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Health-Promoting Community Design

The Causal Influence of Neighborhood Design on Physical Activity Within the Neighborhood: Evidence from Northern California

Susan L. Handy, PhD; Xinyu Cao, PhD; Patricia L. Mokhtarian, PhD

Abstract

Purpose. Test for a causal relationship between neighborhood design and physical activity within the neighborhood by controlling for self-selection.

Design. Cross-sectional and quasi-longitudinal analyses of residents of selected neighborhoods.

Setting. Eight Northern California neighborhoods.

Subjects. Random sample of 1682 adults stratified by movers (moved within 1 year) and nonmovers (moved > 1 year ago) responding to self-administered mail surveys (24.7% response rate).

Measures. Self-reported number of days in last 7 days of moderate to vigorous physical activity somewhere in the neighborhood and self-reported change in physical activity in the neighborhood from prior to moving (for movers) or from 1 year ago (for nonmovers).

Analysis. Zero-inflated Poisson regression for cross-sectional analysis (n = 1497); ordered probit model for quasi-longitudinal analysis (n = 1352).

Results. After we controlled for physical activity attitudes and neighborhood preferences, selected neighborhood design characteristics were associated with physical activity within the neighborhood and changes in selected neighborhood design characteristics were associated with changes in physical activity within the neighborhood.

Conclusions. Both cross-sectional and quasi-longitudinal analyses provided evidence of a causal impact of neighborhood design. Improving physical activity options, aesthetic qualities, and social environment may increase physical activity. Critical limitations included self-report measures of physical activity, lack of measures of duration and intensity of neighborhood physical activity, lack of measures of total physical activity, and limited measures of preferences related to physical activity. (Am J Health Promot 2008;22[5]:350–358.)

Key Words: Physical Activity, Neighborhood, Urban Design, Perceived Environment, Prevention Research. Manuscript format: research; Research purpose: modeling/relationship testing; Study design: nonexperimental; Outcome measure: behavioral; Setting: local community; Health focus: fitness/physical activity; Strategy: built environment; Target population age: adults; Target population circumstances: geographic location

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PURPOSE

The built environment is widely touted as a potential tool for increasing physical activity and thus health.[1-3] This potential is supported by consistent and convincing evidence of an association between the built environment and physical activity.[4-6] However, the effectiveness of the built environment as a strategy depends on a causal relationship with physical activity.[7] The criteria for establishing causality are association, time precedence, and nonspuriousness.[8] Although previous studies have established an association between the built environment and physical activity, they have not adequately addressed the criteria of time precedence and nonspuriousness.

This gap leaves open the possibility that the observed associations are explained by "self-selection," which can be defined as the selection of a residential location with built environment characteristics that are consistent with an individual's behavioral predispositions.[9] For example, those who prefer physical activity may choose to live in neighborhoods conducive to physical activity, in which case the preference rather than the built environment is the causal factor. To the extent that this is true, polices aimed at changing the built environment will not have the desired effect on physical activity unless preferences are also aligned with the changes. To eliminate the rival hypothesis that self-selection explains the observed association, researchers must control for preferences and attitudes related to residential choice and physical activity and must

establish that the built environment precedes the physical activity.

Causality is also more strongly established if a mechanism linking the cause to the effect can be identified. Researchers have used different theoretic frameworks to explain the connection between the built environment and physical activity, including socio-ecologic models, the theory of planned behavior, and utility-maximizing theory.[10] Whichever framework is used, several researchers have recently stressed the importance of matching the specific type of physical activity to the environment in which it occurs.[5,10–13] For example, an individual's physical activity at his or her workplace is likely to be influenced by the built environment characteristics of the workplace but not of the residential neighborhood—at least not directly. Conversely, the type of physical activity most likely to be directly affected by neighborhood design is physical activity within the neighborhood.

Using data collected from Northern California in 2003, this study explored the causal relationship between neighborhood design and physical activity. The combination of three key features provided a stronger assessment of causality than previous studies to date: a focus on the connection between built environment characteristics of the neighborhood and physical activity within the neighborhood, statistical control of preferences for physical activity and neighborhood design characteristics supportive of physical activity, and quasi-longitudinal measures of neighborhood design characteristics and physical activity.

