Health Promoting Community Design

Using Objective and Subjective Measures of Neighborhood Greenness and Accessible Destinations for Understanding Walking Trips and BMI in Seattle, Washington

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Abstract

Purpose. *Examine the influence of destinations within walking distance of a residence and vegetation on walking trips and body mass index (BMI).*

Design. *Cross-sectional analysis of data from residences with varying accessibility and greenness.*

Setting. *Seattle, Washington.*

Subjects. *Stratified random sample of residents, stratified by accessibility and greenness. Response rate: 17.5%, 529 respondents.*

Measures. *Accessibility and greenness were measured objectively by Geographic Information Systems (GIS) Network Analysis and normalized difference vegetation index (NDVI), respectively. Self-reported destinations, natural features, walking trips, BMI, and importance of destinations were measured through a postal survey.*

Results. *Objective accessibility were related to walking trips per month ($r^2 = .110$, $p < .0001$), as was subjective greenness ($r^2 = .051$, $p < .0001$), although objective measures of actual greenness were not. In areas with high accessibility, BMI was lower in areas that had high NDVI, or more greenness ($r^2 = .129428$, model $p < .0001$; t-test of interaction $p = .0257$). Low NDVI areas were associated with overestimation of the number of destinations within walking distance ($F_{1,\ 499} = 11.009$, $p = .001$).*

Conclusions. *Objective and subjective measurements of accessibility and greenness led to an understanding of variation among walking trips and BMI in different neighborhoods. (Am J Health Promot 2007;21[4 Supplement]:371–379.)*

Key Words: Walking, Vegetation, Accessible Destinations, Satisfaction, Prevention Research. Manuscript format: research; Research purpose: relationship testing; Study design: quasi-experimental; Outcome measure: behavioral; Setting: local community; Health focus: fitness/physical activity; Strategy: built environment; Target population: adults; Target population circumstances: geographic location

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PURPOSE

Increasing physical activity can reduce numerous diseases and adverse health conditions.[1,2] Based on the social-ecological model of physical exercise,[3,4] there are several factors in achieving the recommended amount of physical activity,[5] including demographic and social factors.[6,7] In addition to these factors, the configuration of the built environment also may affect physical activity levels. Walking is the most common form of moderate-intensity physical exercise, and it is enhanced by opportunities for utilitarian walking, such as commuting to work or shopping.[5] Built environments that support utilitarian walking by having destinations in close proximity to residential areas have been associated with physical activity behavior, primarily walking.[7–13] Furthermore, built environments that have ''enjoyable scenery'' or a ''pleasing aesthetic environment'' have shown positive correlations with physical activity levels.[6,10,14–22] Although aesthetics has been ill defined, the concept has been mostly related to natural features and vegetation found in the neighborhood or park environment. The most thorough operational definition of aesthetics in active community environment research is from a qualitative study[23] that found that trees, water features, and birds had a particular influence on physical activity behavior. Although visual preferences for natural features, including vegetation, over built features have long been established,[24] understanding how vegetation impacts walking trips is poorly understood.

The most common objective measure of aesthetics in active community environment research has been to count trees along street segments in the study area,[10,21] whereas subjective measures include Likert scale questions to assess scenery in one's residential neighborhood.[6,14,18,19] Although the findings from these studies generally report a consistent positive relationship between the objectively and subjectively measured aesthetic environment and walkability, there has been little research regarding how specific vegetation levels influence walking trips. Based on these studies, we hypothesized that the number of destinations within walkable distance of a residence, hereafter referred to as *accessibility*, and the amount of vegetation within that walkable area, hereafter referred to as *greenness*, would be positively related to the resident's walking trips to different types of destinations and to his or her body mass index (BMI). We suspected that the number of destinations within walking distance influences people to walk more, and that the presence of a more natural environment in the neighborhood, whether real or perceived, would further encourage walking. Residents living in neighborhoods that had numerous types of destinations within walking distance, high amounts of vegetation, and high satisfaction with that vegetation would not only make more walking trips but also would have lower BMI scores.

METHODS

Design

We used a cross-sectional survey to explore the relationships among accessibility, greenness, walking trips, and BMI.

