Self-Selection in the Relationship between the Built Environment and Walking

Available evidence establishes correlations between the built environment and walking, but not a causal relationship, leading researchers to debate whether "self-selection" explains the observed correlations: do residents who prefer to walk choose to live in more walkable neighborhoods? Using data from a survey of residents of eight neighborhoods in Northern California, this article presents new evidence on the possibility of a causal relationship between the built environment and walking behavior. This work improves on most previous studies by incorporating travel attitudes and neighborhood preferences into the analysis of walking behavior, and by using a quasi-longitudinal design to test the relationship between changes in the built environment and changes in walking. Both analyses show that the built environment has an impact on walking behavior even after accounting for attitudes and preferences.

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Empirical Evidence from Northern California

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These days it's hard to miss the fact that Americans are fatter than ever, and it's almost as hard to miss the fact that suburban sprawl is being blamed in the media and in some planning and public health circles for the obesity trend. The logic is simple: low-density, segregated-use suburbs are designed for driving rather than walking, leading people to drive more and walk less, thereby contributing to a decline in physical activity and an increase in weight. Indeed, recent studies show small but statistically significant correlations between suburban sprawl and obesity (McCann & Ewing, 2003) and between time spent driving and obesity (Frank, Andresen, & Schmid, 2004). The solution is, therefore, also apparently simple: design suburbs for walking rather than driving so people will walk more and drive less, thereby increasing physical activity and decreasing weight.

At first glance the evidence is persuasive, but on closer examination, it is less than conclusive. Studies have established a correlation between the built environment and walking behavior; residents of "walkable" neighborhoods walk more than residents of "nonwalkable" neighborhoods (Saelens, Sallis, & Frank, 2003). But as any good textbook on research methods reminds us, correlation does not necessarily mean causality. A correlation between the built environment and walking behavior does not mean that a change in the built environment will lead to a change in walking behavior. In particular, researchers are now debating the role of "self-selection" in explaining the observed correlations. Do residents who prefer to walk choose to live in more walkable neighborhoods? If so, planning still has an important role to play in creating environments that facilitate walking, especially if the supply of such environments is insufficient, a possibility suggested by Boarnet and Crane (2001) and supported empirically by surveys of developers and residents (Levine & Inam, 2004; Levine, Inam, Werbel, & Torng, 2002). But the impact on those not already motivated to walk may be limited.

Using data from a survey of residents of eight neighborhoods in Northern California, this article presents new evidence on the possibility of a causal relationship between the built environment and walking behavior, as well as biking behavior. This work improves on most previous studies by incorporating travel attitudes and neighborhood preferences into the analysis, and by using a quasi-longitudinal design to test the relationship between changes in the built environment and changes in walking. In both analyses, the results show that the built environment has an impact on walking behavior even after accounting for attitudes and preferences.

Literature Review

Two largely separate literatures provide evidence of a link between the built environment and walking. Travel behavior research, based in the fields of transportation engineering, planning, and geography, has focused on walking as a mode of transportation—walking to reach a destination. Physical activity research, based in the fields of psychology and public health, has focused on walking as a form of exercise. A recent review of these two literatures found little consistency in the measures of the built environment or even the measures of walking used in the studies, making it difficult to compare their results (Handy, 2005). Nevertheless, certain patterns emerge. Most notably, accessibility (measured in various ways) emerges as a strong correlate of walking behavior in both literatures, while the role of design variables is more ambiguous. However, the results vary depending on the kind of walking: distance to destinations is more important for walking as a mode of transportation, while design appears to be more important for recreational walking. Both literatures suggest that the built environment alone does not promote walking and may play a secondary role to personal factors.

The issue of causality has become one of the key questions in the debate over the link between neighborhood design and walking behavior. Good scientific practice dictates three criteria for establishing causality between an independent variable (the cause) and a dependent variable (the effect): the cause and effect are statistically associated (association), the cause precedes the effect in time (time order), and no third factor creates an accidental or spurious relationship between the variables (nonspuriousness). Many social scientists add a fourth criterion: the mechanism by which the cause influences the effect is known (causal mechanism; Singleton & Straits, 1999). Most studies so far have met the statistical association criterion but have not met the other three.

Specifically, almost all of the previous studies used nonexperimental cross-sectional designs that established an association between the built environment and walking behavior. However, these designs did not establish whether the cause preceded the effect. In addition, most previous studies controlled for sociodemographic characteristics, eliminating the possibility that income, for example, created a spurious relationship between the built environment and walking behavior. But few of these studies accounted for the effects of attitudes towards walking, thereby ignoring the possibility that associations between attitudes and the chosen built environment, and between attitudes and the choice to walk, created the appearance of a relationship between the built environment and walking. By failing to meet the time order and nonspuriousness criteria, these studies left open the possibility that individuals who preferred to walk "self-selected" into neighborhoods conducive to walking.

Researchers have used various means to address this problem, although most regional travel diary surveys do not include data on attitudes and preferences. Using data from the Puget Sound Transportation Panel to examine changes in travel behavior among residential movers over a 7-year period, Krizek (2000) found relatively weak correlations between the designs of neighborhoods they moved to and changes in their travel, and later a more convincing link between increased accessibility and decreased vehicle travel, though not increases in walking (Krizek, 2003). From the 1994 Portland Travel Diary, Greenwald and Boarnet (2001) used instrumental variables to account for the influence of unobserved preferences on residential location choice. Based on this analysis, they concluded that certain characteristics of the built environment do promote walking, even taking into account the possibility of self-selection.

A few researchers have addressed self-selection by creating their own surveys that ask about preferences and attitudes directly. In a study in Austin, Texas, Handy and Clifton (2001) found that walking differed significantly between neighborhoods of different types, but also that residents selected neighborhoods in part based on their walkability. Using structural equations modeling with data from the San Francisco Bay Area, Bagley and Mokhtarian (2002) found that associations between walking and neighborhood characteristics were largely explained by residents with certain attitudes and lifestyle preferences self-selecting into certain kinds of neighborhoods. On the other hand, when Schwanen and Mokhtarian (2005) used more recent cross-sectional data from the Bay Area, and noted that the type of neighborhood people prefer does not necessarily correspond to where they actually live, they found that neighborhood type does affect travel behavior even after attitudes are accounted for, especially in the suburbs. Using data from the Austin study, we recently found characteristics of the built environment to influence both walking to the store and neighborhood strolling after we accounted for residents' preferences for neighborhoods conducive to walking (Cao, Handy, & Mokhtarian, 2006). Similarly, Khattak and Rodriguez (2005), using survey data from Chapel Hill, NC, found significant differences between walking trips in two types of suburban neighborhoods after controlling for self-selection.

Researchers have provided limited explanations of how the built environment could affect walking. Boarnet and Crane (2001) offer an economic explanation: the built environment influences the price of travel, by affecting travel time and other qualities of travel, which in turn influences the consumption of travel. A similar idea is implicit in discrete choice models of travel behavior, in which individuals choose the alternative that maximizes their utility from among those offered. These models have been widely used to explain the choice of travel modes for a particular trip; in these applications, maximizing utility generally equates to minimizing travel time and other travel costs. Applying this theory to walking is quite possible though not straightforward. First, it is not clear that a decision to walk always represents a simple choice between walking and other modes. While the travel behavior literature generally assumes that demand for travel is derived from the demand for activities, this does not necessarily hold for walking (or even for driving, for that matter; Handy, Weston, & Mokhtarian, 2005; Mokhtarian & Salomon, 2001). For example, the walk itself may be the motivation for a trip (Handy, 1996), in which case the set of alternatives considered could include walking to the store, getting some other form of exercise, or forgoing exercise altogether. Second, evidence on what factors most influence the utility of walking is relatively slim, given the limited range of characteristics of the built environment measured in most surveys, and the factors almost certainly vary depending on whether the walk or the destination is the motivation for the trip.

Even more challenging is the likelihood that residential location, attitudes and preferences, and walking behavior all interact with each other over time, as depicted in Figure 1. If so, then different causal mechanisms may apply in different situations at different times, depending on the combination of the individual's preferences and residential environment (Handy, 2005). For example, for an individual with a high preference for walking who lives in a neighborhood conducive to walking, the built environment acts to enable the preferred behavior and reinforce preferences. For an individual with a low preference for walking, living in a neighborhood conducive to walking might promote a preference for walking, leading to an increase in walking. Alternatively, an individual who does not like to walk may rationalize this by blaming the environment, causing walking behavior to affect perceptions of the environment. An individual who walks frequently, by contrast, has more direct experience with the environment and may have different perceptions of its suitability for walking (positive or negative) as a result. These possibilities point to an important distinction between the built environment as it can be objectively measured and the built environment as perceived by residents; the relationship between the objective environment and the perceived environment is itself an important part of the puzzle.

Methodology

Sorting out the relationships depicted in Figure 1 requires a more sophisticated research design than was feasible for this study. Our more limited objectives were, first, to test the association between the built environment and walking after accounting for attitudes and preferences, and second, to provide a stronger test of causality by examining the association between changes in the built environment and changes in walking. Causal relationships are most validly established through experimental designs in which individuals are randomized to treatment and control groups and behavior is measured for both groups before and after the treatment of interest (Singleton & Straits, 1999). In this study, the treatment is defined as a move from one neighborhood to another, and the lack of randomization is addressed by accounting for preferences and attitudes that might influence the choice of neighborhood. The specific hypotheses addressed here thus are as follows:

1. Differences in the built environment are associated with differences in walking, after accounting for sociodemographic characteristics and for attitudes and preferences. More specifically, environments that offer better opportunities for walking are associated with more walking.
2. Changes in the built environment are associated with changes in walking, after accounting for sociodemographic characteristics and for attitudes and preferences. More specifically, moves to environments that offer better opportunities for walking are associated with increases in walking.

