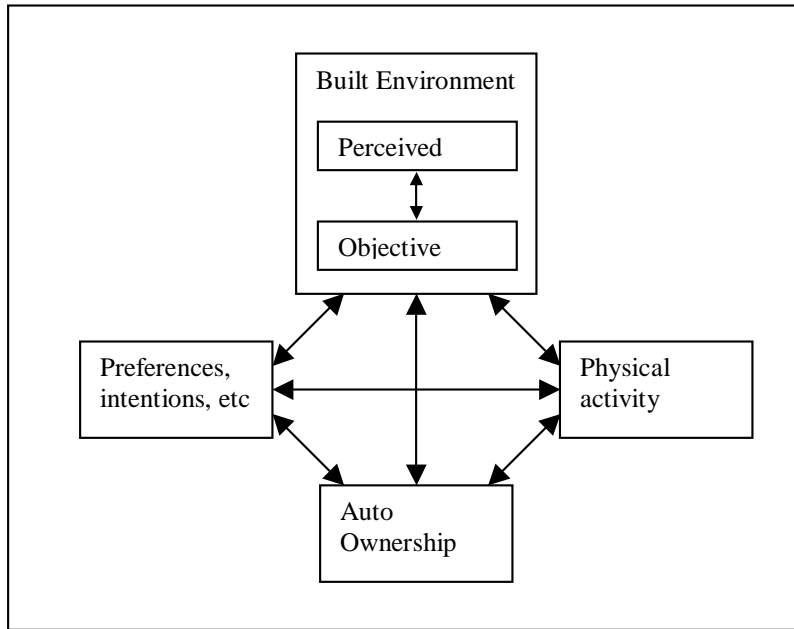
FIGURE 5-1 Expanded conceptual model.

Summary of Existing Research - Travel Behavior Literature

Study	Sampling1	Survey	Active Travel Variable	Controls/confounders	Built Environment Variable2	Results
Tier I Studies						
Bagley and Mokhtarian 2002	515 individuals in 5 neighborhoods in San Francisco Bay Area	1992 3-day travel diary survey	Natural log of walk/bike miles	Age Gender Household size Number of children under 16 Number of vehicles Yrs lived in Bay Area Lifestyle factors (7 factors) Attitudes (10 factors)	Suburban factor Traditional factor	Not significant

Cervero and Duncan 2003	7,889 trips, trips as unit of analysis	2000 Bay Area Travel Survey, two-day activity diary survey, cross-sectional	Choice of walking or biking (with variables for weekend trip, recreation/entertainment, eating/meal, social, shopping purposes)	Disability
				Gender
				Race
				Auto ownership
					ConstraintsDeterrents:
					  Trip distance
					  Slope
					  Rainfall day of trip
					  Dark at time of trip
					  Low-Income neighborhood Characteristics:
					  Employment accessibility
					  Ped/bike design at origin
					  Ped/bike design at destn
					  Land-use diversity - origin
					  Land-use diversity - destn
						Choice of walking:
						-distance
						-slope
						-rainfall
						+land-use diversity - origin
						+weekend trip, recreation/ entertainment, eating/meal, social, or shopping purpose
						Choice of biking:
						-distance
						-dark
						+recreation/entertainment or social purpose
						(logit model)

Summary of Existing Research - Travel Behavior Literature

Study	Sampling1	Survey	Active Travel Variable	Controls/confounders	Built Environment Variable2	Results
Greenwald and Boarnet 2001	1091 residents from Portland region	1994 Portland Travel Survey, 2-day travel diary survey, cross-sectional	Number of walk trips in two days	Age Gender Race Income Square of income Number of children under 16 Cars per driver Employees per household Workday	Population density in block group Population density in zip code Retail density in one mile grid cell Retail density in zip code Percent of network that is a grid Pedestrian environment factor (3 point scale): ease of street crossing, sidewalk continuity, street connectivity, topography Median walk distance Median walk speed	Number of walk trips: + population density + retail density + percent of network that is a grid + pedestrian environment factor + median walk distance + median walk speed (ordered probit model)
Handy, Clifton, and Fisher 1998 and Handy and Clifton 2001*	1368 residents in six neighborhoods in Austin, TX	1994 recal mail survey, cross-sectional	Number of strolling trips per month Number of walking trips to commercial area per month	Age Gender Employment statuts Presence of kids under age 5 Income Pet to walk	Network distance to nearest commercial area (using GIS) Perceptual factors related to safety, shade, houses, scenery, traffic, people, stores, walking incentive, walking comfort	Number of strolling trips: +perceived safety +perceived shade +perceived people +Old West Austin neighborhood Number of walking trips to commercial areas: -distance +perceived stores +perceived walking incentive +perceived walking comfort +Old West Austin neighborhood +strolling frequency (linear regression, 15% and 29% of variation explained)