Measures

We used eight measures in this study: destinations within a .4-mile distance as measured by Geographic Information Systems (GIS) Network Analysis, destinations as measured by self-report, normalized difference vegetation index (NDVI), self-reported natural features, self-reported satisfaction with greenness, importance of destinations index, frequency of walking trips, and BMI.

Accessibility Geographic Information System. We used ArcView GIS 3.3 (Environmental Systems Research Institute[25]) to identify residential parcels, or pieces of land defined by property boundaries, in Seattle within .4 miles of 15 types of destinations. Distances were determined through street networks (excluding highways) rather than straight line distances. Previous studies[10,12,26] have used a wide range of measures, from 300 feet[13] to 20 minutes,[26] to examine walking behaviors. However, recent research conducted by Moudon et al. in the Seattle, Washington, metropolitan area showed that most mean distances to routine destinations (i.e., grocery stores, restaurants, retail) are under one half of a mile from residents' homes, hovering between less than .2 and .4 miles.[27]

We obtained City of Seattle geospatial data from the Washington State Geospatial Data Archive[28] for residential parcels, street networks, and the following destination types: churches, community centers, libraries, p-patches (i.e., neighborhood communal garden spaces), parks, playgrounds, post offices, schools, swimming pools, and theaters. Data for banks, bars, grocery stores, and restaurants were obtained, with permission, from the Urban Form Laboratory at the University of Washington.

We identified residential parcels (single family and multifamily) in the City of Seattle within .4 miles of each of the above destination types by using GIS Network Analysis. We calculated a service area of a .4-mile distance for all destinations within each type listed above and then selected all residential parcels found in that service area. A service area identifies the area within a .4-mile walking path to each destination type. We created a final map of Seattle that represented the number of types of destinations that are within .4 miles of walking distance of residential parcels, hereafter referred to as *objective accessibility*.

Normalized Difference Vegetation Index. As an objective measure of greenness, we calculated the NDVI of the walkable neighborhood for each parcel. The NDVI is a remotely sensed spectral vegetation index derived from satellite-mounted sensors and calculated as [near infrared − red] / [near infrared + red].[29] The NDVI measures the amount of photosynthetically active light that is absorbed in each 30 m × 30 m survey pixel, or its greenness, which varies with the absorption spectra of the objects in that pixel and the percentage of the pixel covered by each type of object. The index ranges from −1 to 1, with more positive values indicating more green, and thus more vegetation, in the pixel. The NDVI has a predictable linear relationship with net primary productivity—the energy accumulated by plants during photosynthesis[30,31]—and has been related to bird reproductive success and morphology,[32] and plant and animal diversity.[33]

We used a dataset acquired from Landsat 5 on July 12, 2002, and processed for geo-registration, instrument calibration, atmosphere correction, and topographic correction by the Urban Ecology Research Laboratory at the University of Washington.[34] We calculated the NDVI of the area within the .4-mile walking distance for each parcel, hereafter referred to as *objective greenness*, in ArcGIS 9.1 (Environmental Systems Research Institute [35]) as the mean of the NDVI values within a circle with the same area (.32 square miles) as the average walkable area defined by GIS Network Analysis.

Sample and Location. A postal survey (postage paid by the researchers) was sent to residents within the City of Seattle. We selected survey addresses by stratified random sampling, which was stratified by NDVI and accessibility. Our stratified sampling process was partly implemented in GIS, where we took a subsample of 45,000 residential parcels from a Washington State Geospatial Data Archive[36] database of over 200,000 total residential parcels in Seattle to summarize the distribution of NDVI and the accessibility for residential parcels. This subsample revealed that there was a significant negative relationship between objective accessibility and objective greenness (adj-$R^2 = 0.22$, $p < .0001$), which required that we conduct stratified sampling to capture the variation in objective accessibility and objective greenness in the residential parcels. We created six strata representing objective accessibility and objective greenness scores (Table 1). The NDVI is influenced by several factors, including land cover and species composition, so to be confident that comparisons were biologically meaningful we created two NDVI classes from the top and bottom 20% of NDVI values of parcel neighborhoods: high