We selected eight neighborhoods in Northern California (see Figure 2) that differ with respect to neighborhood design.[1] We chose the neighborhoods in order to capture variation on three dimensions: neighborhood type, size of the metropolitan area, and region of the state. We distinguished between "traditional" neighborhoods, built mostly in the pre–World II era, and "suburban" neighborhoods built more recently (see Figure 3), but also described the neighborhoods along a variety of dimensions for our multivariate models. Using data from the U.S. Census, we screened potential neighborhoods to ensure that average income and other characteristics were near the average for

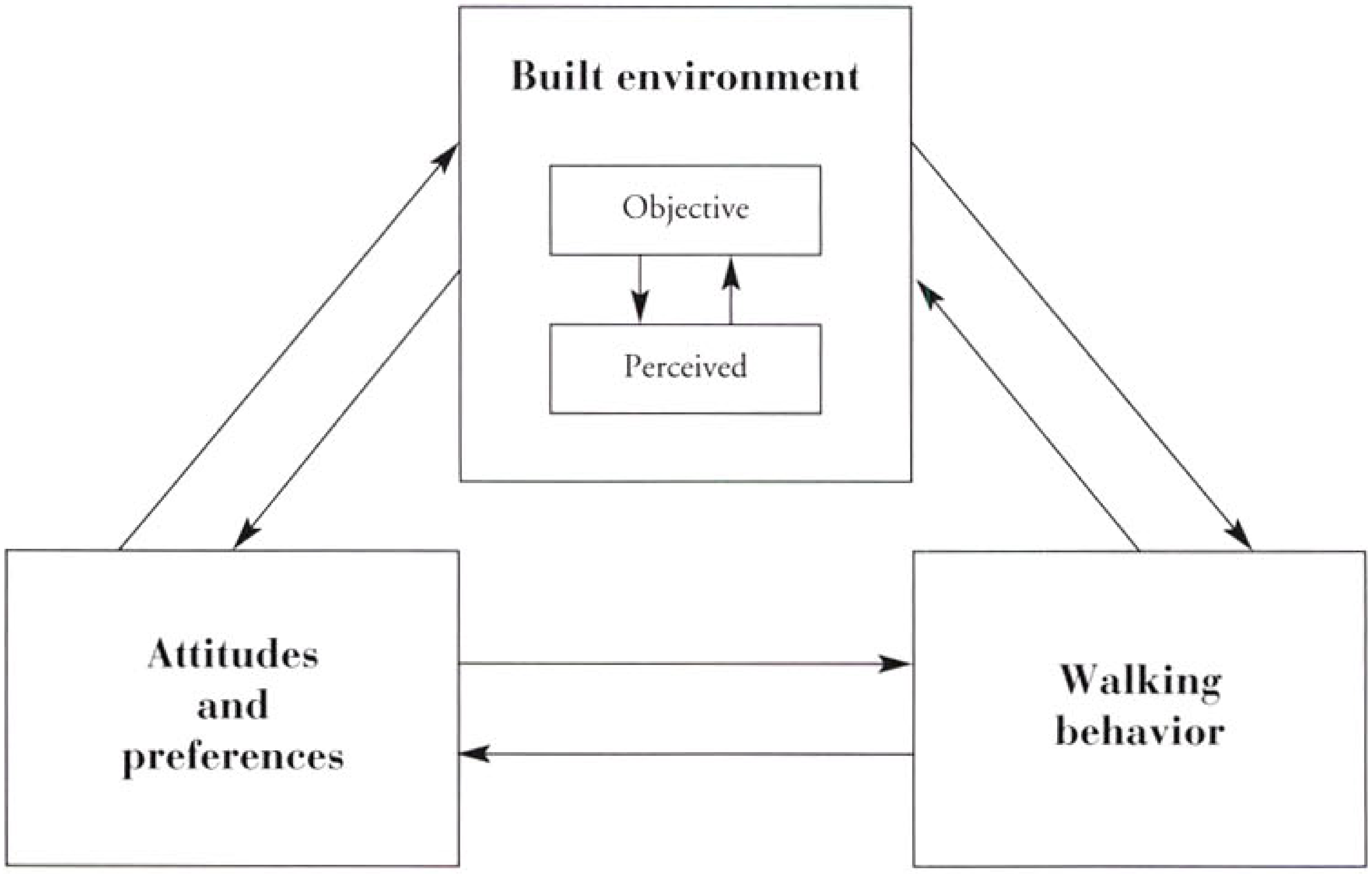


Figure 1. Conceptual model of relationships between built environment, attitudes and preferences, and walking behavior.

the region. We selected four neighborhoods in the San Francisco Bay Area, including two in the Silicon Valley area and two in Santa Rosa, that had been previously studied (Handy, 1992), and four additional neighborhoods (two from Sacramento and two from Modesto) to contrast with Bay Area neighborhoods.

In these neighborhoods, we selected a sample of residents who had moved within the last year and residents who had not. For each neighborhood, we purchased two databases of residents from a commercial provider, New Neighbors Contact Service (www.nncs.com): a database of "movers" and a database of "nonmovers." The database of movers included all current residents of the neighborhood who had moved within the previous year. From this database, we drew a random sample of 500 residents for each neighborhood. The database of nonmovers consisted of a random sample of 500 residents not included in the movers list for each neighborhood. The result was an initial sample of 1,000 residents for each neighborhood, 500 movers and 500 nonmovers.

The survey was administered using a mail-out, mail-back approach. The initial survey was mailed out at the end of September 2003. Two weeks later, a reminder postcard was mailed to the entire sample using first-class mail. At the beginning of November, a second copy of the survey with a revised cover letter was sent to a shorter list that excluded incorrect addresses and individuals who had already responded to the survey. Two weeks later, a second reminder postcard was mailed to this list of residents. As an incentive to complete the survey, respondents were told they would be entered into a drawing to receive one of five $100 cash prizes; the winners were selected in December.

The original database consisted of 8,000 addresses, only 6,746 of which were valid. The number of responses totaled 1,672, yielding a 24.8% response rate based on the valid addresses only. This response rate is similar to those we have achieved in previous studies, and is considered quite good for a survey of this length and complexity, administered to the general population (Sommer & Sommer, 1997). However, any response rate less than 100% raises the possibility that the individuals who respond to the survey are systematically different from those who choose not to respond. Comparing respondent characteristics to the characteristics of all residents of the studied neighborhoods based on the 2000 U.S. Census shows that survey respondents tend to be older on average than neighborhood residents overall, and that the percent of households with children is lower among respondents for most neighborhoods (see Table 1). Median household income for survey respondents was higher than the census median for all but one neighborhood, a typical result for voluntary self-administered surveys. These differences suggest nonresponse bias may have affected the results. However, the biases across neighborhoods appear to be similar, and taking socio-

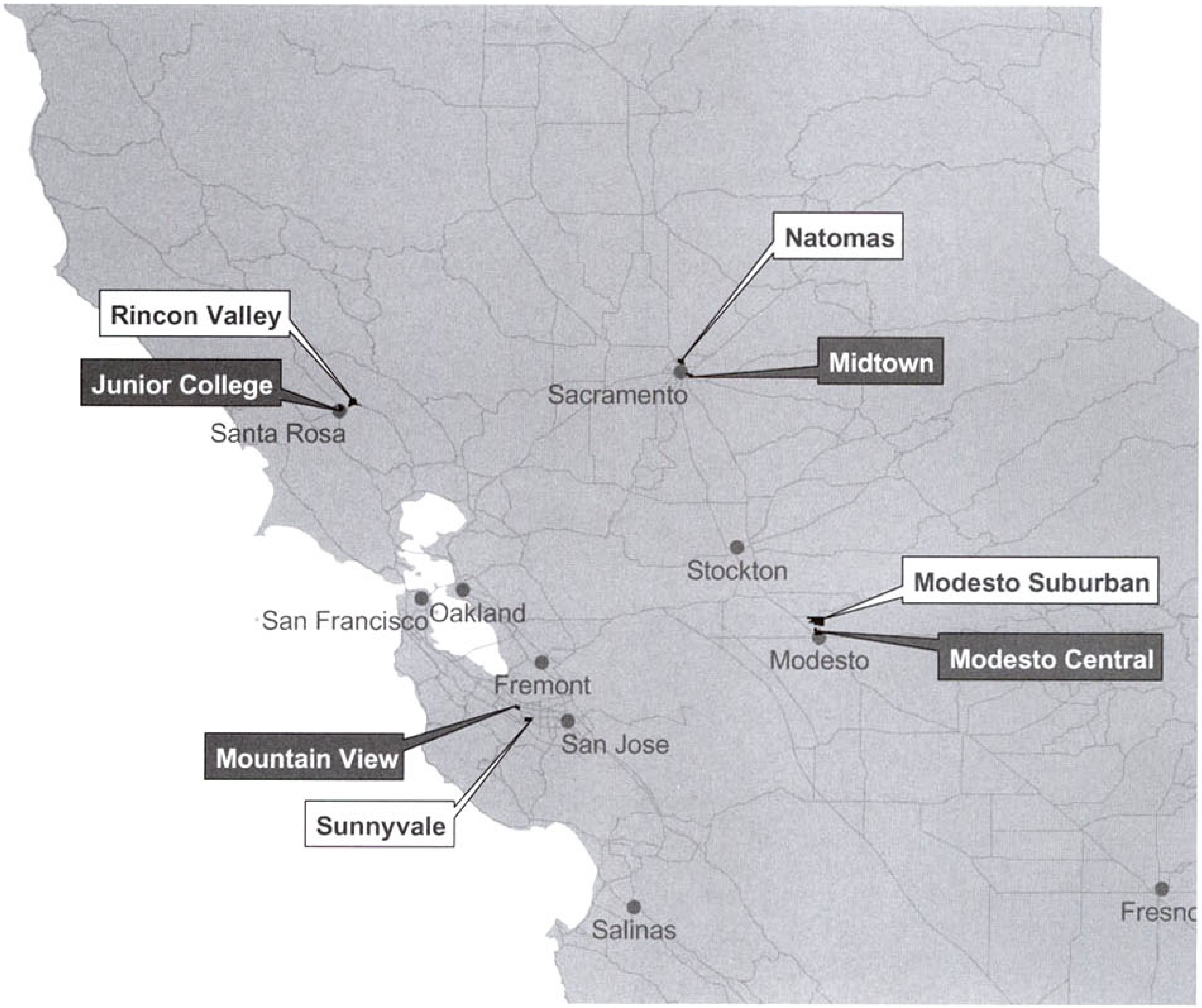


Figure 2. Location of study neighborhoods.