Summary of Existing Research - Travel Behavior Literature

Study	Sampling[1]	Survey	Active Travel Variable	Controls/confounders	Built Environment Variable[2]	Results
Kitamura, Mokhtarian, and Laidet 1997*	1,380 individuals in 5 neighborhoods in San Francisco Bay Area	1992 3-day travel diary survey	Number of non-motorized trips Percent non-motorized trips for all trips	Age Gender Education level Employment status Homemaker (y/n) Student (y/n) Professional (y/n) Drivers licence (y/n) Household size Number of persons over 16 years Number of autos Household income Number of years in Bay Area Apartment/single-family home Attitudes (9 factors)	Study area Macro-scale descriptors (y/n): BART access, mixed land use, high density Pedestrian/bicycle facility indicators (y/n): sidewalk, bike path Micro-scale accessibility indicators: distance to nearest bus stop, rail station, grocery store, gas station, park Perceptions of quality of residential neighborhood: no reason to move, street pleasant for walking, cycling pleasant, good local transit service, enough parking, problems of traffic congestion	Number of non-motorized trips: +North SF neighborhood +BART access +sidewalk Share of non-motorized trips: +high density -distance to nearest bus stop -distance to nearest park (linear regression)

Summary of Existing Research - Travel Behavior Literature

Study	Sampling1	Survey	Active Travel Variable	Controls/confounders	Built Environment Variable2	Results
Kockelman 1997*	9000 households; trips as unit of analysis	1990 Bay Area Travel Survey, one-day travel diary survey, cross-sectional	Choice of walk or bike for all trips by adults	Age Gender Race Household size (members over age 5) Auto ownership Income per household member Drivers license Employment status Professional job	Population density in origin zone, destination zone Employment density in origin zone, destination zone Accessibility (gravity measure, sales and service jobs w/in 30 minutes by walk mode) in origin zone, destination zone Land use balance (entropy index, 6 land use types) for zone, mean for all zones w/in 0.5 miles General land use mix (dissimilarity index, 4 land use types) Detailed land use mix (dissimilarity index, 11 land use types)	Choice of walk or bike: +accessibility in origin zone +accessibility in destination zone (+0.22 elasticity) +mean non-work entropy in origin zone +mean entropy in destination zone (+0.23 elasticity) (logit model)
Krizek 2003	550 households that moved between 1989 and 1997 in Puget Sound, WA region	1989 and 1997 Puget Sound Transportation Panel, 2-day travel diary survey, longitudinal	Percent of trips by walking	Number of vehicles Number of adults Number of kids Number of workers Income	Neighborhood accessibility: density (housing units per acre), land use mix (number of employees of selected types), average block area; measured for 150m grid cells, averaged over all grid cells within 0.4 km Regional accessibility (gravity measure)	Percent of trips by walking: not significant

Summary of Existing Research - Travel Behavior Literature

Study	Sampling[1]	Survey	Active Travel Variable	Controls/confounders	Built Environment Variable[2]	Results
US Environmental Protection Agency 2003	709 trips to K-12 school, trips as unit of analysis	2001 Gainesville Metropolitan Transportation Planning Organization Survey and 2000 Florida Department of Transportation Survey, one-day travel diary survey, cross-sectional	Choice of walking to school Choice of biking to school	Income Cars per household Drivers license	Overall density (jobs and employment) Commercial floor area ratio Percent of streets with sidewalks Average sidewalk width Street density Pedestrian environment factor Walk time to school Bike time to school	Choice of walking: - walk time + sidewalk coverage Choice of biking: - bike time (logit model)

Tier 2 Studies

Study	Sampling[1]	Survey	Active Travel Variable	Controls/confounders	Built Environment Variable[2]	Results
Black, Collins, and Snell 2001	4214 parents at 51 selected infant schools in two regions in the United Kingdom	1996 recall survey distributed through schools	Percent walking as usual mode to school	Full-time home maker Only 1 car Southern county	Distance to school	Percent walking: -distance (<0.5 miles - 89.5% walk, 0.3% bike; 0.5 to 1 mile - 66.4% walk, 1.2% bike; 1.1 to 2 miles - 27.7% walk, 2.0% bike; >2 miles - 5.5% walk, 0.8% bike) (not statistically tested)

