Urban forms, physical activity and body mass index: a cross-city examination using ISS Earth Observation photographs

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ABSTRACT

Johnson Space Center has archived thousands of astronauts acquired Earth images. Some spectacular images have been widely used in news media and in k-12 class room, but their potential utilizations in health promotion and disease prevention have relatively untapped. The project uses daytime ISS photographs to define city forms and links them to city or metropolitan level health data in a multicity context. Road connectivity, landuse mix and Shannon's information indices were used in the classification of photographs. In contrast to previous remote-sensing studies, which tend to focus on a single city or a portion of a city, this project utilized photographs of 39 U.S. cities. And in contrast to previous health-promotion studies on the built environment, which tend to rely on survey respondents' responses to evaluate road connectivity or mixed land use for a single study site, the project examined the built environments of multiple cities based on ISS photos.

It was found that road connectivity and landuse mix were not statistically significant by themselves, but the composite measure of the Shannon index was significantly associated with physical activity, but not BMI. Consequently, leisure-time physical activity seems to be positively associated with the urban complexity scale. It was also concluded that unless they are planned or designed in advance, photographs taken by astronauts generally are not appropriate for a study of a single-site built environment nor are they appropriate for a study of infectious diseases at a local scale. To link urban built environment with city-wide health indicators, both the traditional nadir view and oblique views should be emphasized in future astronauts' earth observation photographs.

INTRODUCTION

In the last three decades, the number of overweight and obese individuals has increased at an alarming rate in the U.S. Substantially reducing overweight and obesity nationwide (i.e., by one-third) has become a top public health objective (Healthy People 2010). Numerous articles and special issues of leading medical and public health journals, such as the September 2003 issues of the *American Journal of Public Health* and the *American Journal of Health Promotion* (Giles-Corti, 2003, Ewing 2003), and numerous issues of the *American Journal of Preventive Medicine* have been devoted to environmental risk factors and determinants that predispose people to being overweight or obese. The February 2003 issue of *Science* also devoted a special section to obesity and environmental factors (Hill 2003). The consensus is that a decrease in physical activity, together with increased energy intake at the societal and population level, largely contributes to the obesity epidemic.

Many investigators have related neighborhood characteristics with physical activity and body mass index (BMI; Egger and Swinburn 1997). A neighborhood, which is usually defined as several city blocks or sometimes by census tract, is conducive to outdoor activities if it can provide various incidental opportunities for walking and biking to shops and parks and to conduct daily business (e.g., banks, postal service). Numerous studies have associated a greater level and intensity of physical activity with mixed land use, neighborhood trails, hilly landscapes, and proximity to parks and recreational facilities (Giles and Donovan, 2003; Leyden, 2003, Lindström 2003). Most studies that have examined environmental determinants of physical activity, however, used respondents' perceived environmental and neighborhood factors (Brownson et al 2001). Objectively measured neighborhood environments are found only in very localized studies that involve very few neighborhoods (Saelens et al 2003), and there is a great demand in the field of health promotion to provide and to link objectively measured neighborhood characteristics to community health indicators such as physical activity.

There are three elements of the built urban environment: urban configuration (i.e., arrangement of physical elements), land use (e.g., the location and density of residential, commercial, and other spaces), and transportation network (e.g., roads, railroad tracks, bridges). Previous remote-sensing studies of urban environments have covered a wide range of topics (e.g., urban sprawl, change in land use, estimates of housing and population density, urban morphology) about built environments (Lo and Yang 2003; Civco et al. 2003) Most of these studies, however, have addressed only one element of the urban built environment or a single study site (i.e., a city). To date, no multicity study has been conducted.

There are many sources of digital data on urban built environments, but most of them are inaccessible at a neighborhood scale. Aerial photographs and high-resolution satellite images are available for all cities in the United States, but they cost tens of thousand dollars for a multicity study. The National Aeronautics and Space Administration (NASA) has more than 500,000 Earth photographs housed at the Johnson Space Center that provide a unique data source for investigating urban environments around the world (Lulla and Dessinov, 2000). Astronauts took the photographs, of varying quality, during numerous shuttle flights and while on board the Mir Space Station or the International Space Station (ISS). The recent ISS photographs are more consistent in quality than the others and include images of major U.S. cities.