METHODS

Design

This study used both cross-sectional and quasi-longitudinal designs to test the association between neighborhood design and physical activity within the neighborhood for residents of suburban and traditional neighborhoods, while controlling for preferences and attitudes. The quasi-longitudinal design used a sample of recent movers and self-reported measures of changes in neighborhood-based physical activity from before to after the move; a sample of residents not recently

moved served as a control group by reporting change in physical activity from 1 year ago. The survey instrument and procedure were approved by the Institutional Review Board of the University of California, Davis.

Sample

The data used in this study came from a self-administered 12-page survey mailed in two rounds in the fall of 2003 to residents of eight neighborhoods in Northern California. The neighborhoods were selected to vary systematically on neighborhood type, size of metropolitan area, and region of the state, and to control for socio-economic status. Neighborhood type was differentiated as "traditional" for areas built mostly in the pre–World War II era and "suburban" for areas built more recently. The two neighborhood types offered significantly different built environment characteristics, although differences between neighborhoods of the same type are also sometimes significant.[14] In this analysis, we focused on the effect of specific neighborhood characteristics rather than neighborhood type.

For each neighborhood, we purchased two databases of residents from a commercial provider, New Neighbors Contact Service (http://www.nncs.com): a database of "movers" and a database of "non-movers." The "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 of the eight neighborhoods. The database of "nonmovers" consisted of a random sample of 500 residents not included in the "movers" list for each neighborhood. The result is a disproportionate sample stratified by neighborhood and mover/nonmover status. For sampling purposes, neighborhood boundaries were defined based on natural boundaries or manmade boundaries such as major arterial streets, census tracts, and planning areas; the resulting neighborhoods were large enough to achieve a sample size of 500 movers.

The original database consisted of 8000 addresses but only 6746 valid addresses. The response rate was 24.7% based on the valid addresses

only. This response rate is considered quite good for a survey of this length; the response rate for a survey administered to the general population is typically 10% to 40%.[15] A comparison of sample characteristics to population characteristics, based on the 2000 U.S. Census (Table 1), showed that survey respondents tended to be older than residents of their neighborhood as a whole and that the percent of households with children was lower for the sample for most neighborhoods. In addition, 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. However, since the focus of our study was explaining physical activity as a function of other variables rather than describing the simple univariate distribution of physical exercise *per se*, these differences were not expected to materially affect the results.[16] Although the overall sample size for the survey was 1682, the sample sizes for the cross-sectional and quasi-longitudinal models, described below, were 1497 and 1352, respectively, owing to missing values for dependent and independent variables.

Measures

The dependent variables used were frequency of moderate to vigorous physical activity within the neighborhood and changes in physical activity within the neighborhood. In the survey, respondents were asked to report: "How many days in the last 7 days did you exercise somewhere in the neighborhood hard enough to breathe somewhat harder than normal for at least 10 minutes?" This question was adapted from a question in the international physical activity questionnaire (IPAQ). A reliability test for frequency of neighborhood physical activity (NPA) produced an intraclass correlation coefficient (ICC) of .20 (n = 23); this low value may be explained in part by the measure of physical activity for an actual week rather than a typical week, and thus it was dependent on weather and other time-dependent factors. We also asked respondents to indicate their changes in NPA compared with their physical activity level just before the move (for

Table 1
Sample vs. Population Characteristics

	Traditional				Suburban			
	Mountain View	SR Junior College	MD Central	SC Midtown	Sunnyvale	SR Rincon Valley	MD Suburban	SC Natomas
Sample characteristics								
n	228	215	184	271	217	165	220	182
% recent movers	45.6	46.0	39.1	43.2	40.1	40.6	34.1	36.8
% women	47.3	54.3	56.3	58.2	46.9	50.9	50.9	54.9
Average autos owned	1.80	1.63	1.59	1.50	1.79	1.66	1.88	1.68
Average age, y	43.3	47.0	51.3	43.4	47.1	54.7	53.2	45.6
Average household size	2.08	2.03	2.13	1.78	2.58	2.19	2.41	2.35
% households with children	21.1	18.6	21.7	8.9	42.4	24.8	25.5	31.9
% home owners	51.1	57.8	75.6	47.0	61.1	68.7	81.0	82.4
Median household income ($000)	98.7	55.5	45.5	64.2	95.0	49.5	55.5	55.3
Population characteristics								
Population	5493	9886	13,295	7259	14,973	13,617	19,045	13,295
Average age, y	36.1	36.3	36.5	42.7	35.9	38.3	38.1	31.7
Average household size	2.08	2.21	2.46	1.79	2.66	2.48	2.51	2.57
% households with children	19.3	20.3	32.9	12.4	35.3	35.4	34.2	41.7
% home owners	34.3	31.2	58.8	34.3	53.2	63.5	61.4	55.2
Median household income ($000)	74.3	40.2	42.5	43.8	88.4	49.6	40.2	46.2

