Complexity in Built Environment, Health, and Destination Walking: A Neighborhood-Scale Analysis

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ABSTRACT *This study investigates the relationships between the built environment, the physical attributes of the neighborhood, and the residents' perceptions of those attributes. It focuses on destination walking and self-reported health, and does so at the neighborhood scale. The built environment, in particular sidewalks, road connectivity, and proximity of local destinations, correlates with destination walking, and similarly destination walking correlates with physical health. It was found, however, that the built environment and health metrics may not be simply, directly correlated but rather may be correlated through a series of feedback loops that may regulate risk in different ways in different contexts. In particular, evidence for a feedback loop between physical health and destination walking is observed, as well as separate feedback loops between destination walking and objective metrics of the built environment, and destination walking and perception of the built environment. These feedback loops affect the ability to observe how the built environment correlates with residents' physical health. Previous studies have investigated pieces of these associations, but are potentially missing the more complex relationships present. This study proposes a conceptual model describing complex feedback relationships between destination walking and public health, with the built environment expected to increase or decrease the strength of the feedback loop. Evidence supporting these feedback relationships is presented.*

KEYWORDS *Health, Built environment, Transportation, Multi-level modeling, Complex systems*

INTRODUCTION

Importance and Objective

Walking is an easy, accessible way to increase physical activity,¹⁷ the importance of which has been widely accepted. The Centers for Disease Control and Prevention¹¹ document "Recommendations for Improving Health through Transportation

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Policy” summarized ways in which health could be a consideration during development of transportation policy, including promoting active transportation and encouraging healthy community design. The CDC also suggests that additional local research is required to increase understanding of the “relationships between transportation, health, and safety outcomes” and to gather “targeted community level data to track the impact of policies, programs, and services.” This project was designed to address these concerns, investigating local, neighborhood scale built environment and associations with residents’ behaviors and their physical health.

Study of how the built environment is associated with physical activity and health^{5,28,33} has increased in recent years as the link is recognized as important in addressing public health issues, such as obesity and cardiovascular health. Prior studies have found mixed results, without systematic development of a better understanding of why given metrics might correlate in one area and not in others.¹⁶

Glass and McAtee²⁶ proposed a conceptual framework which describes the interaction of society, behavior, and biology through time. A new type of variable, a “risk regulator,” is proposed to capture aspects of social structure, such as the built environment, which influence action. Risk regulators impose constraints and provide opportunities which “shape, channel, motivate, and induce behavioral risk factors that cause disease, and the salutary factors that protect against exposure and delay disease progression”.²⁶ The regulators function as control parameters that operate at a system level to up- or down-regulate the likelihood of key risk factors, such as physical inactivity and poor diet. Neighborhood characteristics, such as the presence of sidewalks or of other walkers, may act as risk regulators to contribute to the likelihood of residents walking for transportation. Even though individual residents may still be mainly influenced by personal, internal preferences for walking, offering an improved opportunity for walking through the risk regulator of a walkable neighborhood may increase the percentage of residents walking locally, and therefore may improve local public health.

The main objective of this study was to investigate which features of the built environment at the neighborhood scale correlate with destination walking and public health, as measured by self-reported health status and self-reported body mass index (BMI) in smaller cities. The purpose of the research was to increase understanding of how the built environment affects behavior and health, with the goal of providing a framework to conceptualize how physical and perceived barriers might influence the relationship between destination walking and self-reported health status and BMI. Destination walking, as distinct from recreational walking, was selected as the measure of transportation behavior for this study because of its potential links to community sustainability and resilience.^{40,46} To better measure both the objective and subjective aspects of local walkability, walking was measured as the number of places that respondents reported they “can” walk,³⁹ as well as the number of places respondents report that they “do” walk.

The unique contribution of this paper is to use original data collected on a small spatial scale along with previous studies to suggest a framework for understanding how the built environment is associated with physical health, through a series of interlinked feedback loops.

In order to improve transparency of non-randomized behavioral research, including group-randomized studies, the TREND Statement (TREND: Transparent Reporting of Evaluations with Non-randomized Designs)¹⁴ was developed. The reporting methods of TREND are followed as closely as practicable in this study to enhance transparency and clarity of reporting.