ISS photographs have several advantages for exploring built environments. First, they are in the public domain and are downloadable free of charge. Second, the quality of the photographs is acceptable for testing a research hypothesis or for making a quick assessment of a study area. ISS photos taken from a 400-mm or 800-mm lens provide a ground resolution between 20 and 6 meters, depending partially on the lens used and partially on the distance to the Earth's surface. The photographs taken at a point directly below the ISS (i.e., the nadir view) have the best resolution because of the shorter distance to the Earth. Third, the photographs taken by the astronauts are prepared for the general public, and they require much less knowledge to process or to read than satellite images, such as TM, yet they have spatial resolution that is comparable to TM or to SPOT. Fourth, astronauts are trained observers and can capture images of cities from various angles with variable scales, which may reveal more information about urban morphology than images taken from the nadir view only.

Herein, I describe how I used ISS photographs in an investigation of urban built environments in an attempt to link individual physical activity data for selected U.S. metropolitan areas with characteristics that are likely to be amenable to physical activity. I first identify the national survey data that we linked to the ISS images and then describe how I developed and tested a set of operational measures of the amenability of urban environments to outdoor activities based on selected ISS images.

METHODS

(1) The Behavioral Risk Factor Surveillance System Survey.

I evaluated several national-level data sources that included information about physical activity and BMI at the individual level—the National Health Interview Survey (NHIS), the National Health and Nutrition Examination Survey (NHANES), and the Behavioral Risk Factor Surveillance System (BRFSS) survey. I chose to use the data from the BRFSS survey because it was the only study that had geographic information at the county or metropolitan–area level. The survey was conducted by telephone in 2003 and sampled more than 250,000 respondents from among the noninstitutionalized adult (≥18 years of age) population in the U.S. The 2003 BRFSS survey had several sample-weight variables to correct for variations in sampling schemes (Holtzman 2002). The *final person weight* variable was designed to correct biases so that the final BRFSS survey sample for analysis could be nationally representative. Each respondent was asked about basic demographic and socioeconomic variables and about body weight, height, and the frequency and intensity of leisure-time physical activity. They were also asked about such chronic conditions as hypertension, diabetes, and heart disease and about such health-related behaviors as smoking, diet, and alcohol consumption.

The 2003 BRFSS survey data provide the total number of minutes per week in which the subjects engaged in 1) moderate physical activity or 2) vigorous physical activity during their leisure time. Both moderate and vigorous physical activities were combined into a single measure of time (in minutes) spent engaged in physical activity outside of the workplace.

(2) Measuring outdoor amenability to physical activity.

There are many ways to measure the outdoor amenability of an urban environment. The new urbanism movement, which emerged in the late 1980s, embraces urban design and planning principles that both create great public places and reduce automobile use. The *Good City Form* (Lynch, 1981) provided a language and conceptual framework for describing and evaluating the built environment and defined physical characteristics. In his early (1961) and more recent work (1981), Lynch suggested that the more physically complex a city is, the greater number of incentives there are for residents to walk. According to Lynch, a city can be portrayed vertically, horizontally, and architecturally. These dimensions can be defined abstractly by using the Shannon index (Haken and Portugali 2002), which is an information index that portrays the complexity of three combined dimensions. For the purposes of the current projeect, I only considered the horizontal arrangements of a city that are amenable to physical activity.

Appropriately measuring the link between the built environment and outdoor activities is not a trivial task, even when dealing with a single dimension. The measures most commonly used by researchers reflect the availability of data, as well as the traditional concerns of transportation planning, and are not necessarily suited to the study of the link between the built environment and physical activity. When examining interactions between the built environment and travel behavior, various elements of the environment are more appropriately measured at various geographic scales. Past research has typically focused either on the neighborhood, an area that is often conceptualized as encompassing several city blocks, or on broader regional scales, such as several square miles within a large city or metropolitan area or even an entire metropolitan area. I chose to test measures of the built environment by dividing those measures into local (i.e., neighborhood) and regional characteristics.

Based on Lynch (1981), there are at least three interrelated and often correlated elements of the built environment at the neighborhood scale:

1. Density and intensity of development. Density is a measure of the amount of activity found in a geographic area. It is usually defined as population, employment, or building square footage per area unit (e.g., people per acre, jobs per square mile). The floor-area ratio, defined as the ratio between the floor space in a building and the size of the parcel on which that building sits, is another popular measure of density. Density is perhaps the easiest characteristic of the built environment to measure and is thus widely used. Although the ISS photographs can be used to derive the average building setback, the problem with varying geographic scales makes it difficult to uniformly assess the building setback in a multicity context, so I did not evaluate it. I relied instead on population-density statistics from the 2000 U.S. population census to control and evaluate the density effect.