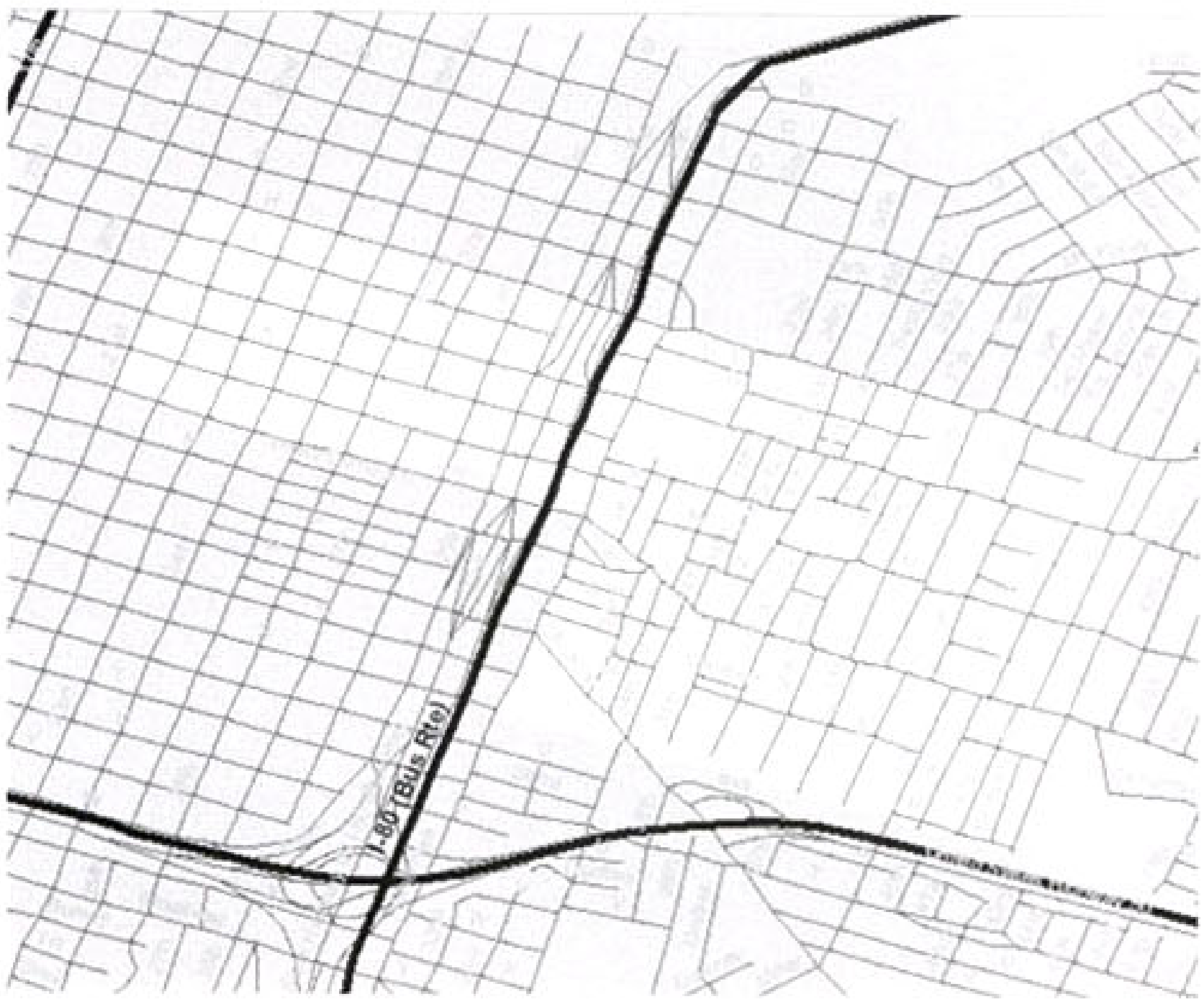
demographic differences explicitly into account as we did helps to minimize this concern (Singleton & Straits, 1999).

Variables

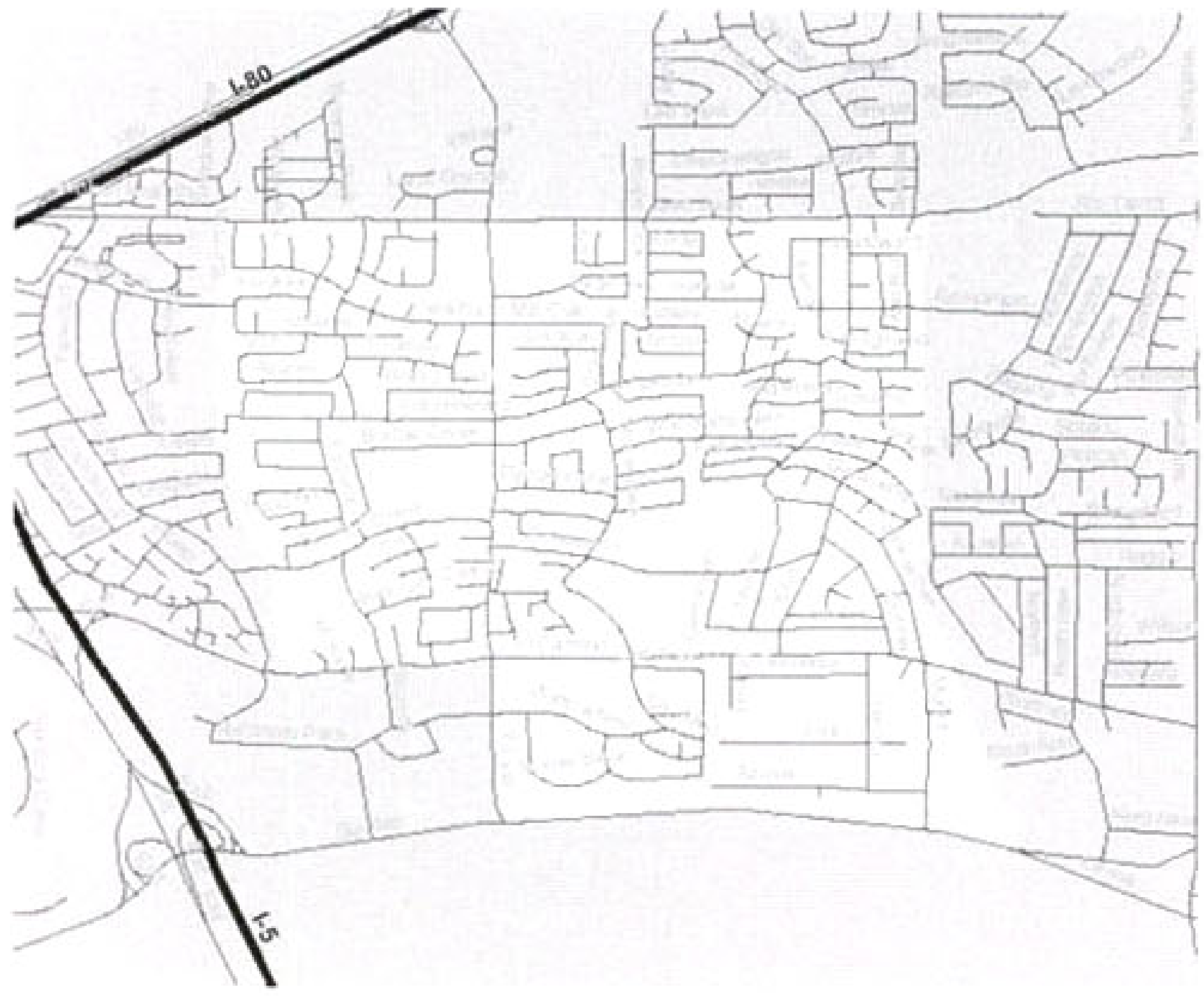
We developed survey questions from surveys used in previous research projects by the first and third authors of this article, and pretested them with UC Davis students and staff and a convenience sample of Davis residents. The variables used in the models presented in the following section are listed in Table 2. We checked the final models for possible collinearity between the explanatory variables using pairwise correlations and an informal analysis of variance inflation factors,[2] concluding that it was unlikely to be a problem.

We measured walking in two ways: the number of times residents walked to the store in the previous 30 days, and the number of times respondents strolled around the neighborhood in the last 30 days. Note that these measures assume that respondents can recall their walking trips with reasonable accuracy; test-retest reliability was higher for strolling trips than for walks to the store.[3] In addition, respondents were asked to indicate how often they walked to selected destinations in a typical month with good weather. Change in walking (including walking to the store and strolling, as well as other walking in the neighborhood) either from just before the move (for the movers) or from one year ago (for the nonmovers) was measured on a 5-point ordinal scale anchored by the categories "a lot less" and "a lot more" now. Change in biking (not confined to the neighborhood) was measured in the same way. Note that these measures also rely on recall, but ask for the respondent's general impression of change in walking or biking rather than specific frequencies of walking in the past, a measure likely to be less reliable.

We measured the built environment using perceived neighborhood characteristics as well as objective measures



Traditional street network



Suburban street network

Traditional residential street

Suburban residential street

Traditional commercial center

Suburban commercial center

Figure 3. Comparison of traditional and suburban neighborhoods: Sacramento.

Table 1. Respondent characteristics vs. Census characteristics, by neighborhood.