METHODS

Measurement and Reporting

Survey instruments to assess the localized form of the built environment, including resident perceptions of the environment, have been developed and tested for reliability. Brownson et al.⁷ compared the results from three different survey instruments to determine their reliability in measuring the social and physical environment. Leyden³⁹ conducted a survey in Ireland to investigate the civic engagement of residents in various types of neighborhoods. The present study builds upon Leyden's work in particular by adding a more explicit health assessment component, through addition of BRFSS* health questions to the survey instrument.¹⁰

The "perception" of the built environment is an important category of barriers to walking. Many recent studies have shown that perception, as distinct from actual physical attributes of the built environment, may impact the decision to walk.³² Perception of walkability can be influenced by the physical attributes of a neighborhood,³⁷ as well as local culture, crime or crime reporting, traffic accidents, and other non-physical attributes, and should be understood as being potentially distinct from physical attributes.

Expanding upon Leyden's work,³⁹ and to separate perception of the built environment from physical attributes and behaviors, destination walking was not only measured as the number of places which survey respondents reported that they "can" walk, but also places that they reported that they "do" walk, as well as the frequency at which respondents engage in destination walking.

Survey Participants

The cities of Manchester and Portsmouth, New Hampshire, were selected for the survey-based study because of their variety of development types and ongoing collaborations between the university and these communities. Focus groups were held with representatives from Manchester and Portsmouth's health, planning, economic development, and parks and recreation departments in order to select neighborhoods, share information, and discuss results and implications across boundaries. Using input from these meetings, ten Portsmouth neighborhoods and ten Manchester neighborhoods were selected to represent the variety of development and socio-economic status present in the cities.

Each residence within the predetermined neighborhoods was assigned a number at random, using the RAND function of Microsoft Excel. The households were sorted on these numbers and the lowest 110 numbers were targeted for surveying. Teams of two researchers delivered paper-copy surveys to each of the selected homes between July and October of 2009. When 100 surveys had been distributed, distribution stopped. The "extra" ten households selected allowed for at-door refusals and non-residences (e.g., vacant homes).

Residents receiving the survey also received a personal note explaining the purpose of the survey, a stamped envelope for returning the paper copy, a card giving the address for the online version of the survey (should this be the preferred method for the resident to answer the survey), and a tote bag as a "thank you" gift to increase response rate.¹⁵ If residents were not home, the tote

*Behavioral Risk Factor Surveillance System, <http://www.cdc.gov/brfss/>

bag containing the survey and other documentation listed was left at the home. All surveying was completed on weekday afternoons, from approximately 1 PM through 6 PM.

A second distribution of the survey was conducted in low-response neighborhoods in November and December 2009. During this second round, survey respondents were asked to consider their warmer weather behavior, as an attempt to avoid seasonal differences in responses. Finally, a follow-up postcard was sent to respondents who had not completed the original survey by the end of December 2009. The survey was closed as of the beginning of February 2010—responses received after that date were discarded.

Interventions

In alignment with the CDC's conceptualization of policy and environmental characteristics as modifiable exposures related to population health, the "interventions" in this study are existing conditions found within neighborhoods and communities. These conditions are measured by built environment metrics, such as presence/condition of sidewalks, road connectivity, distance to services, lot size, and road lane-miles. Residents of neighborhoods are exposed to these conditions in the course of their everyday living. This study, and others like it, could be viewed as an opportunity to understand how a community can attract and encourage residents who prefer to walk, or how a neighborhood might improve perception of walking as a transportation option.

Outcome Variables

The outcome variables for the present study (with survey question phrasing presented in parentheses) included:

- Number of destination types available, as identified by residents ("In the table below, please place a check next to all the locations you *can* walk to in the community in which you live"). This is a continuous integer variable.
- Number of destination types reached by walking ("In the second column, please place a check mark next to those places you actually *do* walk"). This is a continuous integer variable.
- Frequency of walking for transportation ("How often do you walk to get to places in your community? (Circle one) Everyday; Several times per week; Once a week; Once a month; Every couple of months; Once a year; Never; Don't know"). A Likert scale was used to define an ordinal scale for this variable.
- Self-reported body mass index ("About how much do you weigh without shoes? ____ pounds"; "About how tall are you without shoes? ____feet, ____inches"). Body mass index is calculated as (weight in kilograms) divided by (height in meters squared).²⁴ This is a continuous variable.
- Self-reported health ("How would you describe your overall state of health these days? (Please circle one) Excellent; Very good; Good; Fair; Poor; Don't know"). A Likert scale was used to define an ordinal scale for this variable.
- Frequency of exercise ("About how many times per WEEK do you engage in physical activities or exercises for more than 15 consecutive minutes?"). This is a continuous integer variable.