SR indicates Santa Rosa; MD, Modesto; and SC, Sacramento.

the movers) or from 1 year ago (for the nonmovers) on a five-point scale from "much less often now" to "much more often now." This question produced an indicator of the direction and general magnitude of change rather than a measure of the actual change. A reliability test for this measure produced an ICC of .89 (n = 16).

The explanatory variables were grouped into four categories as follows.

Perceptions of and Preferences for Neighborhood Characteristics. To measure perceptions of neighborhood characteristics, respondents were asked to indicate how true 34 characteristics were for their current and previous (only for movers) neighborhoods on a four-point scale from "not at all true" (1) to "entirely true" (4). Preferences for these items were measured through a rating of the importance of these items to respondents when (for the movers) they were looking or if (for the nonmovers) they were to be looking for a new place to live, on a four-point scale from "not at

all important" (1) to "extremely important" (4). We applied principal components analysis with oblique rotation (threshold for suppression of .33) on the combined set of responses for perceptions and preferences to reduce these items (after dropping some) to six factors (Table 2): accessibility, physical activity options, attractiveness, and outdoor spaciousness as characteristics of the built environment; and safety and socializing as characteristics of the social environment. Because we used oblique rotation, the factors can be correlated; however, the largest correlation among the perceptions (between stores within walking distance and physical activity options) was .34, which is far smaller than the typical threshold of concern about multicollinearity ($\geq$.7). Further, with a large enough sample, separate effects even of relatively highly correlated variables can be precisely distinguished, and our sample is considered quite large in this context. Thus, multicollinearity was not a serious concern here. The preference factors

are used to control for self-selection, whereas the perception factors are used as measures of the built environment. Preference for and perception of stores within walking distance, as individual items, were also used in the analysis as an alternative to the accessibility factor.

Objective Accessibility. Following the survey, objective measures of accessibility were estimated for each respondent based on distance along the street network from home to a variety of destinations, classified as institutional (bank, church, library, and post office), maintenance (grocery store and pharmacy), eating out (bakery, pizza, ice cream, and take out), and leisure (health club, bookstore, bar, theater, and video rental). Accessibility measures included the number of different types of businesses within specified distances (a mixed-use indicator), the distance to the nearest establishment of each type (a measure of proximity), and the number of establishments of each business type within specified

Table 2
Definitions of Factors for Perceptions of and Preferences for Neighborhood Characteristics and for Travel Attitudes

Factor	Statement	Loading
Perceptions of and preferences for neighborhood characteristics		
Accessibility	Easy access to a regional shopping mall	0.854
	Easy access to downtown	0.830
	Other amenities such as a pool or 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 options	Good bicycle routes beyond neighborhood	0.882
	Sidewalks throughout 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 kids to play outdoors	0.634
	Good street lighting	0.751
Socializing	Diverse neighbors in terms of ethnicity, race, and age	0.789
	Lots of people out and about within neighborhood	0.785
	Lots of interaction among neighbors	0.614
	Economic level of neighbors similar to my level	0.476
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
Outdoor spaciousness	Large backyards	0.876
	Large front yards	0.858
	Lots of off-street parking (garages or driveways)	0.562
	Big street trees	0.404
Travel attitudes		
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

Source: Handy et al., 2004.[14]

distances (a measure of choices available). Commercial establishments were identified using online yellow pages, and a specially developed routine in ArcGIS 3.0 (ESRI, Redlands, Calif) was used to calculate network distances between addresses for survey respondents and commercial establishments.

Travel Attitudes. Because the main purpose of the larger study was to explore the relationship between the built environment and travel behavior, the survey included measures of travel attitudes. Respondents were asked whether they agreed or disagreed with a series of 32 travel-related statements on a five-point scale from "strongly disagree" (1) to "strongly agree" (5). Factor analysis was then used to reduce these items to six underlying dimensions: pro-bike/walk, protransit, protravel, travel minimizing, safety of car, and car dependence. For the analysis of neighborhood-based physical activity, only the pro-bike/walk factor (Table 2) was used. Since both walking and biking are modes of transport and types of physical activity, an intrinsic preference for walking and biking is one reasonable indicator of preference for physical activity.