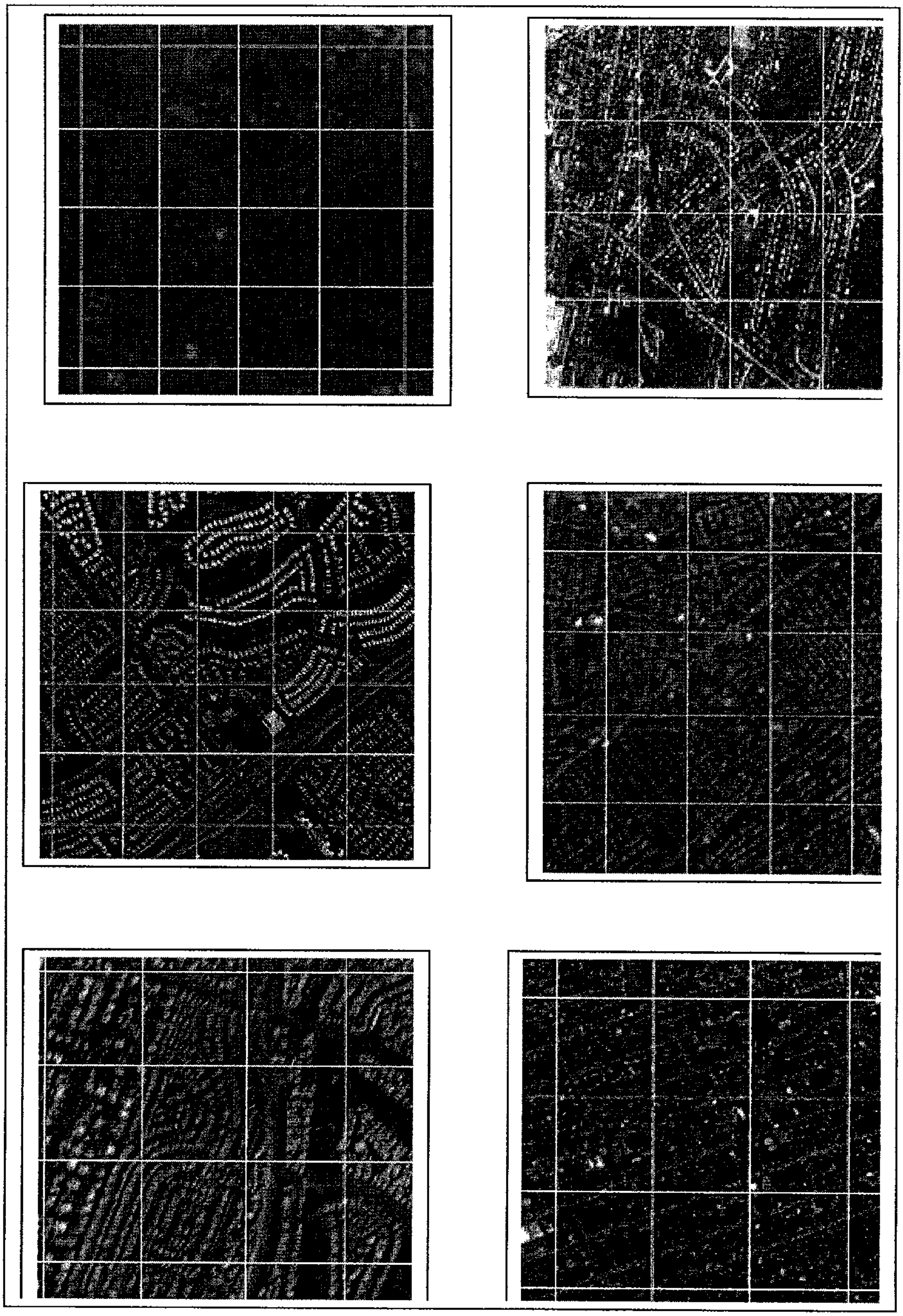
2. Land use mix. Land use mix is defined as the relative proximity of different land uses within a given geographic area. A mixed-use neighborhood would not only include homes but also stores, offices, parks, and perhaps other land uses. I devised a random grid with a center cell and 8 adjacent cells (see Figure 1 for an example). For each grid cell, I counted the number of neighboring cells occupied by different land uses.(Cervero and Kockelman, 1997).
3. Neighborhood connectivity. Connectivity is defined as the directness and availability of alternative routes from one point to another within a number of neighborhoods (Hess, 1997). There are several measurements, such as the number of intersections per square mile, the node-to-line segment ratio, and average block length. The node-to-line segment ratio is hard to manipulate in a global information system (GIS) or remote-sensing environment, because a node at the dead end of a street is still recognized to be a node by the database. To avoid this ambiguity in the GIS database, we used a simple index—the intersection-to-line segment ratio. The greater the node-to-line segment ratio is believed to be associated with greater connectivity of alternative routes (Greenwald and Boarnet 2002). I again used the same random grid from the land-use measure in 2) and counted the number of intersections and road segments within a grid. This process was repeated 20 times for each ISS photograph of a city, and the total numbers of intersections and road segments were used to derive the intersection-to-line segment ratio for each city.