Summary of Existing Research - Travel Behavior Literature

Study	Sampling1	Survey	Active Travel Variable	Controls/confounders	Built Environment Variable2	Results
Cervero and Gorham 1995*	26 neighborhoods, 14 pairs in San Francisco Bay Area, 12 pairs in Los Angeles region	1990 U.S. Census, cross-sectional	Number of walk trips to work Percent walk trips to work	Neighborhoods matched for income	Transit versus automobile neighborhood	Number of walk trips: +transit neighborhoods (23 to 142 more walk trips per 1000 households in SF Bay area; from 1 to to 179 more walk trips per 1000 households in Los Angeles region) Percent walk trips: +transit neighborhoods (1.2 to 13.4 percentage points more walk trips in SF Bay Area, from 1.7 to 24.6 percentage points more walk trips in Los Angeles region)
Cervero 1996*	42,200 housing units in 11 metropolitan statistical areas; trips as unit of analysis	1985 American Housing Survey, questionnaire on commuting, cross-sectional survey	Choice of walk or bike as princpal commute mode	Residence in central city (y/n) Number of autos Household income Highway or railroad or airport w/in 300 ft (y/n) Public transit adequate in neighborhood (y/n) Distance from home to work	Single-family housing w/in 300 ft (y/n) Low-rise multifamily housing w/in 300 ft (y/n) Mid-rise multifamily housing w/in 300 ft (y/n) High-rise multifamily housing w/in 300 ft (y/n) Commercial or non-residential building w/in 300 ft (y/n) Grocery or drug store between 300 ft and 1 mile (y/n)	Walk/bike choice: -single-family -ratio of single-family to multi-family low-rise +mid-rise multi-family +high-rise multi-family +commercial nearby -grocery or drug between 300 ft and 1 mile (logit model)

Summary of Existing Research - Travel Behavior Literature

Study	Sampling1	Survey	Active Travel Variable	Controls/confounders	Built Environment Variable2	Results
Cervero and Radisch 1996*	620 households for non-work survey, 840 households for work survey in six census tracks in two neighborhoods in East Bay in San Francisco Bay Area	1994 recall mail surveys, one for work trips, one for non-work trips, cross-sectional	Choice of non-auto mode for nonwork trips Choice of non-auto mode for work trips	Household size Vehicles per household Annual salary of respondent	Pedestrian versus automobile neighborhood	Choice of non-auto mode for nonwork trips: +traditional Choice of non-auto mode for work trips: not significant (logit model)
Ewing, Haliyur, and Page 1995*	163 households from 6 communities in Palm Beach County, FL	c. 1994 Palm Beach County, FL Travel Survey, two-day travel diary survey, cross-sectional	Percent walk or bike trips of all trips	None	Neighborhood	Percent walk or bike trips: not significant (ANOVA)

Summary of Existing Research - Travel Behavior Literature

Study	Sampling[1]	Survey	Active Travel Variable	Controls/confounders	Built Environment Variable[2]	Results
Frank and Pivo 1995*	1,680 households, weighted to regional total in Puget Sound, WA region, census tract as unit of analysis	1989 Puget Sound Transportation Panel survey, two-day travel diary survey, cross-sectional	Percent walk trips for work trips for census tract Percent walk trips for shopping trips for census tract	Mean age for residents of tract Household type (defined by number of adults and age, share for tract) Drivers license (share for tract) Trips made by employed resident (share of trips ends in tract) Trips made by residents with bus pass (share of trip ends in tract) Trips made by residents with access to less than 1 vehicle (share of trip ends in tract), Mean number of vehicles available per participant ending trip in tract	Gross popuation density at origin Gross population density at destination Gross employment density at origin Gross employment density at destination Land use mix at origin (entropy measure) Land use mix at destination (entropy measure)	Percent walk trips for work: +employment density at origin +population density at origin +population density at destination +land use mix at origin +land use mix at destination Percent walk trips for shopping: +employment density at trip destination +population density at trip origin +population density at destination (linear regression; 31% and 35% of variation explained)
Friedman, Gordon, and Peers 1994*	Selected zones from 550 zones in San Francisco Bay Area region	1980 Bay Area Travel Survey, one-day travel diary survey, cross-sectional	Average number of walk trips per day per household Average number of bicycle trips per day per household Percent walk trips for zone Percent bike trips for zone (all by purpose)	None	Traditional versus standard suburban communities	Number of walk trips: +traditional (1.06 versus 0.83) Number of bike trips: +traditional (0.35 versu 0.24) Percent walk trips: +traditional (12% vs. 8%) Percent bike trips: +traditional (4% vs. 2%) (no statistical testing)

Summary of Existing Research - Travel Behavior Literature

Study	Sampling1	Survey	Active Travel Variable	Controls/confounders	Built Environment Variable2	Results
Handy 1996*	400 residents in four neighborhoods in San Francisco Bay Area	1992 recall phone survey, cross-sectional	Number of strolling trips per month Percent of residents strolling at least once per month Number of walking trips to commerical area per month Percent of residents walking to commercial area at least once per month	Household type (defined by number of adults, work status)	Traditional versus suburban neighborhood	Average strolling frequency: Not significant Percent of residents strolling: Not significant Walking trips to commercial area: +traditional (4.8 to 5.7 vs. 1.0 to 2.8 walks per month) Percent walking to commercial areas: +traditional (56% to 64% vs. 33% to 48%) (ANOVA)
Hanson and Schwab 1987	278 households stratified by life-cycle stage in Uppsala, Sweden	c. 1971 Uppsala 35-day travel diary survey, cross-sectional	Percent of all stops by non-motorized modes Percent of work stops by non-motorized modes	Gender Employment status Automobile availability	Home-based accessibility Work-based accessibility (number of establishments by 0.5 km intervals, weighted by distance, using Euclidean distance)	Percent of all stops: + home-based accessibility Percent of work stops: +home-based accessibility +work-based accessibility (correlation coefficients)
Krizek 2000	550 households that moved between 1989 and 1997 in Puget Sound, WA region	1989 and 1997 Puget Sound Transportation Panel, 2-day travel diary survey, longitudinal	Percent of trips by alternative mode (transit, walk, bike) Change in percent of trips by alternative mode (transit, walk, bike)	None	LADUF rating: land use mix (number of employees of selected types), density (housing units and persons per square mile), urban form rating (average block area per grid cell); measured for 150m grid cells, averaged over all grid cells within 0.4 km Change in LADUF rating	Percent of trips by alternative mode: +LADUF (29% in high , 14% in medium, 6% in low LADUF) Change in percent of trips by alternative mode: -move from high to medium LADUF (9.9 percentage points) (t-tests)