As the outcome variables are determined from survey data, only those residents returning the survey are included in the analysis.

Independent, explanatory variables included:

- Connectivity—the number of intersections (three-legged or greater) within the neighborhood divided by the area of the neighborhood. This is a continuous, integer variable.
- Businesses—the number of services falling within the bounds of each neighborhood. This is a continuous, integer variable.
- Sidewalks—presence and condition of sidewalks as a percentage. This is a continuous variable between zero and one.
- Average lot size—the area of a neighborhood divided by the number of lots. This is a continuous variable.
- Open-ended response, sidewalks—yes/no flag indicating if survey respondent mentioned “sidewalks” in the open-ended question (“Are there things that could be done to make you more likely to walk in your neighborhood?”). This is a nominal variable, 0 or 1.
- Open-ended response, distance to services—yes/no flag indicating if survey respondent mentioned distance to services (e.g. there is nothing close enough to walk to) in the open-ended question listed above. This is a nominal variable, 0 or 1.

Statistical Methods

Confounding variables included in the analysis were age, gender, education level, and household income. These variables have been shown to impact both physical activity^{4,21} and public health,⁴³ and are also related to neighborhood of residence and the neighborhood’s access to physical activity amenities.^{27,31,35} In this present study, individual household income was not found to be significantly correlated to physical activity or public health; however, mean neighborhood income (mean of the survey respondents’ stated incomes) was found to be significant in many of the model runs. Gender was not found to be significant in this analysis. Therefore, age, education, and mean neighborhood income remain in the models summarized in Tables 1, 2, and 3, and results shown are controlled for these variables.

Multi-level modeling (cluster analysis) was used as the survey respondents, selected at random from neighborhoods, is not completely independent of each other, but is grouped geographically by neighborhood. Using individual and neighborhood as the units of analysis, this method was used to investigate how responses varied with built environment variables while accounting for clustering within neighborhoods.¹⁸ City was included as a dummy variable.

RESULTS

Participant Flow, Recruitment, and Sample Size

Surveys that were returned without enough information to identify the residence location of the survey participant (e.g. with the survey number scratched off) were excluded from the study. Similarly, surveys that were returned blank, or without any responses filled in were excluded.

Surveys were distributed to a total of 2004 homes (Manchester, 1,019; Portsmouth, 985). Of those, a total of 679 surveys were returned with enough data to be usable (Manchester, 319; Portsmouth, 360). Therefore, overall net response rate was 33.9% (Manchester, 31.3%; Portsmouth, 36.5%).

TABLE 1 Descriptive statistics of surveyed neighborhoods

Neighborhood name	Code	Average income	Average age	Average education level achieved ^a	% Residents walk at least once a week	Average number places do walk ^b	Average number places can walk
Manch Average	—	\$89 k	52	4.7	55	2.7	5.2
Bodwell	B	\$104 k	42	4.7	65	0.3	1.5
West Granite	G	\$42 k	54	3.5	63	3.5	6.6
Colonial/Pickering	J	\$46 k	41	4.3	22	1.7	2.9
MacCauley/Smyth	M	\$100 k	58	5.1	52	3.0	6.5
North End	N	\$132 k	54	6.2	68	3.6	7.0
Southside/St Anth.	P	\$74 k	54	4.0	42	2.5	6.8
Corey Square	Q	\$45 k	50	3.6	60	3.3	6.3
Rimmon Heights	R	\$63 k	51	4.2	52	3.9	5.4
Wellington	T	\$130 k	53	5.5	44	0.2	1.1
Downtown Manch	X	\$95 k	53	5.3	67	5.9	7.6
Elmwood	Y	\$14 k	44	3.0	80	2.7	4.1
Ports. Average	—	\$85 k	51	5.1	54	4.0	6.9
Atlantic Heights	A	\$74 k	43	4.9	36	2.5	5.7
Christian Shore	C	\$76 k	53	4.7	44	4.5	8.5
Downtown Ports	D	\$90 k	42	5.4	64	7.3	9.4
Elwyn Park	E	\$74 k	63	4.7	60	2.1	5.3
Frank Jones	F	\$85 k	54	5.1	43	1.9	7.4
Islington	I	\$83 k	43	5.6	58	6.5	9.5
Richards Ave	K	\$118 k	44	5.6	38	7.4	10.7
South Side	S	\$92 k	57	5.5	54	6.8	8.5
Sherbourne	V	\$68 k	53	4.3	49	1.5	1.4
Woodlands	W	\$139 k	53	6.1	74	1.7	5.6
Ledgewood	Z	\$33 k	41	3.0	67	2.3	6.4