Table 1

Percentage of All Seattle Residential Parcels in Each Sampling Strata

		Destinations within 0.4 mile distance as measured by Geographic Information Systems Network Analysis		
		0-2 Destinations (Low Accessibility)	3-5 Destinations (Medium Accessibility)	6-12 Destinations (High Accessibility)
Low normalized difference vegetation index (bottom 20% of values)	Proportion of all Seattle residential parcels in strata (%)	1.40	8.20	10.30
	Response rate (%)	16.60	14.52	15.50
	Respondent proportion female (%)	65.06	56.72	44.78
	Respondents older than 51 years (%)	51.22	40.58	44.12
	Respondent's education college degree or more (%)	85.54	84.06	80.88
	Respondent's household income over $50,000 (%)	67.11	55.56	46.15
High normalized difference vegetation index (top 20% of values)	Proportion of all Seattle residential parcels in strata (%)	11.30	7.10	1.70
	Response rate (%)	16.99	20.00	21.10
	Respondent proportion female (%)	57.14	62.14	52.73
	Respondents older than 51 years (%)	65.88	57.28	51.38
	Respondent's education college degree or more (%)	76.47	77.67	88.18
	Respondent's household income over $50,000 (%)	85.14	74.47	82.18

(>.426) and low (<.269). Subjective observations of high and low NDVI areas within our sampling frame revealed that high NDVI neighborhoods had more large trees, parks nearby, or larger parcel sizes. The majority of high NDVI neighborhoods with high accessibility to destinations included parks within a .4-mile walking distance, whereas high NDVI neighborhoods with low accessibility to destinations were composed of large parcels that allowed a higher NDVI because of less impervious surface.

We sampled 550 addresses from each of the six strata using PROC SURVEY-SELECT in SAS.[37] We also weighted the sampling of multifamily housing (e.g., apartments, duplexes) in order to more accurately represent the relative proportions of single-family and multifamily residences in each strata.

We mailed a total of 3300 surveys. We obtained addresses for single-family residents in our sample from the parcel database at the Washington State Geospatial Data Archive,[36] and we obtained addresses complete with resident names and apartment numbers for multifamily residences using the parcel database at the Washington State Geospatial Data Archive and Reference USA database.[38] Our study was approved by the University of Washington Institutional Review Board/Human Subjects Committee. The cover letter included in the survey outlined confidentiality and implied informed consent.

Self-Reported Destinations, Walking Trips, and BMI. Respondents were given a list of the same destinations that we used in the GIS Network Analysis and were asked to indicate whether each destination was within their neighborhood, which we described as within (1) approximately a half of a mile walking distance, (2) roughly a 10- to 15-minute walk, or (3) about 10 blocks. The total number of destinations reported in their neighborhood is hereafter referred to as *subjective accessibility*. Respondents then indicated on a five-point Likert scale how frequently they walked to those destinations found to be within the approximate half-mile distance from their home (Cronbach $\alpha = .80$). We calculated walking trips per month for each respondent based on his or her frequency of walking to all destination types by transforming the Likert categories: never = 0 walking trips per month; about once a year = .0833 trips per month; about once a month = 1 trip a month; about once a week = 4.3 trips per month; and more than once a week = 8.6 trips per month. Table 2 shows the distribution of walking trips made to each destination type. Respondents who indicated that destinations were within walking distance but

Health Promotion hepr-21-00-03.3d 10/1/07 19:06:52 373 Cust # 06050156R

Table 2

Distribution of Likert Scale Categories Assessing Walking Trips to Different Destinations and Mean Participant Rating for the Importance of Walking to that Destination