Sociodemographics. Sociodemographic measures included gender, age, employment status, education, household income, household size, number of children in the household, mobility constraints, and residential tenure. Some changeable sociodemographics such as household size, presence of children, and income were measured currently as well as before moving for movers and from 1 year ago for non-movers.

Analysis
The purpose of both the cross-sectional and quasi-longitudinal analyses was to test the association between the dependent variable and characteristics of neighborhood design, both perceived and objective, while control-

ling for neighborhood preferences, pro-bike/walk attitudes, and sociodemographic characteristics. If neighborhood design characteristics were significant after controlling for these factors in the cross-sectional model, two criteria for causality were established: association and nonspuriousness. If neighborhood design characteristics were significant after controlling for these factors in the quasi-longitudinal model, the third criterion for causality, time precedence, was also established. Although the quasi-longitudinal model is a stronger test of causality than the cross-sectional model, we include the latter as a comparison with previous cross-sectional studies that did not control for attitudes and preferences. We used LIMDEP 7.0 (Econometric Software Inc, Plainview, NY) to estimate models for both analyses, although different modeling techniques were used in each. In determining which variables to include in the model, we generally used a 5% level of significance, although in a few cases we allowed variables to remain at ≤10% when there was a strong conceptual justification for doing so. We present only the final models with insignificant variables excluded.

Because frequency of NPA is a count variable, Poisson regression is a potentially appropriate technique. However, 47.8% of respondents reported 0 days of exercising within the neighborhood. These respondents fall into one of two categories. An individual may never engage in moderate to vigorous physical activity for ≥10 minutes somewhere in the neighborhood, or an individual may sometimes or even regularly engage in such physical activity but did not do so within the measurement period owing to factors such as time constraints, weather, etc. To account for both possibilities, we used zero-inflated Poisson (ZIP) regression, which is appropriate for modeling a count variable with excessive zeros, for the cross-sectional analysis. The Vuong statistic was larger than 1.96, demonstrating that the ZIP model fit the data better than a Poisson model.[17]

The quasi-longitudinal model for change in NPA used measures of changes in the built environment as explanatory variables. For the sample of movers only, changes in the built environment were measured by taking the difference between perceived characteristics of the current and previous neighborhoods; the built environment was assumed unchanged for the sample of nonmovers. For both groups, changes in sociodemographic characteristics were measured, but neighborhood preferences and travel attitudes were assumed unchanged. An ordered probit model was used to estimate the relationship between changes in the built environment and changes in NPA. This technique is appropriate for an ordinal dependent variable, and the 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 physical activity.

RESULTS

Cross-Sectional Analysis

Overall, respondents engaged in NPA on 1.64 days in the last 7 days on average. The ZIP model indicated that several sociodemographic characteristics are associated with the frequency of NPA (Table 3). Older people and/or individuals with a higher education had a tendency to engage in NPA more frequently. By contrast, those who were working, had more children under 5 years, and/or had physical or psychologic limitations on walking engaged in NPA less frequently. The pro-bike/walk factor was positively associated with NPA frequency. Among the variables tested, this variable was the most important in explaining the variations in NPA frequency as indicated by its standardized coefficient. Interestingly, none of the neighborhood preference variables was significant in the model (and hence do not appear in the table); preference for physical activity options was not significant even when the pro-bike/walk factor (correlation of $r = .271$ ($p = .000$) with preference for physical activity options) was excluded from the model.

After we controlled for sociodemographic and attitudinal factors, six neighborhood characteristics were significantly associated with NPA fre-

quency. Individuals living in mixed-use neighborhoods (measured as the number of business types within 400 m of the residence) and/or those living farther from health clubs had higher NPA frequency. Those who had a higher score on perceived physical activity options, social environment, attractiveness, and/or who perceived stores within walking distance tended to engage in NPA more frequently. A comparison of standardized coefficients indicated that neighborhood characteristics are at least as important as sociodemographic characteristics in explaining frequency of NPA.

Quasi-Longitudinal Analysis

Changes in NPA were balanced: 17.1% of respondents reduced their NPA and 20.7% increased their NPA; the remaining reported no change in their NPA frequencies. The ordered probit model indicated that changes in several sociodemographic characteristics are associated with changes in NPA (Table 4). Changes in the number of children under 5 years are negatively associated with changes in NPA. Those with a higher education had a tendency to increase their NPA, whereas people with limitations on walking were more likely to decrease their NPA. Although age is positively associated with frequency of NPA, it is associated with a decrease in NPA over time. The pro-bike/walk factor had a significant and positive association with changes in NPA; again, no measures of residential preferences were significant in the model.