	Traditional neighborhoods				Suburban neighborhoods			
	SV-MV	SR-JC	M-C	S-M	SV-S	SR-RV	M-S	S-N
Respondent characteristics								
*N**	228	215	184	271	217	165	220	182
Percent female	47.3	54.3	56.3	58.2	46.9	50.9	50.9	54.9
Average cars per household	1.80	1.63	1.59	1.50	1.79	1.66	1.88	1.68
Average age (years)	43.3	47.0	51.3	43.4	47.1	54.7	53.2	45.6
Average HH size (persons)	2.08	2.03	2.13	1.78	2.58	2.19	2.41	2.35
Percent of HHs w/children	21.1	18.6	21.7	8.9	42.4	24.8	25.5	31.9
Average number of children	1.60	1.58	1.83	1.58	1.65	1.59	1.98	1.64
Percent homeowners	51.1	57.8	75.6	47.0	61.1	68.7	81.0	82.4
Median HH income ($1,000)	98.7	55.5	45.5	64.2	95.0	49.5	55.5	55.3
Census characteristics								
Population	5,493	9,886	13,295	7,259	14,973	13,617	19,045	13,295
Average age (years)	36.1	36.3	36.5	42.7	35.9	38.3	38.1	31.7
Average HH size (persons)	2.08	2.21	2.46	1.79	2.66	2.48	2.51	2.57
Percent of HHs w/children	19.3	20.3	32.9	12.4	35.3	35.4	34.2	41.7
Percent home owners	34.3	31.2	58.8	34.3	53.2	63.5	61.4	55.2
Median HH income ($1,000)	74.3	40.2	42.5	43.8	88.4	49.6	40.2	46.2
Percent of units built after 1960	54.3	37.2	21.4	22.7	79.9	90.3	94.6	90.2

**N* may vary in subsequent tables owing to missing values on some variables.

Neighborhoods:

SV-MV:	Silicon Valley–Mountain View	SV-S:	Silicon Valley–Sunnyvale
SR-JC:	Santa Rosa–Junior College	SR-RV:	Santa Rosa–Rincon Valley
M-C:	Modesto-Central	M-S:	Modesto-Suburban
S-M:	Sacramento-Midtown	S-N:	Sacramento-Natomas

of accessibility. For perceived characteristics, survey respondents were given a list of 34 items and asked to indicate, on a 4-point scale from "not at all true" to "entirely true," the degree to which the item is true for their current neighborhood. Movers were also asked the degree to which each item was true for their previous neighborhood. Through principal components factor analysis using a combined database of current neighborhood characteristics, previous neighborhood characteristics, and preferred neighborhood characteristics (noted below), these items were reduced to a set of six factors (see Table 3).[4] We measured changes in the built environment for movers by taking the difference between reports for the current and the previous neighborhoods.

Following the survey, we estimated objective measures of accessibility for each respondent based on distance along the street network from home to destinations classified as institutional (church, library, post office, bank), maintenance (grocery store, convenience store, pharmacy), eating out (bakery, pizza, ice cream, take out), and leisure (health club, bookstore, bar, theater, video rental). The accessibility measures include the number of different types of businesses within specified distances, the number of establishments of each type within specified distances, and the distance to the nearest establishment of each type. We identified commercial establishments using on-line yellow pages, and used ArcGIS to calculate network distances.

We measured travel attitudes by asking respondents to indicate the degree to which they disagreed or agreed with a series of attitudinal statements about travel, reducing them to six factors using principal component factor analysis (see Table 4).[5] We also measured preferences for neighborhood characteristics by asking respondents to indicate the relative importance of the 34 neighborhood characteristics in seeking a place to live, later reducing these to the same six factors used for perceived neighborhood characteristics. Because retrospective assessments of attitudes are likely to be unreliable, we did not measure change in attitudes.

Table 2. Variables.

Walking and biking behavior	**Preferred neighborhood characteristics** (continued)
Frequency of walking to store in last 30 days	Socializing preferred
Frequency of strolling around neighborhood in last 30 days	Outdoor spaciousness preferred
Change in walking (5 point scale from "a lot less"to "a lot more")	Attractiveness preferred
Change in biking (5 point scale from "a lot less" to "a lot more")	Stores w/in walking distance preferred (1–4)
Frequency of walking or biking to selected destinations in a typical month with good weather (6-point scale from "never" to "two or more times per week")	Cul-de-sac preferred (1–4)
Sociodemographic characteristics	**Perceived neighborhood characteristics**
Age	Accessibility perceived
Female (0,1)	Physical activity options perceived
Worker (0,1)	Safety perceived
Education level	Socializing perceived
Household size	Outdoor spaciousness perceived
Number of children under 5	Attractiveness perceived
Children under 18 (0,1)	Stores within walking distance perceived (1–4)
Household income	Cul-de-sac perceived (1–4)
Number of autos	Change in accessibility perceived
Number of bikes	Change in physical activity options perceived
Driver's license (0,1)	Change in safety perceived
Driving limitation (0,1)	Change in socializing perceived
Walking limitation (0,1)	Change in spaciousness perceived
Biking limitation (0,1)	Change in attractiveness perceived
Travel attitudes	**Objective neighborhood characteristics**
Pro-bike/walk attitude	Number of types of establishments within 400, 800, and 1600m
Pro-travel attitude	Number of establishments within 400, 800, and 1600m
Travel minimizing attitude	• institutional (church, library, post office, bank)
Pro-transit attitude	• household maintenance (grocery store, convenience store, pharmacy)
Safety of car attitude	• eating out (bakery, pizza, ice cream, take-out)
Car dependent attitude	• leisure (health club, bookstore, bar, theater, video rental)
Preferred neighborhood characteristics	Minimum distance in meters to establishments
Accessibility preferred	• institutional (church, library, post office, bank)
Physical activity options preferred	• household maintenance (grocery store, convenience store, pharmacy)
Safety preferred	• eating out (bakery, pizza, ice cream, take-out)
	• leisure (health club, bookstore, bar, theater, video rental)

We asked each respondent his or her gender and age, educational background, driver's license status, physical or anxiety-related conditions that limit driving or use of other modes of transportation, renter/owner status, total household income, auto ownership, and the ages of each other member of his or her household. We measured changes for movers by comparing reports before and after the move, and for nonmovers by comparing what they reported as current to what they reported to have been true one year ago.

Findings

The following sections explain what we found in a simple comparison of walking behavior for traditional and suburban neighborhoods, a cross-sectional multivariate analysis, and a quasi-longitudinal multivariate analysis.

Traditional versus Suburban Neighborhoods

Our results show that residents of traditional neighborhoods walk substantially more than residents of suburban neighborhoods (see Table 5). A significantly higher

Table 3. Factors for perceived neighborhood characteristics.

Factor	Statement	Loading*
Accessibility	Easy access to a regional shopping mall	0.854
	Easy access to downtown	0.830
	Other amenities such as a community center available nearby	0.667
	Shopping areas within walking distance	0.652
	Easy access to the freeway	0.528
	Good public transit service (bus or rail)	0.437
Physical activity (PA) options	Bike routes beyond the neighborhood	0.882
	Sidewalks throughout the neighborhood	0.707
	Parks and open spaces nearby	0.637
	Good public transit service (bus or rail)	0.353
Safety	Quiet neighborhood	0.780
	Low crime rate within neighborhood	0.759
	Low level of car traffic on neighborhood streets	0.752
	Safe neighborhood for walking	0.741
	Safe neighborhood for children to play outdoors	0.634
	Good street lighting	0.571
Socializing	Diverse neighbors in terms of ethnicity, race, and age	0.789
	Lots of people out and about within the neighborhood	0.785
	Lots of interaction among neighbors	0.614
	Economic level of neighbors similar to my level	0.476
Outdoor spaciousness	Large back yards	0.876
	Large front yards	0.858
	Lots of off-street parking (garages or driveways)	0.562
	Big street trees	0.404
Attractiveness	Attractive appearance of neighborhood	0.780
	High level of upkeep in neighborhood	0.723
	Variety in housing styles	0.680
	Big street trees	0.451

*Represents the degree of association between the statement and the factor.

share of residents in these neighborhoods reported walking to a store at least once in the last 30 days, and the average frequency of walking to the store was 4.9 for traditional neighborhoods versus only 1.8 for suburban neighborhoods. The differences for strolling around the neighborhood were also significant, though not as dramatic: over 86% of residents of traditional neighborhoods strolled at least once in the last 30 days, versus 79% of residents of suburban neighborhoods, with an average frequency of 10.1 versus 7.7 strolls. Walking behavior varied across the traditional neighborhoods, however, with residents of Modesto Central walking to the store at frequencies comparable to those found in suburban neighborhoods rather than the other traditional neighborhoods.

Residents of traditional neighborhoods reported walking to all destinations more frequently than residents of suburban neighborhoods. The differences were smallest for walking to places to exercise (which could include parks, as well as gyms and other destinations) and for walking with no particular destination in mind. Across all destination types, residents of traditional neighborhoods walked more frequently to shops and restaurants than to other destinations; in suburban neighborhoods, places to exercise were the most frequent destinations, followed by shops. In both types of neighborhoods, residents were in general at least as likely to walk once per month or more "with no particular destination in mind" as they were to walk to any one type of destination. Interestingly, the shares of respondents saying they walked at least once a month during a *typical* month were considerably lower than the shares who reported walking to the store or strolling at least once in the *previous* month. These differences, which were consistent across neighborhoods, may stem from differences in the two questions or may reflect a reluctance on the part of respondents to report no walks in the last month if they sometimes do walk.

To what degree are these differences explained by differences in the built environment? A selection of the accessibility measures, presented in Table 6, reveals distinct differences between traditional and suburban neighborhoods. Residents of traditional neighborhoods on average have more businesses and more types of businesses within 400 meters (about ¼ mile) of home. In addition, the average distance to the nearest establishment for residents of traditional neighborhoods (247m) is less than half the distance for suburban residents (557m), and residents of traditional neighborhoods are closer to every type of establishment on average than suburban residents. These differences suggest greater potential for walking in traditional neighborhoods. However, these patterns are not entirely consistent. For example, accessibility in Modesto Central is more similar to suburban than to other traditional neighborhoods, perhaps explaining its lower frequency of walking to the store.

Perceived characteristics also demonstrate fundamental differences by neighborhood type, as reflected in the average factor scores (see Table 7). Residents of traditional

Table 4. Factors for travel preferences.