Destinations	Not Found in Neighborhood	Never	About Once a Year	About Once a Month	About Once a Week	More than Once a Week	Importance of Destinations Mean (SD)*
Parks	80 (15%)	24 (5%)	42 (8%)	115 (22%)	109 (21%)	142 (27%)	4.153 (1.0442)
Grocery stores/markets	92 (17%)	23 (4%)	58 (11%)	103 (19%)	118 (22%)	122 (23%)	3.742 (1.2082)
Restaurants	89 (17%)	48 (9%)	93 (18%)	140 (26%)	109 (21%)	36 (7%)	3.465 (1.2222)
Coffee shops	122 (23%)	58 (11%)	59 (11%)	117 (22%)	98 (18%)	62 (12%)	3.393 (1.2943)
Libraries	242 (46%)	52 (10%)	68 (13%)	91 (17%)	47 (9%)	18 (3%)	3.369 (1.2574)
Play areas and playgrounds	96 (18%)	73 (14%)	73 (14%)	114 (21%)	74 (14%)	85 (16%)	3.276 (1.3777)
Post office	280 (53%)	48 (9%)	44 (8%)	86 (16%)	45 (9%)	14 (3%)	3.047 (1.3100)
Banks	228 (42%)	75 (14%)	43 (8%)	84 (16%)	66 (12%)	22 (4%)	2.947 (1.3145)
Schools	194 (37%)	203 (38%)	49 (9%)	26 (5%)	18 (3%)	27 (5%)	2.728 (1.5220)
Beaches	318 (60%)	22 (4%)	47 (9%)	51 (10%)	38 (7%)	41 (8%)	2.670 (1.3474)
Community centers	223 (42%)	87 (16%)	97 (18%)	65 (12%)	38 (5%)	16 (3%)	2.614 (1.2539)
Bars or pubs	164 (31%)	114 (21%)	74 (14%)	108 (20%)	47 (9%)	9 (2%)	2.420 (1.4144)
Place of your employment	399 (75%)	33 (6%)	7 (1%)	15 (3%)	7 (1%)	50 (9%)	2.415 (1.4050)
Theaters	370 (70%)	57 (10%)	48 (9%)	33 (6%)	8 (2%)	1 (.2%)	2.392 (1.2395)
Public swimming pools	395 (74%)	74 (14%)	17 (3%)	17 (3%)	8 (2%)	7 (1%)	2.292 (1.2481)
P-Patches	353 (66%)	92 (17%)	37 (7%)	21 (4%)	12 (2%)	3 (1%)	2.030 (1.1893)
Churches or places of worship	238 (45%)	194 (37%)	47 (9%)	16 (3%)	19 (4%)	4 (1%)	1.977 (1.2162)

* Five-point Likert scale to rate the importance of each destination. Response categories were: "not at all important," "a little important," "somewhat important," "very important" and "extremely important." Cronbach $\alpha = 0.90$, n = 494.

did not rate at least half of the destinations they indicated were not given a total walking trips per month score (valid n = 513).

We calculated BMI (kg/m^2) from self-reported height and weight. We received 500 responses with valid height and weight responses for calculating BMI. The mean BMI for women was 23.6029 (standard deviation [SD]: 4.27039), and the mean BMI for men was 25.3143 (SD: 3.50080). The use of self-reported height and weight as a reliable and valid measure to calculate BMI has been confirmed by public health researchers.[39]

Self-Reported Natural Features. We created an eight-item natural features scale for this study. We asked respondents to indicate whether each individual scale item was found within an approximate half-mile distance from their home and to indicate their satisfaction with the natural features found in their neighborhood on a five-point Likert scale (Cronbach $\alpha = .83$). Items included in the scale were: (1) birds and other small wildlife; (2) larger wildlife; (3) large trees; (4) lakes or streams; (5) street trees; (6) view of nature from home; (7) natural vegetation in yards; and (8) scenic vistas or views. We calculated the *satisfaction with greenness* as the mean satisfaction number of all natural feature items reported by the participant. Respondents who indicated that destinations were within walking distance but did not rate at least half of the destinations they indicated were not given a total walking trips per month score (valid n = 515). We calculated *subjective greenness* as the total number of natural features reported by each participant.

Importance of Destinations. Respondents were given a list of the same destinations that were used in the GIS Network Analysis and were asked to rate how important each destination was to their quality of life. Respondents used a five-point Likert scale to rate the importance of each destination. Response categories were (1) not at all important, (2) a little important, (3) somewhat important, (4) very important, and (5) extremely important. In this sample, internal consistency for all items was high (Cronbach $\alpha = .90$). We calculated the importance of destination index score from the mean score of all destinations for each individual, and we also calculated the mean importance of destination and SDs for each destination (Table 2). Respondents who did not rate at least half of the destinations listed were not given an Importance of Destinations Index score (n = 494).