^aEducation Scale: (1 Less than high school; 2 Diploma or GED; 3 Some College; 4 Associate degree or technical training; 5 Bachelor's degree; 6 Some graduate training; 7 Graduate or professional degree)
^bBoth the “do” walk and the “can” walk destinations are the number self-reported by survey respondents

Analyzing 68 published internet survey-based studies, Cook et al.¹² reported a mean response rate of 39.6% (std dev=19.6%), and a slightly lower 34.6% (std dev=15.7%) for a subset of surveys with more complete data. Fox et al.²⁰ reported a mean

TABLE 2 Matrix of regression analysis physical metrics and behavior (controlled for age, education level, and neighborhood-average income)

Independent variables	Destination walking—outcomes		
	Do walk	Can walk	Frequency
Sidewalks	5.89(4.3, 7.5) 0.82*	5.37 (2.6,8.1) 1.40*	3.22 (2.3,4.1) 0.45*
Connectivity (3+ legs)	6.09(4.5, 7.7) 0.80*	4.95 (1.9,8.0) 1.54*	2.99 (1.9,4.1) 0.55*
Number of businesses in neighborhood	0.16(0.056,0.27) 0.055*	0.097(−0.30,0.22) 0.0647	0.053 (−0.014,0.12) 0.034
Average lot size	−0.63 (−1.5, 0.20) 0.36	−0.36 (−1.4, 0.69) 0.54	−0.32 (−0.78,0.15) 0.24
Open-Ended “Sidewalks”	0.27 (−0.20,0.74) 0.24	0.23 (−0.31,0.77) 0.28	0.25 (−0.051,0.55) 0.15
Open-Ended “Dist to Services”	−1.41 (−2.1,−0.75) 0.34*	−1.22 (−2.0,−0.46) 0.39*	−0.77 (−1.2,−0.35) 0.22*

Format: coefficient (95% confidence interval) standard error *(if significant to 95%)

TABLE 3 Matrix of regression analysis behavior and health (controlled for age, education level, and neighborhood-average income)

Independent variables	Dependent, explanatory variables				
	BMI	Self-reported health	Do walk	Can walk	Frequency
BMI	N/A	-1.364 (-1.77, -0.96) 0.206*	-0.155 (-0.27, -0.042) 0.058*	-0.0798 (-0.18, 0.021) 0.0517	-0.252 (-0.45, -0.059) 0.099*
Self-reported health	-0.0486(-0.063, -0.034) 0.0074*	N/A	0.0240 (0.003, 0.045) 0.011*	0.0158 (-0.002, 0.034) 0.00923	0.0466 (0.011, 0.082) 0.018*
Do walk	-0.0568 (-0.10, -0.013) 0.022*	0.238 (0.017, 0.46) 0.11*	N/A	0.314 (0.25, 0.38) 0.032*	0.705 (0.60, 0.82) 0.056*
Can walk	-0.0467 (-0.095, -0.0019) 0.025	0.188 (-0.066, 0.44) 0.130	0.408 (0.33, 0.49) 0.042	N/A	0.470 (0.34, 0.61) 0.069
Frequency	-0.0378 (-0.065, -0.011) 0.014*	0.175 (0.034, 0.32) 0.072*	0.302 (0.26, 0.34) 0.022*	0.157 (0.12, 0.20) 0.021*	N/A
	Figure 2 protective effect	Figure 2 protective effect			

Format: coefficient (95% confidence interval) standard error *(if significant to 95%)

response rate of 40.0% (std dev=17.1%) for surveys without extensive follow-up. The present study has a response rate within one standard deviation of these reported mail and internet survey response rates.