After we accounted for the influences of sociodemographic characteristics and attitudes, the model showed a significant effect of current perception of neighborhood safety and measures of change in three neighborhood characteristics: physical activity options, socializing, and attractiveness. Standardized coefficients showed that changes in attractiveness are most important in explaining changes in NPA; the influences of other neighborhood characteristics were comparable to those of the sociodemographic traits.

DISCUSSION

Public health officials and researchers alike advocate neighborhood design policies to encourage physical

Table 3
ZIP Model for Exercise Frequency

Variables	Unstandardized Coefficients	Standardized Coefficients†	p
Constant	0.347	0.978	0.016
Sociodemographics			
Age	0.00363	0.0550	0.024
Education	0.0348	0.0449	0.012
Worker	−0.0947	−0.0363	0.075
# of children ≤5 years in household	−0.0786	−0.0348	0.036
Limitations on walking	−0.320	−0.0662	0.004
Travel attitudes			
Pro-bike/walk	0.129	0.129	0.000
Neighborhood characteristics			
# of business types within 400 m	0.0208	0.0471	0.017
Distance to nearest health club (km)	0.116	0.0561	0.004
Perceived physical activity options	0.0455	0.0395	0.083
Perceived socializing	0.0517	0.0447	0.026
Perceived attractiveness	0.0914	0.0866	0.000
Perceived stores within walking distance	0.0665	0.0549	0.004
N	1497		
τ	−0.393		0.000
Log-likelihood (Poisson)	−2967.4		
Log-likelihood (ZIP)	−2522.2		
Vuong statistic for testing ZIP	12.80		0.000

ZIP indicates zero-inflated Poisson.
† The dependent variable was not standardized, and the model was re-estimated.

Table 4
Ordered Probit Model for Changes in Exercise

Variables	Unstandardized Coefficients	Standardized Coefficients†	p
Constant	1.621	1.650	0.000
Sociodemographics			
Changes in # of children ≤5 years in household	−0.187	−0.0558	0.060
Current age	−0.00541	−0.0729	0.014
Current education	0.0558	0.0729	0.017
Current limitations on walking	−0.381	−0.0669	0.056
Travel attitudes			
pro-bike/walk	0.0926	0.0906	0.003
Neighborhood characteristics			
Changes in perceived physical activity options	0.0681	0.0586	0.046
Changes in perceived socializing	0.0670	0.0549	0.052
Changes in perceived attractiveness	0.143	0.151	0.000
Current perceived safety	0.0726	0.0672	0.025
Threshold parameter 1	0.659		0.000
Threshold parameter 2	2.488		0.000
Threshold parameter 3	3.307		0.000
N	1352		
Log-likelihood at constant	−1563.7		
Log-likelihood at convergence	−1516.9		
χ^2	93.6		0.000

† The dependent variable was not standardized, and the model was re-estimated.

activity. The effectiveness of such policies depends on a causal relationship between neighborhood design and physical activity. Using data from eight neighborhoods in Northern California, this study investigated the existence of a causal relationship.

Both the cross-sectional and quasi-longitudinal analyses provided evidence of a causal impact of neighborhood design on NPA. First, we controlled for the influence of attitudes and residential preferences to eliminate rival hypotheses. Not surprisingly, individuals who favored walking and biking were more likely to engage in NPA, suggesting a possible self-selection effect. However, preferences for neighborhood characteristics were not significant in either model. This discrepancy could be explained by a degree of disconnect between physical activity preferences and residential location: not all individuals who like to walk and bike put importance on this factor when deciding where to live. In any event, the significance of neighborhood design characteristics in the model after accounting for possible self-selection suggested that the relationship is not spurious. This result provided stronger evidence of causality than previous studies that showed an association between the built environment and physical activity but did not control for attitudes and preferences. Second, the quasi-longitudinal analysis showed that changes in the built environment resulting from a residential relocation are associated with subsequent changes in NPA after we controlled for attitudes, preferences, and sociodemographic characteristics. Thus, we have established three requisites for causality inference: association, nonspuriousness, and time precedence.