ANALYSIS

We computed correlation coefficients using Pearson correlation to examine the relationship between (1) walking trips per month, BMI, and objective accessibility; (2) subjective accessibility and objective accessibility; (3) subjective greenness and objective greenness; and (4) satisfaction with greenness and objective greenness. All reported p values are two tailed, and we used $\alpha < .05$ as the threshold for statistical significance. Data analyses were conducted using Statistical Analysis Software version 8.02 (SAS Institute Inc.[37]) and SPSS.[40]

We used multiple regression implemented in *PROC GLM* in SAS[37] to explore the influences of objective greenness and accessibility on BMI, walking trips per month, subjective greenness, satisfaction with greenness, and subjective accessibility, controlling for the demographic variables of age, gender, income, and education. These control variables were chosen because

Health Promotion hepr-21-00-03.3d 10/1/07 19:06:55 374 Cust # 06050156R

they commonly affect perception in active living research.[41–43] We also regressed the importance of destination index on walking trips per month and BMI, controlling for relevant demographic variables. Control variables were first entered into the model, and then the main explanatory variable (e.g., walking trips or BMI) was introduced into the model. Scatter plots revealed linear relationships among these variables, except for the relationship between BMI and age, which was modeled quadratically.

We used analysis of variance (ANOVA) to examine the differences in respondents' estimation of destinations within walking distance between areas of high and low objective greenness. Respondents' estimation of destinations within walking distance was calculated by subtracting the total number of self-reported destinations from the total number of destinations reported by the GIS Network Analysis for each respondent.

RESULTS

A total of 529 surveys were completed and returned, for an overall response rate of 17.5%. We had 8.5% of the surveys returned to us as undeliverable, primarily from multifamily households and due to incomplete addresses. Three respondents indicated in the survey that they did not have the physical ability to walk at least half of a mile and were taken out of any further analysis. Characteristics of the respondent population: 56.8% female, 52.5% older than 51 years, 82.2% with a college degree or more, and 70.2% with an annual household income of more than $50,000. Data from the 2000 U.S. Census for the city of Seattle report that the Seattle total population is approximately 50.1% female, with 19.4% older than 54 years in age, 47.2% with a college degree or more, and 46.1% with a household income of more than $50,000.[44]

Although the response rate was lower than desired, the primary variables—number of destinations within walking distance as measured by the GIS Network Analysis and NDVI level—did not differ between respondents (mean accessibility: 4.18, mean NDVI : .360) and nonrespondents (mean accessibility: 4.16, mean NDVI: .336). The response rate was not independent of sampling strata (χ^2 test, p = .0407), but objective greenness and objective accessibility scores did not differ between respondents and nonrespondents when category membership was taken into account (p = .916). Furthermore, the proportion of single-family households to multifamily households was the same among respondents as among the total population for each sampling strata. Demographic variables also were similar among strata (Table 1).

Destinations and Walking Trips and Importance of Destinations

We found in this study that the most frequently walked types of destinations found in one's neighborhood were parks and grocery stores (Table 2). Other destination types that were frequently walked to and had means above 3.0 on the five-point Likert scale rating importance of walking to these destinations to participants' quality of life were restaurants, libraries, coffee shops, playgrounds, and post offices (Table 2). We found a strong association between the importance of destination index score and walking trips per month when controlling for gender, sex, age, and income (r^2 = .341410, $p < .0001$ [model]; regression coefficient for importance of destinations index = 0.0197742, $p < .0001$).

Accessibility Measures

Objective accessibility was correlated with subjective accessibility (r = .314, $p < .0001$). The regression of subjective accessibility on objective accessibility, controlling for age, income, gender, and education, was significant (Table 3). Walking trips per month were related to objective accessibility (r = .329, $p < .0001$). Our multiple regression results showed that having a destination within walking distance had a significant positive relation with walking trips after controlling for demographic variables (Table 3); however, BMI was not significantly correlated with walking trips per month ($r = -.08198$, p = .0701).

Greenness Measures

Objective greenness was correlated with subjective greenness (r = .289, $p < .0001$). Controlling for age, gender, education, and income, the regression of subjective greenness on objective greenness was highly significant (Table 3). We found that the regression of walking trips per month on subjective greenness was significant after controlling for demographics, although objective greenness was not (Table 3). We also found that after controlling for demographics, satisfaction with greenness neared significance when associated with the number of walking trips (Table 3). The regression of satisfaction with greenness on objective greenness was significant, controlling for age, gender, education, and income (Table 3).