Characteristics of the survey respondents by neighborhood are given in Table 1. The average income of respondents in the neighborhoods varied widely, from approximately \$14,000 to over \$130,000 per year. Average age of respondents ranged from low 40's to low 60's, with an average of 52. The average education level achieved by neighborhood shown in Table 1 varies from "some college" to "some graduate training."

Outcomes and Estimation

A summary of results, including the estimated effect size and 95% confidence interval, is given in Tables 2, 3, and 4. Table 2 shows that several built environment metrics are associated with destination walking. The strongest associations with destination walking were found for sidewalks and connectivity. Survey respondents who mentioned that there were few places to walk (open-ended response mentioning distance to services, 11.7% of respondents) reported walking to significantly fewer locations and less often. However, survey respondents who mentioned sidewalks needing improvement (open-ended response mentioning sidewalks, 26.6% of respondents) tended to be those who reported that they do walk (coefficient of 0.214, significance level of 84% in adjusted model). Adding additional control variables of city (dummy variable) and number of times respondent reports having exercised for 15 minutes or more (a measure of physical activity), increases the significance of each of the physical metrics in Table 2. The number of businesses in the neighborhood is then significant to over 99% ($p<0.015$) for all of the behavioral outcome variables.

Table 3 shows that destination walking is related to health. This table reflects model results with BMI and self-reported health as independent variables (working to explain behavior) and as dependent variables (explained by behavior). The table is setup as a matrix, so that relationships in each direction (selective and protective) can be observed. Selective effects occur when individuals with certain characteristics (lower BMI, better physical health) might choose to walk more often. Protective effects occur when the act of walking might elicit certain physical reactions in a population (lower BMI, better physical health). Both selective and protective effects may be important, and so each effect is necessarily considered in analysis of how

TABLE 4 Matrix of regression analysis physical metrics and health (controlled for age, education level, and neighborhood-average income)

Explanatory Variables	Health—outcomes, independent variables	
	BMI	Self-reported health
Sidewalks	−0.303 (−1.67, 1.07) 0.70	0.0798 (−0.16, 0.32) 0.12
Connectivity (3+ legs)	−0.357 (−1.70, 0.98) 0.68	0.108 (−0.13, 0.35) 0.12
Number of businesses in neighborhood	0.0638 (−0.036, 0.16) 0.051	0.00635 (−0.011, 0.024) 0.0091
Average lot size	−0.0408 (−0.50, 0.42) 0.23	−0.0591 (−0.14, 0.020) 0.040
Open-Ended “Sidewalks”	0.335 (−0.56, 1.23) 0.46	0.0310 (−0.13, 0.19) 0.083
Open-Ended “Dist to Services”	−0.0748 (−1.31, 1.16) 0.63	−0.031 (−0.26, 0.20) 0.12

Format: coefficient (95% confidence interval) standard error *(if significant to 95%)

transportation decisions and health are interrelated. In both directions, actual destinations (places respondent does walk) and frequency of walking are significantly associated with BMI and self-reported health, while the potentially available places to walk (places respondent can walk) is not significantly correlated. Both protective and selective relationships were significant while controlling for age, education level, and the neighborhood-average income level. Individual income was not significant, and therefore is not included in the final models. Similarly, the number of places that respondents reported that they can walk was not significant. Including control variables for city (dummy variable) and number of times respondent reports having exercised for 15 minutes or more (a measure of physical activity), does not substantially change the relationships shown in Table 3.

As shown in Table 4, when controlling for mean neighborhood income, individual age, and individual education level, none of the relationships comparing physical built environment metrics and health are significant to the 95% level (all p values are greater than 0.20). Average lot size is at 86% significance for self-reported health (coefficient = -0.059 ; $p = 0.14$), while all other variables are nonsignificant. In the unadjusted model, without controlling for any of those factors, only the number of neighborhood businesses (BMI coefficient = 0.123 , $p = 0.037$; self-reported health coefficient = -0.014 , $p = 0.245$) and average lot size (BMI coefficient = 0.399 , $p = 0.147$; self-reported health coefficient = -0.14 , $p = 0.005$) were significant of the variables listed in Table 4. Including city (dummy variable) and number of times respondent reports having exercised for 15 minutes or more does not substantially change the relationships shown in Table 4.