In addition, the neighborhood design characteristics significant in the models had logical connections with NPA. Interestingly, attractiveness appeared to have a larger effect than physical activity options. This finding is consistent with prior studies that showed an association between aesthetics (measured in various ways) and walking for recreation[18,19] and makes sense if walking is a significant share of NPA. In short, the nicer the environment, the more attractive walking is to residents. In addition, socializing has an impact comparable to that of physical activity options, suggesting that the social environment and the built environment are important in promoting NPA, although it is likely that the built environment has some impact on the social environment.[20] Seeing other people out and about in the neighborhood and knowing one's neighbors can increase the sense of safety that residents feel and also the pleasure they gain from walking. The factor for physical activity options has the most obvious connection to NPA: the availability of facilities for NPA, whether walking, biking, or playing in the park, makes NPA easier and safer. The significance of these factors (current levels in the model for frequency of NPA and changes in the factors in the model for changes in NPA) was robust across both models.

Prior research on the link between neighborhood design and physical activity used two general types of measures of neighborhood-based physical activity: walking for transport, recreation, or both[18,19,21,22] and use of neighborhood facilities such as parks and trails.[23–25] These measures differ from our measure of NPA in two important ways: they are likely to include physical activity beyond neighborhood boundaries and they do not include all types of physical activity that may occur within neighborhood boundaries. Our measure may thus be a better match with neighborhood-scale measures of the built environment, although matching the built environment and physical activity at even greater levels of specificity (e.g., availability of basketball courts within the neighborhood and playing basketball in the neighborhood) might prove insightful. It is important to note, however, that the definition of "neighborhood" is not straightforward. Although we defined boundaries of the neighborhoods for sampling purposes, the definitions of boundaries for both NPA and perceived neighborhood characteristics were left up to each respondent. While boundaries are likely to remain roughly consistent for each respondent across the survey questions, the boundaries are likely to vary from respondent to respondent. In other words, we may have a spatial match between physical activity and built environment measures, but we do not know at what scale that match occurs. In addition, our measure leaves open the possibility that respondents included exercise done at home (e.g., on stationary bikes, treadmills, trampolines) as occurring "within the neighborhood." Although this inclusion is technically correct, the incidence of home-based exercise is probably not directly influenced by the characteristics of the outdoor neighborhood environment, and thus any inclusion of at-home physical activity would attenuate the explanatory power of the models.

A critical limitation of this study was the use of self-reported measures of physical activity. Self-reported measures suffer from problems such as recall error and social bias. However, validity and reliability tests show that the performance of the IPAQ instruments, on which our measure was based, is acceptable.[26] In addition, because the purpose of this article was to test for causality rather than to quantify effect size, a measure that accurately captures relative differences in physical activity between neighborhoods, even if it does not accurately measure absolute amount of physical activity, is sufficient. Another limitation is the lack of measures of duration and intensity of NPA; it is possible that even frequent NPA was of limited duration and intensity. The survey did not ask what types of NPA respondents engaged in, although the nature of the question used to measure NPA should have omitted casual strolls and other low-intensity activities. We presume that NPA included activities involving movement through the neighborhood (e.g., brisk walking, running, biking, in-line skating) and activities taking place at a fixed location within the neighborhood (e.g., basketball, tennis, softball, soccer, playground activities, depending on the availability of facilities). Future studies could explore the nature of NPA in terms of all of these dimensions: frequency, duration, intensity, and type. In addition, we did not have a measure of total physical activity. It is possible that a change in the built environment that leads to an increase in NPA does not increase total physical activity if NPA substitutes for

other forms of physical activity. Indeed, the positive association between distance to a health club and frequency of NPA in the cross-sectional model supports the possibility of substitution (i.e., the farther away the health club, the more likely the respondent will exercise within the neighborhood instead of at a health club). Lacking these measures, we were not able to assess net effects on total physical activity or the overall importance of neighborhood design for health.