Factor	Statement	Loading*
Pro-bike/walk	I like riding a bike	0.880
	I prefer to bike rather than drive whenever possible	0.865
	Biking can sometimes be easier for me than driving	0.818
	I prefer to walk rather than drive whenever possible	0.461
	I like walking	0.400
	Walking can sometimes be easier for me than driving	0.339
Pro-travel	The trip to/from work is a useful transition between home and work	0.683
	Travel time is generally wasted time	-0.681
	I use my trip to/from work productively	0.616
	The only good thing about traveling is arriving at your destination	-0.563
	I like driving	0.479
Travel minimizing	Fuel efficiency is an important factor for me in choosing a vehicle	0.679
	I prefer to organize my errands so that I make as few trips as possible	0.617
	I often use the telephone or the Internet to avoid having to travel somewhere	0.514
	The price of gasoline affects the choices I make about my daily travel	0.513
	I try to limit my driving to help improve air quality	0.458
	Vehicles should be taxed on the basis of the amount of pollution they produce	0.426
	When I need to buy something, I usually prefer to get it at the closest store possible	0.332
Pro-transit	I like taking transit	0.778
	I prefer to take transit rather than drive whenever possible	0.771
	Public transit can sometimes be easier for me than driving	0.757
	Walking can sometimes be easier for me than driving	0.344
	I prefer to walk rather than drive whenever possible	0.363
Safety of car	Traveling by car is safer overall than walking	0.753
	Traveling by car is safer overall than taking transit	0.633
	Traveling by car is safer overall than riding a bicycle	0.489
	The region needs to build more highways to reduce traffic congestion	0.444
Car dependent	I need a car to do many of the things I like to do	0.612
	Getting to work without a car is a hassle	0.524
	We could manage pretty well with one fewer car than we have (or with no car)	-0.418
	Traveling by car is safer overall than riding a bicycle	0.402
	I like driving	0.356
Did not make a major contribution to any particular factor		
	Air quality is a major problem in this region	
	My household spends too much money on owning and driving our cars	
	I am willing to pay a toll or a tax to pay for new highways	

*Represents the degree of association between the statement and the factor.

neighborhoods gave higher scores on average to accessibility, socializing, and attractiveness, while residents of suburban neighborhoods gave higher scores on average to safety. The differences on physical activity options and spaciousness factors were not significant. The difference on accessibility suggests that residents of traditional neighborhoods perceive greater opportunities for walking than residents of suburban neighborhoods, and higher scores on the socializing and attractiveness factors might imply a better walking environment. Things are not quite this simple, however.

Table 5. Walking behavior by neighborhood type and neighborhood.

		Traditional neighborhoods					Suburban neighborhoods					*p*-value	
Walking behavior	*All*	**Mean**	**SV-MV**	**SR-JC**	**M-C**	**S-M**	**Mean**	**SV-S**	**SR-RV**	**M-S**	**S-N**	**Nbhd. type**[a]	**Nbhd.**[b]
% Walking to store at least once in last 30 days	*59.8*	**74.9**	81.9	73.2	50.5	86.9	**42.5**	47.9	37.0	39.4	45.0	**0.00**	0.00
# Walks to store in last 30 days	*3.5*	**4.9**	5.3	5.0	2.2	6.3	**1.8**	2.0	1.4	1.8	2.1	**0.00**	0.00
% Strolling at least once in last 30 days	*83.1*	**86.5**	88.5	87.2	75.7	91.4	**79.2**	83.7	76.1	77.7	78.2	**0.00**	0.00
# Strolls around the neighborhood in last 30 days	*9.0*	**10.1**	9.7	10.6	8.2	11.2	7.7	8.0	8.3	7.9	6.7	**0.00**	0.00
% Walking more than once per month to													
Church/civic	*18.9*	**29.0**	37.7	23.9	12.6	36.9	**7.2**	5.8	11.0	3.3	10.1	**0.00**	0.00
Service	*29.3*	**43.1**	59.0	39.2	18.7	49.2	**13.3**	15.6	9.8	11.8	15.7	**0.00**	0.00
Restaurant	*37.9*	**57.7**	71.1	49.8	25.3	74.9	**14.9**	15.9	16.0	15.4	12.0	**0.00**	0.00
Shop	*42.8*	**57.4**	58.8	56.0	32.0	74.6	**26.0**	27.3	24.1	22.3	30.7	**0.00**	0.00
Exercise place	*37.6*	**44.2**	52.4	37.5	27.3	54.4	**30.0**	33.5	29.4	24.8	32.6	**0.00**	0.00
No particular destination	*48.3*	**57.4**	58.9	54.8	43.1	68.4	**37.7**	35.8	36.6	40.1	38.2	**0.00**	0.00
N	*1664*	**887**	219	205	171	253	**777**	205	158	205	173		

Notes:

a. Based on t-test for difference of means or Pearson chi-square statistic from cross-tab analysis for traditional neighborhoods versus suburban neighborhoods.

b. Based on F-statistic from analysis of variance or Pearson chi-square statistic from cross-tab analysis across all neighborhoods.

Average scores by neighborhood followed the overall pattern by neighborhood type only for attractiveness.

If self-selection occurs, then these differences are not independent of the attitudes and preferences of the residents who choose these neighborhoods. Travel attitudes showed distinct, and potentially important, differences by neighborhood type (see Table 7). The differences in average scores between suburban and traditional neighborhoods were significant for four of the six factors. Residents of traditional neighborhoods had higher scores on average for the pro-bike/walk and pro-transit factors and lower scores on average for the safety of car and car-dependent factors. The differences on the pro-travel and travel-minimizing factors were not significant, however. These differences suggest a strong connection between neighborhood choice and attitudes about travel modes but not between neighborhood choice and attitudes about travel itself. And again, differences by neighborhood were not always consistent with this pattern.

Preferences for neighborhood characteristics also differed significantly by neighborhood type (see Table 7). Suburban residents scored safety and outdoor spaciousness higher on average, while residents of traditional neighborhoods rated socializing and attractiveness higher. The scores for accessibility and physical activity options were not significantly different by neighborhood type, however, and again, neighborhood type did not predict results for individual neighborhoods perfectly. All traditional neigh-

Table 6. Objective neighborhood characteristics: Traditional vs. suburban neighborhoods.

		Traditional neighborhoods					Suburban neighborhoods					*p*-value	
	All	Mean	SV-MV	SR-JC	M-C	S-M	Mean	SV-S	SR-RV	M-S	S-N	Nbhd. type[a]	Nbhd.[b]
Number within 400m													
Establishment types	*1.8*	**2.6**	2.5	2.1	1.2	4.1	**0.8**	1.1	0.8	0.8	0.6	**0.00**	0.00
Institutional	*1.0*	**1.5**	1.5	1.2	0.7	2.3	**0.4**	0.4	0.2	0.5	0.3	**0.00**	0.00
HH maintenance	*0.6*	**0.9**	0.6	0.8	0.4	1.4	**0.2**	0.3	0.3	0.1	0.1	**0.00**	0.00
Eat out	*0.6*	**0.7**	0.6	0.8	0.2	1.5	**0.2**	0.3	0.2	0.2	0.3	**0.00**	0.00
Leisure	*0.6*	**0.9**	1.0	0.5	0.2	1.5	**0.3**	0.4	0.3	0.2	0.2	**0.00**	0.00
Minimum distance in meters to													
Any establishment	*389*	**247**	284	235	298	192	**557**	462	581	502	704	**0.00**	0.00
Institutional	*552*	**377**	417	381	427	305	**760**	574	727	683	1087	**0.00**	0.00
HH maintenance	*580*	**380**	351	408	478	317	**819**	873	851	663	898	**0.00**	0.00
Eat out	*646*	**526**	587	438	816	349	**789**	794	955	696	740	**0.00**	0.00
Leisure	*647*	**508**	547	618	654	293	**814**	692	932	799	869	**0.00**	0.00
N	*1623*	**882**	220	208	183	271	**741**	209	155	197	180		

Notes:

a. Based on *t*-test for difference of means for traditional neighborhoods versus suburban neighborhoods.

b. Based on *F*-statistic from analysis of variance across all neighborhoods.

borhoods had lower average scores than all suburban neighborhoods only on preferences for safety.

Cross-sectional Analysis of Travel Behavior

Multivariate analyses help to sort out the relative importance of these different effects on walking behavior: once attitudes and preferences (as well as sociodemographic characteristics) are controlled for, is the built environment related to walking?

Because the frequency of walking to the store constituted count data with overdispersion, we estimated a negative binomial regression model for this variable (using the Limdep 8.0 statistical package). The final model had a deviance R^2 of 0.32,[6] a strong result for a cross-sectional model of individual travel behavior, and yields interesting insights into walking behavior (see Table 8). Among sociodemographic characteristics, age and being a worker had the largest standardized coefficients, negative in both cases. Among attitudes, a pro-bike/walk attitude had the largest standardized coefficient, with a pro-transit attitude also positively associated with walking frequency and a safety of car attitude negatively associated. The significance of preferences for neighborhood characteristics was also notable. Respondents expressing a preference for physical activity options and for having stores within walking distance walked to the store more frequently, all else equal, suggesting a self-selection effect. Respondents with preferences for safety and for cul-de-sacs walked less frequently, all else equal; these variables are likely associated with a preference for suburban neighborhoods, again pointing to self-selection. However, neighborhood characteristics were significant even after accounting for these attitudes and preferences, suggesting the possibility that the built environment has a direct causal effect on walking behavior. Not surprisingly, the distance to potential destinations, both objective and perceived, played an important role; more subjective factors such as perceived safety and attractiveness were also significant but less important than distance.

The model for frequency of strolling, also a negative binomial regression, had a deviance R^2 of only 0.11, with fewer significant variables (see Table 9), suggesting that strolling is less well explained by the variables examined here than is walking to the store. Among sociodemographic variables, being a worker had the largest standardized coefficient (negative), followed by income (positive), and having limits on walking (negative). The pro-bike/walk and pro-transit attitudes were again significant, with positive effects on the frequency of strolling; in this model, the travel-minimizing attitude was also positively associated

Table 7. Perceptions, attitudes, and preferences: Traditional vs. suburban neighborhoods.