Ancillary Analyses

BMI varied with neighborhood (interclass coefficient (ICC) = 4.5%)¹⁸, as did self-reported health (ICC = 5.4%), indicating that multi-level analysis is appropriate in this case. Much of the interclass coefficient, however, is attenuated by the inclusion of age, education level of respondent and mean income of neighborhood (ICC of the adjusted BMI model = 0.044% ; ICC of the adjusted self-reported health model = 0.00%).

The number of places respondents reported that they “do” walk also varied with neighborhood (ICC = 37.6% unadjusted, and 36.6% when controlled for age, mean neighborhood income, education level, city (dummy variable), and number of times respondent exercised more than 15 minutes in the past week). The sidewalk variable is able to explain much of this variation (ICC = 12.3% adjusted model).

The number of places respondents reported that they “can” walk varied with neighborhood (ICC = 40.1% unadjusted, and 37.8% adjusted for variables listed above). Sidewalk variable explained just over 10% of the variation (ICC = 25.4% adjusted model).

Adverse Events

No adverse events or unintended effects were observed or expected in any of the study conditions.

DISCUSSION

Figure 1 summarizes one potential pathway for the built environment to influence physical health, through physical activity. Although health can be influenced by the built environment in many ways (e.g., air quality, water quality, building material toxicity, social capital or community cohesion, etc.), here we discuss only the “walkability” of the

FIGURE 1. Potential pathway for built environment to influence physical health; linear relationship, with built environment influencing transportation, which impacts health.

environment. If the relationship between built environment and health was linear as shown in Figure 1, then, as strong associations were observed between the built environment and destination walking, and between destination walking and health, it would seem to follow that there would be observable strong associations between built environment and health.⁴⁸ These last associations were not observed.

Destination walking, health, and the built environment are likely related in a non-linear, complex way.^{9,19} Each of the three has independent drivers and the three have been shown to interact with each other.⁹ Perhaps, then, a more complex relationship, such as a feedback loop or a series of feedback loops, might more accurately describe the relationship between built environment, destination walking, and health.² Viewing the system more broadly a walkable built environment may be seen as a risk regulator, offering the opportunity for walking, which may then result a healthier population than might be found in a non-walkable neighborhood, even if individual residents are not greatly influenced by the change.²⁶ One view of how this relationship might look is shown in Figure 2. The main feedback loop, marked “A” at the center, shows that healthier people walk more through a selective effect, which makes this population increasingly healthy through a protective effect.

Two additional feedback loops are important to transportation decisions in the framework of this research. The built environment impacts transportation decisions via a feedback loop, marked “B” in Figure 2, as infrastructure available for walking has been shown to increase the likelihood of walking,^{3,42,49} and increased local walking has been shown to provide support for improving the local walking infrastructure.²⁵ A third feedback loop, marked “C” in Figure 2, shows that the perception of the built environment, independent of the actual built environment, also interacts with transportation decisions as the perception that the built environment is walkable may increase the likelihood of walking,^{1,37} and increased walking in an area may increase the perception that the area is walkable.^{1,34}

A final pathway relevant to this study is marked “D” on Figure 2. Health is related to how the built environment is perceived as walkable.^{6,45} There are other pathways through which health and the built environment could be correlated,^{13,41} such as availability of healthful foods,⁴⁴ air quality,^{22,23} quality of housing stock,^{36,47} and so on. However, these pathways, not being relevant to destination walking, are set aside for this present research.

Support for several of the relationships shown in Figure 2 was apparent in our results. Table 2, showing correlations between the built environment and transportation behaviors, supports half of the feedback loop marked “B” in Figure 2: the built environment impacts transportation decisions. The present study did not measure

1. (Schweitzer et al, 2004) 2. (Braun, 1998) 3. (Frank and Engelke, 2001) 4. (Feinstein, 1993). 5. (Dannenberg et al, 2003).
6. (Hinde and Dixon, 2004). 7. (Pucher and Dijkstra, 2003). 8. (Booth et al, 2005). 9. (Badland and Schofield, 2005)
10. (Jacobsen, 2003). 11. (Addy et al, 2004). 12. (Leslie et al, 2005). 13. (Geraghty et al, 2009). 14. (Wang and Brownell, 2005).

FIGURE 2. Potential pathway for built environment to influence physical health; positive feedback loop with accelerating or decelerating influences, annotated with a sample of the available literature for each interaction.

advocacy or policy changes to confirm the second half of the “B” loop. Table 3, showing correlations between the built environment and health, contains support for both sides of feedback loop “A” as labeled in the table: both protective and selective effects.