Summary of Existing Research - Travel Behavior Literature

Study	Sampling1	Survey	Active Travel Variable	Controls/confounders	Built Environment Variable2	Results
McCormack, Rutherford, and Wilkinson 2001	663 households from throughout region, split into three zones; 300 households in each of three mixed land-use neighborhoods, neighborhood as unit of analysis	1989 Puget Sound Transportation Panel, 2-day travel diary survey, 1992 same survey implemented in 3 selected neighborhoods, cross-sectional	Percent walk trips for shopping trips for neighborhood Percent walk trips for all trips for neighborhood (only walk trips longer than 5 minutes)	None	Straight-line distance to nearest commercial stree Neighborhood type	Percent walk trips for shopping trips: -distance to nearest commercial street Percent walk trips for all trips: +walkable neighborhood (17.7 to 18.1 vs. 2.0 to 2.8) (No statistical testing)
McNally and Kulkarni 1997*	20 neighborhoods in Orange County, CA, neighborhood as unit of analysis	1991 Southern California Association of Governments, one-day activity diary survey, cross-sectional	Number of walk trips, percent walk trips	Income	Traditional neighborhood development, planned unit development, and mixed (classified based on rattio of cul-de-sacs to total intersections, ratio of 4-way to total intersections, intersections/acre, ratio of access points to development perimiter, commercial area to total area, population density)	Number of walk trips: Not significant Percent walk trips: Not significant (ANOVA)
Moudon, et al. 1997 and Hess, et al. 1999	12 sites in Seattle area, controlled for density, site as unit of analysis	c. 1996 observations for 16 hours at entry points across cordons for sites, cross-sectional	Number of pedestrians	None	Urban versus suburban neighborhood	Number of pedestrians: +urban neighborhood (38 vs. 12 pedestrians per hour per 1000 residents) (not statistically tested)

Summary of Existing Research - Travel Behavior Literature

Study	Sampling[1]	Survey	Active Travel Variable	Controls/confounders	Built Environment Variable[2]	Results
Parsons Brinckerhoof Quade and Douglas, Inc. 1993*	400 zones in Portland	1985 Portland Metro travel survey, one-day travel diary survey, cross-sectional	Percent walk or bicycle trips (for trips longer than 6 blocks) for zone	None	Pedestrian environment factor (3 point scale): ease of street crossing, sidewalk continuity, street connectivity, topography Residential density Transit access to employment (number of jobs within 30 minutes by transit)	Percent walk or bike trips: +PEF (from 1.4% in low PEF to 9.6% in high PEF to 18.6% in central business district) +residential density (from 2.0% at 0-2 households per acre to 10.4% at 5 or more households per acre) +transit access (from 2.0% at low access to 13.5% at high access) (no statistical testing)

*Included in Saelens, Sallis et al. 2003b.

[1]Unit of analysis is individual unless otherwise noted.

[2]Built environment variables are objectively measured unless otherwise noted.

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Tier 1 Studies						
Ball et al. 2001*	3392 adults in Australia	1996 Physical Activity Sruvey for state of New South Wales, cross-sectional survey	Walking vs. not walking for exercise in last 2 weeks	Age Gender Education level	Neighborhood aesthetics (5-point scales): neighborhood friendly, local area attractive, pleasant walking near home. Convience to facilities (5-point scales): park/beach within walking distance, cycle path accessible, shops within walking distance.	Walking: +neighborhood aesthetics (high 41% more likely to walk than low) +convenience to facilities (high 36% more likely to walk than low) (logistic regression)
Booth et al. 2000*	402 adults 60 years and older in Australia	1995 Supplement to the Population Survey Monitor by the Australian Bureau of Statistics, cross-sectional survey	Sufficiently active vs. inactive (based on vigorous activities, moderate activities, and walking for exercise, leisure, or recreation)	Age Gender Country of birth Marital status Employment status Living situation Attitudes	Exercise equipment at home (y/n) Feel safe walking during day (y/n) Footpaths safe for walking (y/n) Access to facilities (y/n): local exercise hall, recreation center, cycle paths, golf course, gym, park, swimming pool, tennis course, bowling green	Active: +footpaths safe for walking +access to recreation center +access to cycle track +access to golf course +access to park +access to swimming pool (logistic regression)