	Traditional neighborhoods					Suburban neighborhoods					p-value	
	Mean	SV-MV	SR-JC	M-C	S-M	Mean	SV-S	SR-RV	M-S	S-N	Nbhd. type[a]	Nbhd.[b]
Perceived characteristics												
Accessibility	**0.15**	0.30	0.25	−0.41	0.32	**−0.18**	−0.07	−0.52	−0.36	0.23	**0.00**	0.00
PA options	**0.01**	0.35	−0.29	−0.40	0.25	**−0.01**	−0.02	−0.14	−0.02	0.10	**0.45**	0.00
Safety	**−0.14**	0.12	−0.20	0.07	−0.46	**0.16**	0.46	0.27	0.14	−0.25	**0.00**	0.00
Socializing	**0.09**	0.21	0.03	−0.15	0.21	**−0.12**	−0.05	−0.37	−0.14	0.06	**0.00**	0.00
Spaciousness	**0.00**	−0.21	0.06	0.74	−0.37	**−0.01**	−0.19	−0.16	0.25	0.03	**0.82**	0.00
Attractiveness	**0.28**	0.01	0.17	0.32	0.57	**−0.33**	−0.39	−0.33	−0.07	−0.56	**0.00**	0.00
Transportation attitudes												
Pro-bike/walk	**0.20**	0.21	0.19	−0.14	0.42	**−0.23**	−0.17	−0.22	−0.41	−0.10	**0.00**	0.00
Pro-travel	**−0.03**	−0.19	0.02	0.08	0.00	**0.03**	−0.13	0.00	0.10	0.17	**0.27**	0.00
Travel minimizing	**0.01**	0.06	0.08	−0.11	−0.01	**−0.01**	−0.08	0.00	−0.12	0.19	**0.69**	0.00
Pro-transit	**0.15**	0.42	−0.07	−0.28	0.38	**−0.17**	0.07	−0.31	−0.38	−0.09	**0.00**	0.00
Safety of car	**−0.27**	−0.40	−0.25	0.01	−0.36	**0.31**	0.04	0.24	0.48	0.50	**0.00**	0.00
Car dependent	**−0.06**	0.08	−0.02	−0.10	−0.19	**0.07**	0.28	0.09	0.07	−0.19	**0.01**	0.00
Preferred characteristics												
Accessibility	**0.03**	0.22	−0.01	−0.33	0.16	**−0.04**	−0.13	−0.25	−0.08	0.32	**0.14**	0.00
PA options	**0.01**	0.03	−0.09	−0.25	0.25	**−0.02**	−0.13	−0.23	0.00	0.28	**0.60**	0.00
Safety	**−0.18**	−0.18	−0.14	0.07	−0.39	**0.21**	0.26	0.16	0.23	0.17	**0.00**	0.00
Socializing	**0.05**	−0.05	0.04	−0.08	0.24	**−0.05**	0.66	−0.28	0.07	0.16	**0.05**	0.00
Spaciousness	**−0.05**	−0.15	−0.01	0.33	−0.26	**0.06**	−0.08	−0.02	0.16	0.17	**0.02**	0.00
Attractiveness	**0.04**	−0.16	−0.12	0.26	0.19	**−0.05**	−0.29	−0.06	0.12	0.05	**0.04**	0.00
N	**888**	227	214	182	265	**762**	211	161	212	178		

Notes: Scores normalized to a mean value of 0 and variance of 1.

a. Based on t-test for difference of means for traditional neighborhoods versus suburban neighborhoods.

b. Based on F-statistic from analysis of variance across all neighborhoods.

with strolling, although the standardized coefficient was not large. Once these variables were accounted for, two measures of the built environment had a statistically significant effect on strolling: socializing perception and attractiveness perception. This result is consistent with expectations: accessibility to stores and other destinations should not matter for strolling trips, but the quality of the environment, both physical and social qualities, should. These models thus support both sides of the debate: residents who prefer walking, either to the store or strolling around the neighborhood, do self-select into traditional neighborhoods, but certain qualities of the built environment seem to have an effect even when self-selection has been accounted for.

Quasi-longitudinal Analysis of Travel Behavior

Our quasi-longitudinal analysis provides a more direct test for a causal relationship between the built environment and walking by examining the association between changes in the built environment and in walking. As noted above, we measured change in walking either from before the move (for movers) or from one year ago (for the nonmovers) on a 5-point scale ranging from "a lot less" to "a lot more" walking now; change in biking was similarly measured. We measured changes in the built environment for movers by taking the difference between perceived characteristics of the current and previous neighborhoods; we assumed the built environment to be constant for nonmovers. We measured changes in selected sociodemographic variables

Table 8. Negative binomial regression for walking to the store frequency.

Variable	Coefficient	Standardized coefficient*	p-value	Marginal effect
Constant	0.408	0.845	0.080	1.517
Limits on walking	−0.398	−0.078	0.026	−1.481
Age	−0.010	−0.145	0.000	−0.036
Number of autos	−0.082	−0.069	0.048	−0.305
Worker	−0.328	−0.126	0.001	−1.219
Pro-bike/walk attitude	0.314	0.313	0.000	1.168
Pro-transit attitude	0.228	0.227	0.000	0.848
Safety of car attitude	−0.121	−0.121	0.002	−0.451
PA options preferred	0.115	0.118	0.004	0.426
Safety preferred	−0.124	−0.102	0.008	−0.459
Stores within walking distance preferred	0.172	0.168	0.000	0.639
Cul-de-sac preferred	−0.063	−0.065	0.084	−0.236
Safety perception	−0.076	−0.071	0.029	−0.281
Attractiveness perception	0.083	0.078	0.038	0.308
Stores within walking distance perception	0.286	0.268	0.000	1.065
Distance to nearest grocery store (km)	−0.200	−0.144	0.000	−0.745
# types of businesses within 800m	0.050	0.191	0.000	0.186
Dispersion parameter α	1.208	0.067	0.000	
N	1480			
Deviance R^2	0.32			

*All independent variables (except constant term) standardized and model re-estimated; dependent variable not standardized.

(age, household size, presence of children, income) for both movers and nonmovers, but assumed travel attitudes and preferences for neighborhood characteristics to be constant.

We estimated the relationships between changes in the built environment and changes in walking, while controlling for attitudes, using an ordered probit model. This technique is appropriate for an ordinal dependent variable, and its model structure is parsimonious. The resulting equation can be interpreted as representing an underlying latent variable, in this case a continuous function representing the propensity to change one's travel, from substantially decreasing to substantially increasing walking or biking. A statistically significant association between a change in the built environment and change in walking or biking provides evidence of a causal relationship.

In the model predicting change in walking (see Table 10), change in the attractiveness factor had the highest standardized coefficient: increasing attractiveness was associated with either a smaller decrease in walking or a larger increase. Several sociodemographic variables were significant, with older age, a current limitation on walking, an increase in income, or the addition of children under the age of five to the household contributing to a larger decrease or smaller increase in walking. Only one attitudinal variable was significant: higher levels of the pro-bike/walk factor were associated with either a smaller decrease or a larger increase in walking. After accounting for these effects, changes in several perceptions of the built environment had a positive impact on walking change (led to smaller decreases or larger increases): accessibility, physical activity options, safety, and socializing. Three objective measures were also positively significant: minimum distance to a bank, number of banks within 800m, and number of types of businesses within 1600m. Although we measured these variables for the current neighborhood, high levels were more likely when moves increased rather than decreased them. The positive sign on minimum distance to a bank suggests neighborhoods with more segregated land uses have a positive effect on walking change, counter to intuition, but positive signs for the

Table 9. Negative binomial regression for strolling frequency.

Variable	Coefficient	Standardized coefficient*	p-value	Marginal effect
Constant	1.722	2.073	0.000	15.141
Limits on walking	−0.630	−0.126	0.000	−5.540
Age	0.008	0.115	0.002	0.067
Worker	−0.480	−0.186	0.000	−4.219
Female	0.188	0.094	0.002	1.653
Income ($1,000)	0.004	0.131	0.000	0.032
Pro-bike/walk attitude	0.233	0.233	0.000	2.051
Pro-transit attitude	0.091	0.091	0.002	0.803
Travel minimizing attitude	0.062	0.062	0.048	0.548
Socializing perception	0.146	0.123	0.000	1.281
Attractiveness perception	0.110	0.103	0.000	0.963
Dispersion parameter α	1.241	0.052	0.000	
N	1534			
Deviance R^2	0.11			

*All independent variables (except constant term) standardized and model re-estimated; dependent variable not standardized.

number of banks and the number of types of businesses within set distances, which suggest a greater mix of land uses, are as expected. A higher score for the spaciousness of the current neighborhood was also significant, associated with either a larger decrease or a smaller increase in walking. These results also support the hypothesis that changes in the built environment are associated with changes in walking and point to increases in accessibility, alternatives to driving, safety, socializing interactions, and attractiveness as increasing walking in the neighborhood.

The implications of the model can also be depicted graphically. Figure 4 shows the predicted probabilities for each category of change in walking (from "a lot less" to "a lot more"), given different changes in accessibility, for an individual who has average values of the other explanatory variables in the model. The upward slope of the lines for "a little more" and "a lot more" walking shows that the probability of an average individual being in these categories increases as accessibility improves, while the downward slope of the lines for "a little less" and "a lot less" walking shows that the probability of an average individual being in these categories decreases as accessibility improves. However, it would take a tremendous increase in the accessibility factor (4 points, equal to 4 standard deviations) to make an average person more likely to walk more (a little or a lot) than to walk about the same amount. This analysis suggests that while the impacts of changes in accessibility are significant, only large improvements produce substantial increases in walking.

Attitudes played a much more significant role in the model for change in biking (see Table 11).[7] Residents who owned more bikes, were younger, and had higher levels of education were more likely to report increases in biking. But a pro-bike/walk attitude had a standardized coefficient more than twice as high as that for any other variable. Other attitudes were also significant: travel minimizing attitude, pro-transit attitude, and spaciousness preference were all negatively associated with changes in biking (greater decrease or smaller increase in biking), while an attractiveness preference was positively associated. Once these attitudes and preferences were accounted for, several measures of the built environment were significant. An increase in the alternatives factor or the socializing factor was associated with a greater increase or smaller decrease in biking. The current number of household maintenance businesses (grocery store, convenience store, pharmacy) within 1600m had a positive effect on change in biking, as did the minimum distance to a health club, although the standardized coefficients were small. This model suggests that a positive attitude toward biking and walking is most important in explaining changes in biking, but that changes in the built environment also contribute.

Table 10. Ordered probit model for change in walking.