Relationship Among Greenness and Accessibility Measures

The presence of each type of destination within .4 miles determined by GIS was related to self-reported presence of particular destinations (e.g., subjective accessibility) (Table 4). However, respondents tended to overestimate which destinations were within a half mile from their home, and this overestimation was related to the objective greenness. Respondents in areas with low objective greenness scores overestimated destinations within walking distance more than respondents in areas of high objective ($F_{1,\,499}$ = 11.009, p = .001) scores. However, objective greenness was not associated with walking trips (Table 3). Overestimation of distance also has been related to increased familiarity with the environments,[45] although we found that length of residency was not related to respondents' estimation of distance to destinations ($r = -.051$, p = .257).

With respect to the BMI response variable, our multiple regression showed an interaction effect between objective accessibility and objective greenness (model r^2 = .129428, model $p < .0001$; t-test of interaction p = .0257). In high NDVI areas there is a negative relationship between BMI and objective accessibility, but in low NDVI areas there is a slight positive relationship between BMI and objective accessibility (Figure 1).

DISCUSSION

Summary

Our study has shown that having numerous types of destinations in close proximity to residential areas is related to increased total walking trips. We also have shown that perceived importance of walking to these different types of destinations is related to walking trips. Walking trips are not only affected by how many types of destinations are within

Health Promotion hepr-21-00-03.3d 10/1/07 19:06:55 375 Cust # 06050156R

Table 3

Linear Regression Results for Accessibility and Greenness Measures

Dependent Variable	Independent Variables	β†	Standard Error	*p*	Adjusted R^2
Subjective					0.110
accessibility	Constant	7.288	1.498	.000	
(n = 446)*	Gender	0.175	0.385	.651	
	Age	−0.225	0.152	.141	
	Education	0.467	0.216	.031	
	Income	−0.157	0.111	.159	
	Objective accessibility	0.519	0.076	.000	
Walking trips					0.122
(n = 447)*	Constant	11.887	6.175	.055	
	Gender	0.688	1.589	.665	
	Age	−1.487	0.628	.018	
	Education	1.398	0.892	.118	
	Income	0.140	0.458	.760	
	Objective accessibility	2.269	0.312	.000	
Subjective greenness					0.200
(n = 454)*	Constant	−0.006	0.053	.913	
	Gender	0.029	0.013	.028	
	Age	0.021	0.005	.000	
	Education	−0.011	0.007	.141	
	Income	0.027	0.004	.000	
	Objective greenness	0.024	0.004	.000	
Walking trips					0.020
(n = 448)**	Constant	25.812	6.166	.000	
	Gender	−0.289	1.675	.863	
	Age	−1.891	0.673	.005	
	Education	1.610	0.936	.086	
	Income	−0.019	0.514	.970	
	Objective greenness	−3.715	5.746	.518	
Walking trips					0.051
(n = 455)*	Constant	15.329	6.433	.018	
	Gender	−0.320	1.624	.115	
	Age	−2.322	0.653	.000	
	Education	1.450	0.918	.115	
	Income	−0.341	0.472	.471	
	Subjective greenness	2.047	0.540	.000	
Satisfaction with					0.097
greenness	Constant	2.734	0.238	.000	
(n = 447)*	Gender	0.160	0.064	.013	
	Age	0.063	0.026	.014	
	Education	0.057	0.036	.109	
	Income	0.060	0.019	.002	
	Objective greenness	0.698	0.220	.002	
Walking trips					0.032
(n = 448)***	Constant	19.393	7.111	.007	
	Gender	−0.694	1.673	.678	
	Age	−2.357	0.666	.000	
	Education	1.618	0.935	.084	
	Income	−0.302	0.483	.532	
	Satisfaction with greenness	2.273	1.223	.064	

† β indicates unstandardized beta coefficient.
* $p < .0001$
** $p < .024$
*** $p < .003$

approximately a half of a mile distance from one's home, but also by perception of natural features found in the neighborhood and, possibly, the satisfaction with those features. We found that when participants perceived many natural features in their neighborhood, participants in this study made more walking trips, as shown by our multiple regression results. We interpret these findings to mean that subjective perceptions of vegetation may influence a person's decision to walk, in addition to actual or perceived number and type of destinations found within a half-mile distance. However, we cannot determine causality of this relationship. Do people perceive more natural features and possibly have more satisfaction with those natural features in their neighborhood because they are making more walking trips to different destination types, or do they walk more to different destination types because they perceive their neighborhood as having more vegetation, wildlife, and scenic views? Our finding regarding the overestimation of distance related to objective greenness suggests that the latter possibly is occurring—having more natural features in the neighborhood was related to a more accurate estimation of distance in this study, which may stem from more familiarity with the neighborhood environment by additional walking trips. However, our study did not directly test the association between familiarity with the residential neighborhood and walking trips.