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Brownson, et al. 2001	1818 adults, U.S., modified BFRSS sampling plan, over-sampling of lower income individuals	1999-2000 cross-sectional phone survey , questions based on BFRSS, NHI, other surveys	Meeting recommedations for moderate or vigorous activity (y/n)	Age Gender Race/ethnicity Household income Education	Places to exercise (y/n): indoor, outdoor Specific access variables (y/n): walk/jog trail, neighborhood streets, park, shopping mall, indoor gym, treadmill Neighborhood characteristics (y/n): sidewalks, enjoyable scenery, heavy traffic, hills, streelights, unattended dogs, foul air from cars/factories Personal barriers (y/n): no safe place, bad weather	Meeting recommendations: +places to exercise indoor or outdoor +places to exercise outdoor only +walking/jogging trail +park +indoor gym +treadmill +sidewalks present +enjoyable scenery +heavy traffic +hills (Logistic regression)
Craig et al. 2002	27 neighborhoods in Canada (totaling 10,983 residents)	1996 Canadian Census, cross-sectional survey	Percent of residents walking to work	Income University education Poverty Degree of urbanization (urban, suburban, small urban)	Observations of 18 characteristics on 10-point scales; heirarchical linear modeling to create ecologic score for each neighborhood	Percent walking to work: +ecologic score (1 unit increase in score associated with 25 percentage point increase in walking)

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
DeBourdeaudhuij et al. 2003	521 adults in Ghent, Belgium	c. 2002 cross-sectional mail survey, using International Physical Activity Questionnaire (IPAQ)	Minutes of sitting, walking, moderate-intensity activities, vigorous-intensity activities in last 7 days	Age Gender Eduation level Employment status Occupation Living situation BMI	Neighborhood variables (3-, 5-, or 7-point scales): Residential density (3 items), land use mix—diversity (13), access to local shopping (2), ease of walking to transit stop (1), availability of sidewalks (1), availability of bikelanes (2), neighborhood aesthetics (4), perceived safety from crime (2), perceived safety from traffic (2), connectivity (2), satisfaction with neighborhod services (2), emotional satisfaction with neighborhood (4) Recreational Variables: (7-point scales or y/n) Worksite environment (10 items), physical activity equipment at home (13), convenience of physical activity facilities (18)	Women: Sitting : -perceived safety from crime +land use mix - diversity Walking: +availability of sidewalks Moderate Activity: +physical activity equipment in home +satisfaction with neighborhood services Vigorous activity: +physical activity equipment in home +convenience of physical activity facilities Men: Sitting: -emotional satisfaction with neighborhood Walking: +land use mix - diversity +ease of walking to transit stop Moderate Activity: +access to local shopping +emotional satisfaction with neighborhood Vigorous Activity: +physical activity equipment in home +convenience of physical activity facilities +worksite environment

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Eyler et al. 2003	4122 women 20 to 50 years from diverse racial/ethnic groups (White, African American, Latina, and Native American)	2001-2002 Women and Physical Activity Survey, cross-sectional phone and interview survey	Meets recommendations for moderate or vigorous activity vs. doesn't meet Does any physical activity vs. does none	Racial/ethnic group Urban, rural, mixed settings	Traffic (3 point scale) Presence of sidewalks (y/n) Street lighting at night (3 point scale) Presence of unattended dogs (problem/not a problem) Safety from crime (y/n) Places within walking distance (y/n) Places to exercise (y/n)	Meets recommendations: African-American, Urban: -fair lighting (vs. poor) African-American, Mixed: +presence of sidewalks Native-American, Mixed: +unattended dogs not a problem White, Rural: -fair lighting (vs. poor) Does any activity: African-American, Rural: - very good/good lighting (vs. poor) Latina, Urban: -light traffic (vs. heavy)