An additional limitation is the incomplete measurement of preferences related to physical activity in this study. Although the study included a measure of preferences for walking and biking, common forms of physical activity within a neighborhood, it did not include measures of preferences for other forms of NPA (e.g., playing basketball). A potentially more serious limitation lies in the nature of the neighborhood preference variables, which were measured retrospectively for movers (important to their move to the present location) and prospectively for nonmovers (if they were considering a move). This approach creates temporal inconsistency between movers and nonmovers, and movers' reported preferences prior to the move may reflect memory bias (the prospective approach for nonmovers was in fact chosen to avoid the problem of memory bias over long periods of time). In addition, the significant correlation between preference for physical activity (measured here using the pro-bike/walk factor) and preference for physical activity options within the neighborhood (including bike lanes, sidewalks, and parks) points to the need for more sophisticated techniques, such as structural equations modeling, to separate direct effects and indirect effects (through residential location) of attitudes on physical activity behavior. By using such techniques and by controlling for attitudes and preferences, future cross-sectional studies can provide stronger evidence of causality than existing studies do.

Although our quasi-longitudinal approach provided a stronger test of causality than a strictly cross-sectional study, a true longitudinal study is obviously superior. Few such studies have been completed so far on the topic of the built environment and physical activity, and most of these have notable limitations themselves. One approach is to measure attitudes and behavior before and after a move, thus eliminating the potential for recall error and memory bias found in our study, although attitudes must still be accounted for to control for self-selection. Krizek,[27] for example, used a panel survey to examine changes in walking for residents moving from one neighborhood type to another, although the survey did not include measures of attitudes or preferences. A second approach is to measure behavior before and after a change in the built environment for a fixed set of residents. This approach isolates the effect of a single change to the built environment, rather than testing the impact of changes in neighborhood design overall. It reduces the problem of self-selection, although it does not eliminate self-selection because the preferences of the residents may have influenced the process that brought about the change in the built environment. It is possible that the effect of the built environment change is moderated by attitudes even if self-selection does not occur. Examples include the effect of traffic control and pedestrian facilities around schools on walking to school,[28] the effect of improved street lighting on walking,[29] and the effect of bike lanes on the amount of biking[30]; these studies lacked measures of attitudes, however, and control groups in the case of the latter two. Such studies depend on a good match between research funding and the timing of appropriate projects and are thus challenging to carry out in practice, but more are needed to shed further light on the causal impact of neighborhood design on physical activity. True longitudinal studies could also improve upon this study by using objective measures of NPA, including duration and intensity; objective measures of total physical activity; and measures of a broader range of preferences related to physical activity.

Despite its limitations, this study offers some encouragement that certain changes in the built environment in a neighborhood may lead to more physical activity within the neighborhood. An increase in attractiveness (appearance, level of upkeep, variety in housing styles, big street trees) is the most important factor for encouraging an increase in NPA; increases in physical activity options (bike routes, sidewalks, parks) may also increase NPA. In addition, characteristics of the social environment (which may themselves be influenced by the built environment) encourage NPA, particularly increases in socializing (diverse neighbors, people out and about, interaction among neighbors, similar economic levels) and safety (quiet, low crime, low traffic, safe for walking, street lighting).

Local governments have many tools at their disposal to help bring about these changes.[31] Creating environments conducive to NPA is easier in new developments than existing environments. Cities can modify zoning and subdivision ordinances to ensure closer proximity to parks and open spaces and to require more from developers in the way of infrastructure for pedestrians and bicyclists. Mixed-use development, which is promoted as a way of increasing street life, may create an inviting social environment for exercisers. Changing the environment in existing neighborhoods is much more

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SO WHAT? Implications for Health Promotion Practitioners and Researchers

This study provides evidence of a causal impact of neighborhood design on neighborhood physical activity and thus supports the hypothesis that changes in the built environment will lead to increases in physical activity within the neighborhood. Key neighborhood design characteristics are attractiveness (comprising appearance, level of upkeep, variety in housing styles, big street trees) and physical activity options (bike routes, sidewalks, parks). Social environment characteristics, both socializing (diverse neighbors, people out and about, interaction among neighbors, similar economic levels) and safety (quiet, low crime, low traffic, safe for walking, street lighting), are also important. Local governments can increase these qualities through a variety of policies and programs.

challenging. Policies to promote infill development, programs that aim to revitalize blighted neighborhoods, and investments in pedestrian infrastructure such as sidewalks can help. Traffic-calming programs, implemented to reduce vehicle volume and speed, are an important strategy; the more recent "road diets" and "complete the streets" movements may also play a role. Improvements in street lighting, neighborhood watch programs, and weed and seed programs could help to increase the sense of safety in a neighborhood, and neighborhood events such as farmer's markets, block parties, or walking and cycling groups might increase levels of socializing. Clearly, a comprehensive package of policies and programs is needed to encourage neighborhood physical activity.

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