Variable	Coefficient	Standardized coefficient*	p-value
Constant	1.139	1.681	0.000
Current age	−0.006	−0.084	0.003
Current income ($1,000)	0.002	0.073	0.021
Limits on walking	−0.512	−0.101	0.000
Change in income ($1,000)	−0.004	−0.064	0.015
Change in # children <5 yrs.	0.269	0.077	0.004
Pro-bike/walk attitude	0.153	0.152	0.000
Distance to nearest bank (km)	0.174	0.082	0.035
# Banks within 800m	0.050	0.091	0.005
# Types of businesses within 1600m	0.028	0.073	0.040
Current spaciousness perception	−0.068	−0.064	0.030
Change in accessibility factor	0.123	0.103	0.000
Change in PA options factor	0.124	0.103	0.000
Change in safety factor	0.153	0.150	0.000
Change in socializing factor	0.174	0.140	0.000
Change in attractiveness factor	0.194	0.200	0.000
Threshold parameter 1	0.645	0.645	0.000
Threshold parameter 2	2.160	2.160	0.000
Threshold parameter 3	2.877	2.877	0.000
N	1505		
Log-likelihood at 0	−2735.015		
Log-likelihood at constant	−2059.568		
Log-likelihood at convergence	−1883.789		
Pseudo-R^2	0.311		
Adjusted pseudo-R^2	0.306		

*All independent variables (except constant term) standardized and model re-estimated; dependent variable not standardized.

Conclusions

These analyses are not definitive, nor do they completely clarify the nature of the causal relationship between the built environment and walking, as depicted in Figure 1. To more definitely answer this question, future studies should use research designs that more closely resemble true experiments. Researchers should consider longitudinal panel studies of the sort underway in Perth, Australia (School of Population Health, 2004), which is surveying respondents prior to and following a residential move. They should also consider intervention studies of the sort completed by Boarnet, Day, Anderson, Afonzo, and McMillan (2005) and Boarnet, Anderson, Day, and McMillan (2005), which measured walking before and after a change in the built environment such as the construction of sidewalks or improvement to pedestrian signals. In the meantime, the results presented here provide some encouragement that changes to the built environment that increase the opportunities for walking may in fact lead to more walking.

Still, translating this conclusion into planning practice raises additional questions. First, what aspects of the built environment are most important for encouraging an increase in walking? Our models point to increases in accessibility, particularly close proximity to potential destinations such as shops and services, as the most important for encouraging an increase in walking. Enhancements to other qualities of the built environment might also increase walking: physical activity options (bike routes, sidewalks, parks, public transit), safety (quiet, low crime, low traffic, safe for walking, safe for kids to play, street lighting), attractiveness (appearance, level of upkeep, variety in

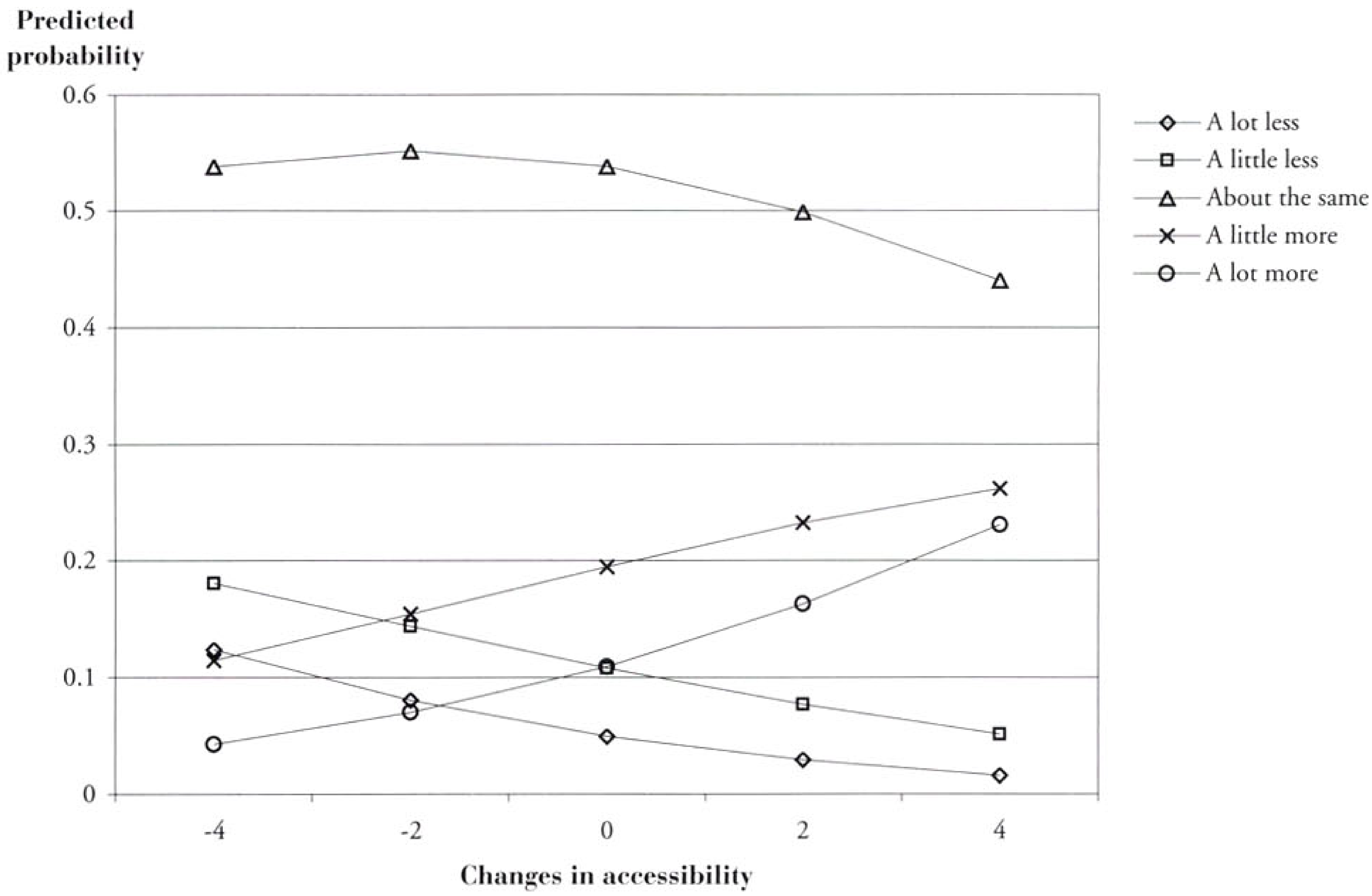


Figure 4. Predicted probabilities of categories of change in walking as a function of changes in accessibility.

housing styles, big street trees), and socializing (diverse neighbors, people out and about, interaction among neighbors, similar economic levels). Because these qualities are often found together in a given neighborhood, our analysis could not tease out the relative importance of the individual qualities or subsets of qualities. The optimal package of qualities is still uncertain.

Second, what policies can most effectively and efficiently bring these changes about? Creating environments conducive to walking is undoubtedly easier in new developments than existing environments. Cities can modify zoning and subdivision ordinances to allow proximity to shops, services, parks, and other potential destinations for walking trips and to require more from developers in the way of infrastructure for pedestrians and bicyclists. The nascent movement toward form-based codes might facilitate such efforts. Changing the environment in existing neighborhoods is much more challenging. Policies to promote infill development, programs that aim to revitalize or protect traditional neighborhood commercial areas, and investments in pedestrian infrastructure such as sidewalks and specially designed street crossings can help. Traffic calming programs, popular throughout the U.S., are an important strategy; the more recent "road diets" and "complete the streets" movements may also play a role. Improvements in street lighting and neighborhood watch programs could help to increase the sense of safety in a neighborhood, and neighborhood events such as block parties or walking groups might increase levels of socializing.

Finally, will the increase in walking be enough to justify the effort and expense? Our results suggest that it will take large changes in accessibility to produce a significant increase in walking. Yet the health benefits of even a small amount of walking are well documented (e.g., U.S. Department of Health and Human Services, 1996); the Centers for Disease Control and Prevention (CDC) recommends 30 minutes of moderate-intensity exercise like brisk walking five days a week (CDC, 2005). Of course, walking is only one form of exercise. We did not measure total levels of physical activity and thus cannot be certain that higher levels of walking are associated with higher total levels of physical activity. (However, see Rodríguez, Khattak, & Evenson in this issue.) Walking is one of the most popular forms of physical activity and is the predom-

Table 11. Ordered probit model for change in biking.

Variable	Coefficient	Standardized coefficient*	p-value
Constant	0.915	1.181	0.000
Current number of bikes	0.064	0.097	0.004
Current age	−0.011	−0.155	0.000
Education level	0.067	0.087	0.005
Pro-bike/walk attitude	0.365	0.359	0.000
Travel minimizing attitude	−0.078	−0.077	0.014
Pro-transit attitude	−0.124	−0.121	0.000
Spaciousness preferred	−0.114	−0.111	0.002
Attractiveness preferred	0.085	0.074	0.019
Change in alternatives factor	0.169	0.144	0.000
Change in socializing factor	0.150	0.121	0.000
# HH maintenance businesses within 1600m	0.015	0.090	0.012
Distance to nearest health establishment (km)	0.143	0.071	0.045
Threshold parameter 1	0.351	0.351	0.000
Threshold parameter 2	2.261	2.261	0.000
Threshold parameter 3	2.908	2.908	0.000
N	1328		
Log-likelihood at 0	−1986.72		
Log-likelihood at constant	−1616.71		
Log-likelihood at convergence	−1474.99		
Pseudo-R^2	0.258		
Adjusted pseudo-R^2	0.252		

*All independent variables (except constant term) standardized and model re-estimated; dependent variable not standardized.

inant form of physical activity for lower income groups (Siegel, Brackbill, & Heath, 1995). Walking is more likely to be a replacement for no physical activity than for more vigorous forms of physical activity. In addition, research shows that individuals who engage in a combination of types of physical activity, including walking, are more likely to meet recommended levels of physical activity than those who engage in only one type, even if it is vigorous (Giles-Corti & Donovan, 2003).

The trend in levels of walking is also important when justifying such policies on the grounds of health benefits: certain changes in the built environment may lead to increases in walking, but if the overall trend is a decline in walking, then our efforts may only moderate this decline. Our data show that nearly 32% of respondents say they are walking more now than they were before they moved or one year ago, while fewer than 18% percent say they are walking less. Comparing our data for the Bay Area neighborhoods to data from a 1992 survey by Handy (1996) using the same survey questions in the same neighborhoods (Table 12), the share of residents walking and their frequency of walking are stable or increasing, with one exception.[8] The steady level of walking over a period of a decade provides encouragement that more concerted efforts to improve the walking environment may do more than simply stem the decline.