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Giles-Corti, and Donovan 2002 (Prev Med)	1803 adults 18 to 59 years in Perth, Australia, excluded from study: unemployed, resident in suburb for less than 1 year, exercised as recommended at work, medical condition likely to affect physical activity, not proficient in English	1995-1996 cross-sectional in-person survey	Walking for transport in past 2 weeks (y/n) Walking for recreation in past 2 weeks (y/n) Walking at recommended levels (y/n, based on 12 or more sessions in 2 weeks totalling 360 minutes or more)	Age Gender Number of children under 18 Household income Education level Work outside home (y/n) Personal access to car (y/n) SES of area of residence	Access to built facilities (gravity measures by quartile, from GIS): sport and recreation centers, gyms, swimming pools, tennis courts, golf courses, Access to natural facilities (gravity measures by quartile, from GIS): attractive public open space, beach, river Physical environment determinant score (sum of three measures, divided into tertiles) Perceptions of neighborhood (5 point scale, 11 items, 3 factors): neighborhood attractiveness, safety and interest; social support for walking locally; traffic and traffic hazards Perceptions of (y/n): sidewalks, streets well lit, public transit within walking distance, park within walking distance, shop within walking distance	Walking for transport: -high access to beach (38% less) +high perception that neighborhood has lots of traffic (26% more) +sidewalks (65% more) +shops within walking distance (3 times) +sometimes access to motor vehicle (3.46 times) +no access to motor vehicle (4.13 times) Walking for recreation: +high access to beach (49% more than lower) +perception neighborhood attractive, safe, interesting (49% more) +sidewalks (41% more) Walking as recommended: +high access to public open space (43% more) +perception neighborhood attractive, safe, interesting (50% more) +sidewalks (65% more) +no access to motor vehicle (2.87 times) (logistic regression)

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Giles-Corti, and Donovan 2002 (Soc Sci Med)*	1803 adults 18 to 59 yrs in Perth, Australia	1995-1996 cross-sectional in-person survey	Exercising as recommended (y/n, based on walking for recreation and transportation, light-moderate physical activity, vigorous physical activity) Use of facilities (y/n)	Age Gender Number of children under 18 Household income Education level	Functional (y/n, observed): sidewalk, shop. Appeal: type of street, trees (y/n, observed), extent of tree coverage. Access to built facilities (gravity measures by quartile, from GIS): sport and recreation centers, gyms, swimming pools, tennis courts, golf courses. Access to natural facilities (gravity measures by quartile, from GIS): attractive public open space, beach, river. Physical environment determinant score (sum of three measures, divided into tertiles).	Exercising as recommended: -second tertile of access to built facilities relative to top tertile (29% less likely) +high physical environment score relative to low (43% more likely) Use of attractive open space: +access Use of river: +access Use of swimming pool: +access (logistic regression)
Giles-Corti and Donovan 2003 (AJPH)	1803 adults 18 to 59 years in Perth, Australia	1995-1996 cross-sectional in-person survey	Walking at recommended levels (y/n, based on 12 or more sessions in 2 weeks totalling 360 minutes or more)	Age Gender Number of children under 18 Household income Education level	Functional (y/n, observed): sidewalk, shop Appeal: type of street, trees (y/n, observed), extent of tree coverage Access to built facilities (gravity measures by quartile, from GIS): sport and recreation centers, gyms, swimming pools, tennis courts, golf courses, Access to natural facilities (gravity measures by quartile, from GIS): attractive public open space, beach, river Physical environment determinant score (sum of three measures, divided into tertiles)	Walking at recommended levels: +high physical environment score (2.13 times as likely as low score) +high access to attractive open space (1.47 times as likely as low access) (logistic regression)

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
King et al. 2000*	2912 women 40 years and older in U.S., modified BFRSS approach	1996-1997 U.S. Women's Determinant Study, cross-sectional survey	Active vs. underactive vs. sedentary over last 2 weeks (based on moderate activity and vigorous activity)	Age Race/ethnicity Employment status Marital status Education level Residence (urban/rural/other)	Presence of (y/n): sidewalks, heavy traffic, hills, streetlights, unattended dogs, enjoyable scenery, frequently see others exercising, high levels of crime. Safe to walk or jog alone during the day (5-point scale). Barriers (5-point scale): lack a safe place to exercise, poor weather.	Active: +hills +unattended dogs + enjoyable scenery +frequently see others exercising (logistic regression)
Troped et al. 2001*	413 adults with mean age 51 years in Arlington, MA	1998 cross-sectional mail survey	Use vs. nonuse of bikeway	Age Gender Physical activity limitation Education level	Neighborhood features (y/n): sidewalks, heavy traffic, hills, streetlights, unattended dogs, enjoyable scenery, frequently see others exercising, high levels of crime. Neighborhood character (3-point scale): rating of neighborhood as residential, mixed, or commercial. Neighborhood safety (5-point scales): how safe walking during day. Reported distance from bikeway. Reported steep hill on way to bikeway. Reported cross busy street to access bikeway.	Bikeway use: -reported distance (.65 times as likely for every 0.25 increase in distance) - busy street to cross (2 times as likely if no street to cross) (logistic regression)

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Troped et al. 2001*	413 adults with mean age 51 years in Arlington, MA	1998 cross-sectional mail survey	Use vs. nonuse of bikeway	Age Gender Physical activity limitation Education level	Network distance to bikeway (from GIS). Steep hill to bikeway (from GIS). Cross busy street to bikeway (from GIS).	Bikeway use: -distance to bikeway (0.58 times as likely for every 0.25 miles) -steep hill to bikeway (1.9 times as likely if no steep hill) (logistic regression)
Wilcox et al. 2000*	2,912 women 40 years and older in U.S., modified BFRSS sampling plan	1996-1997 U.S. Women's Determinant Study, cross-sectional survey	Active vs. underactive vs. sedentary over last 2 weeks (based on moderate activity and vigorous activity)	Age Race Education level Geographic region	Presence of (y/n): sidewalks, heavy traffic, hills, streetlights, unattended dogs, enjoyable scenery, frequently see others exercising, high levels of crime. Safe to walk or jog alone during the day (5-point scale). Barriers (5-point scale): lack a safe place to exercise, poor weather.	Not sedentary in rural women: +lack of scenery +frequency of seeing others exercising