A neighborhood was considered to be pedestrian friendly if it was densely developed with a mixed land-use pattern and a highly interconnected street network. Although different types of land use may be attractive, more road connectivity in an urban landscape also means simple layout, such as the Manhattan road network, which, according to Lynch (1981), could make walking during leisure time less attractive (more incidental physical activity from necessary walks). So one way to deal with this problem is to use a modified Shannon index (Haken and Portugali 2002). Shannon indices have several forms of operational equations, and almost all of them are taken as a ratio of possibility. If a road network is simple, the possibility of a road being extended to other possible routes is greater. In contrast, a road network that is more complex and, therefore, more interconnected, is less likely to be reconfigured, which means that the amount of possible information is less.

The $\log_2$ of the inverse of the road connectivity index is a proxy of the Shannon index. Similarly, the greater the number of land-use types, the greater the possibility of spatial configuration and the greater the amount of information. For any land-use pattern that has more than 1 category, the simplest land use for a grid cell would be one type of use only, and the most complex landuse would be 3 categories. Hence, when each neighboring cell has all three types, the total would by 3 times 8 (cells), or 24, the $\log_2$ (total neighboring land-use types/8) is another proxy of the Shannon index. By combining the calculations of both road and landuse complexity indices, I derived information about the complexity index of road and landuse as

$$\text{Shannon Index} = \log_2(1/(\text{road index}) + (\text{land-use index})/8) \qquad (1)$$

Figure 1. Random grid-samples of selected IIS photo (from left to right Boulder, CO; Bangor, ME; Phoenix, AZ; Boston, MA; Las Vegas, NV; Louisville, KY)



Anticipating some problems with the road-connectivity index based on the intersection-to-line segment ratio, I also tried to calculate the number of circular networks within a mile grid by using the U.S. Census TIGER file and comparing the results for the Houston metropolitan area. The TIGER road network, however, proved to be too approximative. Many streets in the Houston metropolitan area, for instance, would have a dead end, but the TIGER file does not contain this information (not shown, available upon request). For this reason, the TIGER file data would result in more error than those obtained from the ISS photos if they can be carefully selected.

Since I want to be able to distinguish between three types of land use—residential, recreational (green and water), and other built-up lands—I set the ground resolution to be ± 10 meters. This requirement limited the camera lens to > 400 mm. In addition, the ISS photographs must cover a part of metropolitan area where the BRFSS survey had some respondents so that survey data could be linked to the ISS photos. Combining these two requirements, and some photo-quality requirements (e.g., clear sky), I found about 70 ISS photos that cover 39 U.S. cities. For a complete list of the ISS photos used in this study, see Appendix 1.

(3) Deriving city measures.

I used a center grid-cell about 100 meter wide to form a 3 × 3 grid to move around for evaluating land use based on the method in 2); I then this 3 × 3 grid to evaluate the road network based on the method in 3). For each photo, I randomly move this center grid 20 times to select sample grid. Since each selected grid location is randomly generated, I could not control its location. Nevertheless, I made sure that there was no overlap between two center cells in any randomly selected location. In addition, if the center cell did not cover a residential area, I regenerated the grid until it covered a residential neighborhood. An analytical algorithm for each city is:

Step 1. Generate a 100-meter box, together with 8 neighboring boxes, by using the queen's rule.
Step 2. If the center box touches a residential neighborhood, then selected the grid, otherwise, repeat step 1 until the condition is met.
Step 3. For each center box, count the number of land uses (3 types; bodies of water are excluded) in an adjacent cell and record it.
Step 4. Count the number of intersections and road segments within the 9-cell grid and store them in the memory (if a street extends outside the grid, do not count it).
Step 5. Repeat steps 1 through 4 a total of 20 times. For each repetition, the center box cannot overlap any other center box.
Step 6. Summarize the measures made in step 3 and divide them by 20; the result becomes the average land-use mix index. Add the total number of intersections and road segments in step 4 and the ratio of the two becomes the intersection-to-road segment ratio.