Implications

The ultimate goal of improving walkability will also rely on addressing residents’ perceptions of walkability as well as the localized physical form of the built environment (loop “C” in Figure 2). It is instructive that respondents who perceived too few destinations, even if this perception did not correlate well with physical measurements, walked significantly less often. This indicates that loops B and C (Figure 2) are independent, and that outreach programs involving awareness of local businesses and other destinations may be effective. For instance, city or private programs highlighting local business, such as “get to know your corner store” or “walkable local places,” might encourage residents to think about their neighborhoods in new ways, and to consider alternative forms of transportation.²⁹ Programs to encourage neighborhood residents to walk in a group¹⁸ have been shown to be successful at raising awareness of walking as a transportation option.

Understanding the complexity of relationships between destination walking, health, and the built environment is broadly applicable, particularly to the study of neighborhood-scale behavior and health. The method of determining the physical or perceived barriers to walking at the neighborhood level and prioritizing these barriers for redesign is also applicable to communities in the United States and abroad. Similarly, working with municipal representatives to address perception of walkability at various levels in the city is a method that could be adopted elsewhere. Cities undergoing expansion or redevelopment may find this approach particularly of interest in analyzing how new form might connect with existing form. However,

cities undergoing economic decline might also be interested in using the method to analyze how best to prioritize limited funds for neighborhood revitalization.

Although a survey method was used in this study, the results here are suggestive of more streamlined methods, such as using field visits to identify locations where sidewalks are in poor repair, road network connectivity is limited, or where neighborhood businesses are not frequented by local residents on foot. Community-based focus groups and structured interviews, using the principles of Community-Based Participatory Research,³⁸ may be appropriate, especially to investigate perceptions of walkability.

Limitations

As with any environmental health study, there are numerous confounders, some of which are listed in Figure 1. In addition to the usual confounders of age, individual and neighborhood-average income level, and education level, which are controlled here, confounders of the relationship between the built environment and destination walking might include resident personal proclivity to drive, self-selection of neighborhoods more/less conducive to driving based on personal preference, socioeconomic status of the individual relative to the neighborhood, and local culture of walking.² The relationship between destination walking and health may also be influenced by variation in reasons for walking (e.g., doctor-ordered therapy to improve existing condition, financial inability to purchase car). Many of these confounders are difficult to measure precisely, and therefore the use of regression-based techniques to mitigate their effects may not be fruitful.

It is important to consider that residence self-selection, or the decision for people with certain inclinations (e.g., preference for walking) to live in certain types of neighborhoods (e.g., more conducive to walking), impacts results in this type of study.⁸ As it is rarely feasible to randomly assign households or residents to interventions such as neighborhood type,³⁰ personal preference necessarily impacts the intervention to which an individual is exposed.

In addition, this present study only included neighborhoods in two cities, with a relatively low response rate for the lower income neighborhoods (higher income neighborhood response rate=42%; lower income response rate=26%). Expansion to other small cities with additional variety in socioeconomic status of neighborhoods would enable researchers to look at the impact of socioeconomic status and the influence that city-wide planning efforts, culture, bus systems, etc. might have on personal transportation decisions of residents in a variety of neighborhood types.

SUMMARY AND CONCLUSIONS

Municipalities and public health officials may wish to increase residents' physical activity in order to improve public health. It is apparent that the built environment is correlated with physical activity, and that physical activity is correlated with health. However, the perception of the built environment may also be an important factor in residents' behavior, and there may not be a direct pathway from the built environment to improved health. Further work with the cities involved in the study can identify instances where the physical built environment, or the perception thereof, can be changed to improved local walkability.

Our results show that the built environment is correlated with physical activity, and that physical activity is correlated with health. However, we also demonstrate that to fully understand the complexity of relationships between the built

environment and health outcomes may require additional analytic tools, such as those used in systems science, to complement regression-based methods.

The next steps in this research include examining differences between the two cities studied, making recommendations to policy changes that might support capitalizing on selective effects to increase the incidence of walkability in neighborhoods, investigating which specific built environment changes seem to impact the relationship between behavior and health and the pathways by which this occurs, and comparing results in other neighborhoods and communities to further investigate the implications of these findings.

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