Tier 2 Studies

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Berrigan and Troiano 2002	14,827 adults 20 years or older in U.S.	NHANES III, cross-sectional survey	Walk 1 or more miles 20 or more times per month (y/n) Leisure time physical activity other than walking 20 or more times per month (y/n)	Age Gender Race/ethnicity Household income Education Health-related activity limitation Region	Year when home built (<1946, 1946 to 1973, 1974 to present)	Walking: +Age of house (< 1946 43% more than 1974 to present house; 1946-1973 house 36% more than 1974 to present house) Leisure time physical activity: Not significant (logistic regression)

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Brownson et al. 2000	1,269 adults in 17 communities in 12 rural counties in Missouri, modified BFRSS method	1998 cross-sectional phone survey	Used walking trails (y/n, for those with access) Increased walking since using trails (y/n, for those with access)	Age Gender Race/ethnicity Marital status Education level Income	Population of community (<5,500, 5,500 to 10,000, more than 10,000). Trail length (<1/4 mile, 1/4 to 1/2 mile, >1/2 mile). Trail surface (asphalt, chat, woodchips). Distance to trail (< 5 miles, 5-10 miles, 11-29 miles, 30 or more miles).	Used walking trails: +5,500 to 10,000 population +1/4 to 1/2 mile length -chat surface (vs. asphalt) -woodships surface (vs. asphalt) Increased use: -population +trail length -chat surface (vs. asphalt) -distance to trail (20% to 30% less if 5 or more miles) (logistic regression)
CDC 1999*	12,767 adults in Maryland, Montana, Ohio, Pennsylvania, Virginia	1996 BFRSS, cross-sectional phone survey	Active vs. inactive (based on walking, moderate activity, and vigorous activity)	Gender Race/ethnicity Education level Income	Perception of safety from crime in neighborhood (4-point scale)	Active: +perceived safe from crime in neighborhood (logistic regression?)

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Hovell et al. 1989*	2,053 adults in San Diego	1986 Cross-sectional mail survey	Walking for exercise (number of minutes per week)	Age Gender Education level Smoking Alcohol Diet	Number of exercise-related items at home (10 items, y/n). Number of exercise facilities perceived as convenient (15 items, y/n). Neighborhood environment (scale?): safety of exercising in neighborhood, ease of exercising in neighborhood, frequency of seeing others exercising.	Walking: + neighborhood environment (linear regression, 12% of variance explained)
MacDougall et al. 1997*	1,765 adults in Adelaide, Australia	1987 cross-sectional mail survey by the South Australia Community Health Research Unit	Moderately active vs. inactive (based on moderate activity, vigorous sport, walking for exercise)	Age Education General health Social connections	Satisfaction with recreation facilities (5-point scale). Satisfaction with living environment (5-point scale).	Moderately active: +satisfied with recreation facilities (logistic regression)
Parks et al. 2003	1,818 adults, U.S., modified BFRSS sampling plan, over-sampling of lower income individuals	1999-2000 cross-sectional phone survey, questions based on BFRSS, NHI, other surveys	Meets public health recommendations vs. insufficient activity or inactive	Age Race Gender Stratified by urban, suburban, rural and by high and low income	Places to exercise (y/n): walk/jog trail, neighborhood streets, park, shopping mall, indoor gym, treadmill Number of places to exercise (0 to 4). Personal barriers (y/n): no safe place, bad weather.	Meets for Urban: +walking/joging trails +park +indoor gym +treadmill +other equipment +number of places Meets for Suburban: +walking/jogging trails +indoor gym Meets for Rural: +indoor gym +4 places to exercise

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Powell et al. 2003	4,532 adults in Georgia	2001 Georgia BFRSS	Meets physical activity recommendations	None	Some place to walk (y/n): Not home based: public park, school track, gym or fitness center, walking or jogging trail, shopping mall, other place. Home based: neighborhood streets or roads, neighborhood sidewalk, treadmill at home.	Meeting recommendations: +public park +school track +gym or fitness center +walking or jogging trail +other place +neighborhood streets or roads +neighborhood sidewalk
Ross 2000	2,482 adults in Illinois	1995 Survey of Community, Crime and Health, cross-sectional phone survey	Number of days walking per week Number of days of strenuous exercise per week	Age Gender Race Ethnicity Marital status Education Household income Below poverty line Neighborhood poverty, race, ethnicity, and education characteristics	City of Chicago vs. suburb of Chicago vs. small city vs. small town or rural area	Walking: +Chicago vs. small town or rural area
Rutten et al. 2001	3,343 adults, 6 European countries (Belgium, Finland, Germany, Netherlands, Spain, Switzerland)	MAREPS study, 1997-1998 cross-sectional phone survey	Level of vigorous activity (sedentary, not/somewhat vigorous, vigorous, very vigorous)	None	Perceived physical activity related opportunities: Residential area offers many opportunities to be physically active (5-point scale). Local clubs and other providers in community offer many opportunities (5-point scale). Community does not do enough for citizens and their physical activity (5-point scale).	From sedentary to not/somewhat vigorous: +perceived physical activity related opportunities (ANOVA)