But even if increases in physical activity are not substantial enough to justify the cost of improvements in the walking environment, other benefits may be. (See also Frank, Sallis, Conway, Chapman, Saelens & Bachman in this issue.) Many communities have found over the years that equity, safety, traffic, air quality, and quality of life benefits are substantial enough to justify significant investments in pedestrian infrastructure and other improvements to the built environment. In addition, evidence suggests a significant unmet demand for communities that offer the

Table 12. Change in walking for Bay Area neighborhoods from 1992 to 2003.

Neighborhood	Average walk frequency (per 30 days)		Percent walking at least once (per 30 days)		Average strolling frequency (per 30 days)		Percent strolling at least once (per 30 days)	
	1992	2003	1992	2003	1992	2003	1992	2003
Mountain View	4.8	5.3	56%	82%*	10.1	9.7	78%	89%*
Junior College	5.7	5.0	64%	73%	12.6	10.6	85%	87%
Sunnyvale	2.8	2.0*	48%	48%	11.6	8.0*	78%	84%
Rincon Valley	1.0	1.4*	33%	37%	10.8	8.3	78%	76%

*Statistically significant difference based on *t*-test or chi-square test.
Note: Source for 1992 data is Handy (1996).

opportunity to walk (e.g., Levine et al., 2002; Levine & Inam, 2004; Myers & Gearin, 2001). Enabling people to find neighborhoods that better match their preferences is itself an important benefit. In the end, expanding the range of choice—for kinds of places to live, for modes of travel or exercising—may be the most significant benefit of all.

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Notes
1. The methodology is described in more detail in Handy, Mokhtarian, Buehler, and Cao (2004).
2. Pairwise correlations of explanatory variables in each model were mostly below 0.2 and all below 0.6, indicating a low level of collinearity. Variance inflation factors (VIFs) can be calculated for linear regression models to estimate the impact of collinearity on estimates of model coefficients. Because we use negative binomial regression and ordered probit techniques, we could not calculate VIFs for our models directly. However, we used the explanatory variables in our models to estimate linear regression models and calculated VIFs for these models. This approach provides an informal assessment of the impact of collinearity for our models. The VIFs were all below 2, indicating no worrisome collinearity effects.
3. Reliability was tested using a subsample of 23 respondents who completed the survey twice, once in the first mailing of the survey and again when they received the second mailing of the survey (because their initial survey arrived too late to exclude them from the second mailing). The correlation for strolling was 0.712, while the correlation for walks to the store was 0.325. The low correlation for walking to the store could reflect an actual change in behavior owing to seasonal changes in weather, although strolling was not similarly affected. Alternatively, the higher frequency of strolling may make it easier for respondents to accurately recall these trips. Because the test is based on a self-selected sample of respondents willing to complete the survey twice without our asking, it may overestimate the reliability of the measures.
4. The factors were derived using principal components factor analysis with oblique rotation, with a suppression threshold of 0.33. We considered multiple criteria in determining the number of factors, including eigenvalues greater than or equal to 1, the point at which the scree plots leveled off, and ease of interpretability. The highest pairwise correlation was 0.533, between the factors for accessibility and physical activity options.
5. The factors were derived using principal components factor analysis with oblique rotation, with a suppression threshold of 0.33. We considered multiple criteria in determining the number of factors, including eigenvalues greater than or equal to 1, the point at which the scree plots leveled off, and ease of interpretability. The highest pairwise correlation was 0.325, between the factors for pro-bike/walk attitude and pro-transit attitude.
6. The deviance R^2 measure of goodness of fit (recommended by Cameron & Windmeijer, 1996) represents the proportionate reduction, due to the explanatory variables in the model, in the deviance of the log-likelihood of the constant-only model from the maximum possible log-likelihood.
7. Because bicycling and walking are both forms of physical activity, it is possible that they serve as substitutes for each other to some degree. In other words, an individual who now bicycles more might be walking less as a result. If so, the errors in the models for change in walking and change in bicycling could be correlated, leading to consistent but inefficient coefficient estimates, and biased standard errors. A seemingly unrelated regression (SUR) analysis can be performed for linear models, but is not readily available for nonlinear ordered probit models such as ours.
8. Rincon Valley, which had several large tracts of undeveloped land in 1992 and a somewhat rural character, has experienced a notable amount of infill development over this period, as well as an improvement in pedestrian infrastructure along major arterials. A commercial resurgence in downtown Mountain View that started before 1992 has continued, fostered in part by the opening of the city's performing arts center. In addition, a major transit center, where the Caltrain commuter rail meets up with the Valley Transit Authority's light rail system, opened during

the 1990s. By comparison, the Sunnyvale neighborhood has seen few changes to the built environment, beyond some infill housing and turnover in local businesses.

References

Bagley, M. N., & Mokhtarian, P. L. (2002). The impact of residential neighborhood type on travel behavior: A structural equations modeling approach. *Annals of Regional Science, 36*(2), 279–297.

Boarnet, M. G., & Crane, R. (2001). *Travel by design: The influence of urban form on travel.* New York: Oxford University Press.

Boarnet, M. G., Day, K., Anderson, C., Alfonzo, M., & McMillan, T. (2005). California's Safe Routes to School program: Impacts on walking, bicycling, and pedestrian safety. *Journal of the American Planning Association, 71*(3), 301–317.

Boarnet, M. G., Anderson, C., Day, K., & McMillan, T. (2005). Evaluation of the California Safe Routes to School legislation: Urban form changes and children's active transportation to school. *American Journal of Preventive Medicine, 28*(2 Suppl. 2), 134–240.

Cameron, A. C., & Windmeijer, F. A. G. (1996). R-squared measures for count data regression models with applications to health-care utilization. *Journal of Business and Economic Statistics, 14*(2), 209–220.

Cao, X., Handy, S., & Mokhtarian, P. L. (2006). The influences of the built environment and residential self-selection on pedestrian behavior. *Transportation, 33*(1), 1–20.

Centers for Disease Control and Prevention. (2005). Physical activity for everyone: Recommendations: How active do adults need to be to gain some benefit? Retrieved December 5, 2005, from http://www.cdc.gov/nccdphp/dnpa/physical/recommendations/adults.htm

Frank, L. D., Andresen, M., & Schmid, T. (2004). Obesity relationships with community design, physical activity, and time spent in cars. *American Journal of Preventive Medicine, 27*(2), 87–96.

Giles-Corti, B., & Donovan, R. J. (2003). Relative influences of individual, social environmental, and physical environmental correlates of walking. *American Journal of Public Health, 93*(9), 1582–1589.

Greenwald, M., & Boarnet, M. (2001). Built environment as determinant of walking behavior: Analyzing nonwork pedestrian travel in Portland, Oregon. *Transportation Research Record, 1780*, 33–42.

Handy, S. L. (1992). Regional versus local accessibility: Variations in suburban form and the effects on nonwork travel. Unpublished doctoral dissertation, University of California, Berkeley.

Handy, S. L. (1996). Urban form and pedestrian choices: A study of Austin neighborhoods. *Transportation Research Record, 1552*, 135–144.

Handy, S. L. (2005). *Critical assessment of the literature on the relationships among transportation, land use, and physical activity* (Resource paper for TRB Special Report 282). Washington, DC. Available: http://trb.org/downloads/sr282papers/sr282Handy.pdf

Handy, S. L., & Clifton, K. J. (2001). Local shopping as a strategy for reducing automobile travel. *Transportation, 28*, 317–346.

Handy, S. L., Mokhtarian, P. L., Buehler, T., & Cao, X. (2004). *Residential location choice and travel behavior: Implications for air quality* (Prepared for the California Department of Transportation). Available: http://aqp.engr.ucdavis.edu/Documents/Final_report_editted_updated1.pdf

Handy, S. L., Weston, L., & Mokhtarian, P. L. (2005). Driving by choice or necessity? *Transportation Research A, 39*(1–2), 183–203.

Khattak, A., & Rodriguez, D. (2005). Travel behavior in neo-traditional neighborhood developments: A case study in U.S.A. *Transportation Research A, 39*(6), 481–500.

Krizek, K. (2000). Pretest-posttest strategy for researching neighborhood-scale urban form and travel behavior. *Transportation Research Record, 1722*, 48–55.

Krizek, K. (2003). Residential relocation and changes in urban travel: Does neighborhood-scale urban form matter? *Journal of the American Planning Association, 69*(3), 265–281.

Levine, J., & Inam, A. (2004). The market for transportation-land use integration: Do developers want smarter growth than regulation allows? *Transportation, 31*(4), 409–427.

Levine, J., Inam, A., Werbel, R., & Torng, G. W. (2002). *Innovation in transportation and land use as expansion of household choice* (MTI Report 01-19). San Jose, CA: Mineta Transportation Institute, San Jose State University.

McCann, B., & Ewing, R. (2003). *Measuring the health effects of sprawl: A national analysis of physical activity, obesity, and chronic disease.* Retrieved February 8, 2005, from http://www.sactaqc.org/Resources/Literature/Public_Health/HealthSprawl.pdf

Mokhtarian, P. L., & Salomon, I. (2001). How derived is the demand for travel? Some conceptual and measurement considerations. *Transportation Research A, 35*(8), 695–719.

Myers, D., & Gearin, E. (2001). Current preferences and future demand for denser residential environments. *Housing Policy Debate, 12*(4), 633–659.

Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine, 25*(2), 80–91.

School of Population Health, University of Western Australia. (2004). *The RESIDE (RESIDential Environments) project.* Retrieved February 8, 2005, from http://www.publichealth.uwa.edu.au/welcome/research/hpreg/hpreg/staff/gilescorti/reside

Schwanen, T., & Mokhtarian, P. L. (2005). What affects commute mode choice: Neighborhood physical structure or preferences toward neighborhoods? *Journal of Transport Geography, 13*(1), 83–99.

Siegel, P. Z., Brackbill, R. M., & Heath, G. W. (1995). The epidemiology of walking for exercise: Implications for promoting activity among sedentary groups. *American Journal of Public Health, 85*(5), 706–710.

Singleton, R. A., & Straits, B. C. (1999). *Approaches to social research* (3rd ed.). New York: Oxford University Press.

Sommer, B., & Sommer, R. (1997). *A practical guide to behavioral research: Tools and techniques* (4th ed.). New York: Oxford University Press.

U.S. Department of Health and Human Services. (1996). *Physical activity and health: A report of the Surgeon General.* Atlanta, GA: Author.