Our study results regarding BMI suggest that greenness may be an important factor to consider in addition to accessibility in active living research. Even though our study did not show a relationship between objective measures of greenness and walking, we did find that BMI was lower in areas that had both high objective accessibility and high objective greenness than in areas with high accessibility but low greenness. This result also is supported by previous studies[10,46] that have found a strong relationship between objective natural features and physical activity.

Our results suggest that the NDVI that was used to objectively measure greenness in this study could be a useful measure for understanding the relationship between the natural environment, people's walking behaviors, and BMI. The NDVI is a rough measure of vegeta-

Table 4

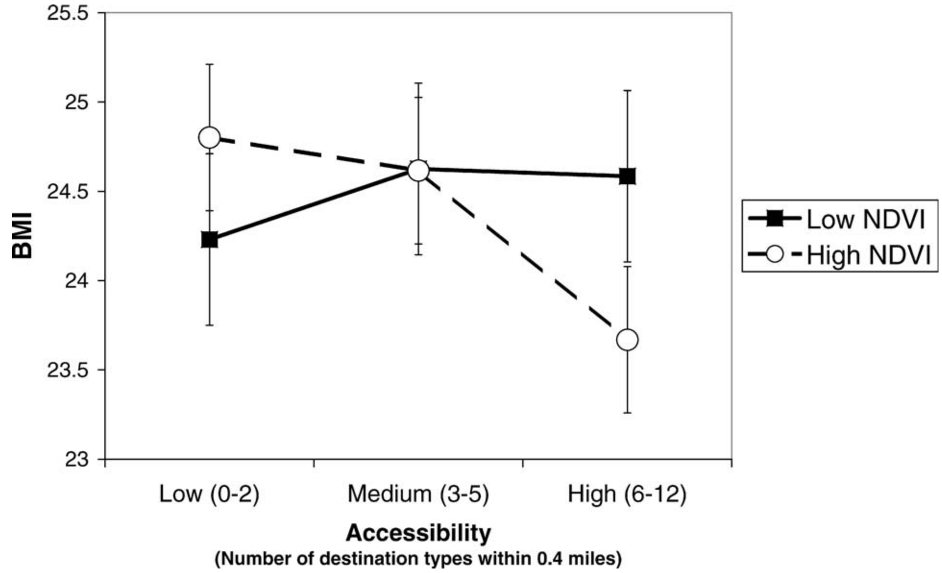
Kappa Index Between Self-Reported Destinations Within Approximately 0.5 Miles of Respondents' Homes and Geographic Information (GIS) Network Analysis of Destinations Within 0.4 Miles of Respondents' Homes

Destinations	Number of Respondents Indicating a Destination Was Within Approximately 0.5 Miles from Their Home	Number of Respondents Who Lived Within a 0.4-Mile Distance of a Destination	κ
Banks	286 (54%)	107 (20%)	0.248
Bars or pubs	347 (66%)	65 (12%)	0.042
Beaches	197 (37%)	13 (3%)	0.070
Churches or places of worship	275 (52%)	321 (61%)	0.240
Community center	290 (55%)	50 (10%)	0.115
Grocery stores/markets	420 (80%)	241 (46%)	0.163
Libraries	274 (52%)	76 (14%)	0.223
P-patches	163 (31%)	81 (15%)	0.225
Parks	428 (81%)	327 (62%)	0.154
Play areas and playgrounds	415 (79%)	260 (49%)	0.181
Post office	236 (45%)	25 (5%)	0.087
Public swimming pools	122 (23%)	8 (2%)	0.041
Restaurants	421 (80%)	322 (61%)	0.284
Schools	320 (61%)	254 (48%)	0.250
Theaters	145 (28%)	46 (9%)	0.234

tion that has many sources of variance, including species composition,[47] water content,[48] or ground cover,[49] yet in our analysis the NDVI had a fairly strong correlation with respondents' perception and satisfaction of their natural environment. Furthermore, it allowed us to capture the variation in environment over a large spatial scale in our stratified sampling. It is relatively inexpensive to acquire the satellite-generated datasets from publicly accessible resources, although using NDVI requires rudimentary knowledge of GIS and remote sensing theory.