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Saelens et al. 2003	107 adults, 2 neighborhoods in San Diego	c. 2002 cross-sectional mail survey and accelerometers	Moderate-intensity physical activity (minutes during last 7 days) Vigorous-intensity physical activity (minutes during last 7 days) Total physical activity (minutes during last 7 days)	Age Education level	High-walkability vs. low-walkability neighborhood	Moderate-intensity: +high-walkability (194.8 vs. 130.7 minutes) Total physical activity: +high-walkability (210.5 vs. 139.9 minute)
Sallis et al. 1989*	1,789 adults in San Diego	c. 1988 cross-sectional mail survey	Frequency of vigorous exercise (times per week for at least 20 minutes with increase in heart rate or breathing)	Age Gender Education level Smoking Alcohol Diet	Number of exercise-related items at home (10 items, y/n). Number of exercise facilities perceived as convenient (15 items, y/n). Neighborhood environment (scale?): safety of exercising in neighborhood, ease of exercising in neighborhood, frequency of seeing others exercising. Barriers (5-point frequency scale): lack of equipment, lack of facilities, lack of good weather.	Vigorous exercise: + home equipment (linear regression; 27% of variation explained with all variables included)
Sallis et al. 1990*	2,053 adults with mean of 48 years in San Diego		Sedentary vs. exerciser (based on 3 or more exercise sessions per week)	Age Education level Income	Density of pay and free facilities	Exerciser: +density of pay facilities

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Sallis et al. 1992*	1,719 adults in San Diego	propsective study: follow-up to Sallis et al. 1989; mail survey	Frequency of vigorous exercise (times per week for at least 20 minutes with increase in heart rate or breathing) Change in vigorous exercise over 24 months	Age Gender Education level Income Race/ethnicity Marital status Smoking	Number of exercise-related items at home (10 items, y/n). Number of exercise facilities perceived as convenient (15 items, y/n). Neighborhood environment (scale?): safety of exercising in neighborhood, ease of exercising in neighborhood, frequency of seeing others exercising. Barriers (5 point frequency scale): lack of equipment, lack of facilities, lack of good weather.	Change in vigorous activity in sedentary men: -neighborhood environment (linear regression)
Sallis et al. 1997*	110 college students with mean age 20.6 in San Diego	c. 1996 survey administered through college class	Walking for exercise (minutes/week) Strength exercise (days/week) Vigorous exercise (days/week)		Exercise facilities in home (y/n, 15 items). Neighborhood environment (sum of 3 items): Presence of (y/n): sidewalks, heavy traffic, hills, streetlights, dogs unattended, enjoyable scenery, crime; rating neighborhood as residential, commercial, or mixed; safe for walking during day (5-point scale). Convenient facilities: places to exercise on a frequently traveled route or within 5 minute walk (y/n, 18 places).	Walking for exercise: not significant Strength exercise: +home equipment Vigorous exercise: not significant (linear regression)
Shaw et al. 1991*	14,674 adults 18 to 69 years in Canada who wished to participate in more physical activity	1983 Canada Fitness Survey, cross-sectional survey	Participation in 35 recreational activities (hours per week)	Gender	No facilities nearby (y/n). Available facilities are inadequate (y/n).	Participation for women: +no facilities nearby +available facilities inadequate Participation for men: +available facilities inadequate (ANOVA)

Summary of Existing Research - Physical Activity Literature

Study	Sampling	Survey	Physical Activity Variable	Controls/Confounders[1]	Built Environment Variables	Results[2]
Stahl et al. 2001*	3,343 adults, 6 European countries (Belgium, Finland, Germany, Netherlands, Spain, Switzerland)	MAREPS study, 1997-1998 cross-sectional phone survey	Active vs. inactive (based on participation in any gymnastics, physical activity, or sports)	Age Gender Education level Country	Local opportunity scale (5-point scales): area offers many opportunities to be active, local clubs and other providers offer many opportunities, community doesn't do enough for citizens and their physical activity.	Active: +local opportunities (logistic regression)

*Included in Humpel, Owen, and Leslie 2002.

[1]Sociodemographic and geographic variables only; many studies include other individual measures and social environment measure

[2]Results of multivariate analyses reported when available