It should be noted, however, that walking trips had a stronger association with subjective measure of greenness than with NDVI. In this study, NDVI was a useful tool to help capture variation in sampling, although it was less accurate in capturing how variations in vegetation level contribute to perceptions of natural features, satisfaction with those natural features, and walking behavior. More research regarding the interaction between objective and subjective measures

Figure 1
Relationship Between Normalized Difference Vegetation Index (NDVI), Objective Accessibility, and Body Mass Index (BMI)
Mean BMI ± standard error is shown



Health Promotion hepr-21-00-03.3d 10/1/07 19:06:57 377 Cust # 06050156R

of greenness and satisfaction with that greenness is needed to formulate a tool to help predict the influence of vegetation on walking or other physical activities. NDVI may be more useful in studies understanding walking behaviors for leisure rather than walking trips to destinations.

Our findings suggest a social-ecological approach to physical activity that includes a close look at the design of residential neighborhoods. We suggest that neighborhoods be designed with both proximity to destinations and vegetation patterns in mind. Neighborhoods within close proximity to destinations but devoid of vegetation lack natural scenic qualities that are preferred over built environments,[24] and they possibly offer restorative qualities[50,51] that may be important factors in motivating a person to walk for utilitarian or recreation purposes. In addition, residential and urban trees and vegetation also contribute to an overall healthy environment by improving air and water quality.[52,53] Large street trees are often thought to lead to sidewalk cracks and unevenness,[54] which has been linked with decreased physical activity.[55] However, recent evidence shows that street tree shading may actually protect and extend the lifetime of sidewalk pavement.[56]

Limitations

Our study has several limitations. First, the response rate for the postal survey, which included self-reported items such as walking trips, BMI, and perceptions of neighborhood vegetation, was lower than expected. Even though the survey respondents were equally distributed among varying levels of accessibility and greenness (Table 1), the generalizability of these results is limited due our small response rate. However, we controlled for important socio-demographic variables: age, income, education, and sex, which have been shown to affect physical activity measures,[41–43] although we did not collect data regarding race. Second, we failed to collect data regarding physical activity measures beyond frequency of walking trips to certain destinations in one's neighborhood as defined as approximately .5 miles from the participant's home. Additional physical activity measures would have further bolstered our results regarding the influence of destinations within a half-mile distance, vegetation levels, and BMI. Future studies should incorporate more physical activity measures with the objective measures used in this study. Finally, the cross-sectional design of this study limits our ability to determine causality.

Conclusion

Our study has illustrated the importance of using objective and subjective measures in understanding the relationship among the built environment, walking behavior, and BMI. By looking at the relationship among objective and subjective accessibility to different types of destinations within walking distance, as well as objective and subjective measures of vegetation found in residential neighborhoods we found that subjective measures of vegetation influenced walking trips, and we found suggestive evidence that subjective measures of satisfaction with natural features influenced walking trips. In addition, we found that objective measures of vegetation interacted with objective accessibility to influence BMI. Future research regarding the development and refinement of audits of walking environments should include objective measures of vegetation and measures of satisfaction of natural features and vegetation—in addition to accessibility measures—to more accurately understand the variation in walking behaviors in residential neighborhoods.

SO WHAT? Implications for Practitioners and Researchers

This study seems to indicate that actual levels of vegetation and participants' perception of natural features and satisfaction with natural features found within residential areas are important factors to consider when researching the relationship between environmental factors and walking behavior. Combined with other research, there seems to be preliminary support for the assertion that objective measures of vegetation may interact with the amount of accessible destinations within the neighborhood to affect BMI, and subjective measures of vegetation may affect walking behaviors. Health promotion researchers should include detailed objective measures of vegetation by using NDVI in future environmental audits of residential neighborhoods and longitudinal studies, along with subjective measures of participants' perception of vegetation found in the area of study. We also suggest that researchers explore satisfaction measures of natural features, such as the natural features index that was created for this study to further understand the relationship between satisfaction with natural features and walking behaviors.

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