When there was more than one photo for each city, the two with the sharpest images were used, and each was sampled 10 times. The sampling was done in ArcView

3.2. For several cities (e.g., Green Bay, Wisconsin; Kansas City, Missouri; Indianapolis, Indiana), the ISS photographs had insufficient information, so I used some aerial photographs to supplement the evaluation process. I first tried to automate the process. However, the photo image has limited spectrum information, both supervised and unsupervised classification resulted in more time spending on visual correction of the resulted classification. I eventually did visual classification. The whole process took about 20 working days.

After deriving each measure for all 39 cities, I used equation 1 to calculate a Shannon index. I downloaded the population density information from the U.S. Census Bureau and added it to the three measures. I then linked the three measures of physical friendliness (i.e., population density, mixed land use, and road connectivity) along with the Shannon index to individual data in the BRFSS survey for further analyses.

(4) Multivariate analysis.
I then conducted a multivariate analysis using a multilevel model with the number of minutes spent per week engaging in physical activity being the dependent variable. Assuming that individuals from each city or metropolitan area would respond similarly to the three measures of outdoor amenability to physical activity, a multilevel analysis is appropriate because individual variables are nested within the city variables (Duncan, Jones and Moon 1998). In other words, the city variables will not change among individuals living in the same city. I fit a fixed-effect multilevel model with an intercept that accounts for this hierarchical structure. In the model, I also controlled for individual risk factors such as age, sex, race, vegetable intake, and smoking status. Suppose, for example, that the dependent variable is physical activity y, a simple fixed effect model is

$$y_{ij} = \beta_0 + \beta_1 x_{1ij} + \beta_2 x_{2ij} + ,\ldots, + \beta_k x_{kij} + \phi_1 \mathrm{road}_j + \phi_2 \mathrm{landuse}_j + \phi_3 \mathrm{popd}_j + \mu_{0j} + \varepsilon_{ij} \qquad (2)$$

wherein the βs are parameter estimates for individual-level variables (x) that are indexed by individual (i) and county (j) and the ϕs are parameter estimates for county-level variables that are indexed only by j. Both β and ϕ are the fixed effects, leaving μ_{0j} as the only county-specific random effect (Goldstein et al. 2002). Preliminary results showed that BMI had no relationship with any of the measures, so I will not report them here.

RESULTS

Descriptive analysis. The complete list of the three measures, together with physical activity, is given in Table 1. Overall, the mixed-land-use scores were high for the larger cities and low for the smaller cities. Phoenix, Arizona, and Boston, Massachusetts, had the lowest mixed--land-use score at 11, and Boulder, Colorado, had the highest score at 18. Recall that the score equals 8, but it means that each neighboring cell has one type of land use. If the score is more than 16, it means that each neighboring cell on average has two types of land use (i.e., other built environments versus residential, or recreational versus residential, or recreational versus other built environments. Ironically, Boulder also had a lower score in street connectivity, as measured by the intersection-to-road segment ratio. So superficially, at least, one amenity measure does not predispose the other. Interestingly, the average BMI in Boulder was second lowest among the 39 cities, and its average physical activity score was 93.47, which is much higher than the mean (85.8) for all the cities.

Table 1. Road connectivity, mixed landuse and Shannon indices among 39 cities

Metropolitan Area	Road index	Land Use index	Shannon Index	BMI	Physical activity (mim)	# Obs Matched
Arlington, VA	0.56	16.37	1.82	24.14	82.66	133
Atlanta, GA	0.55	13.20	1.67	26.96	78.41	460
Austin, TX	0.43	17.90	2.06	26.04	83.76	256
Baltimore	0.54	14.73	1.76	27.58	71.97	293
Bangor, ME	0.35	15.19	2.10	27.13	85.95	247
Boston, MA	0.71	11.52	1.39	25.88	79.53	935
Boulder, CO	0.38	18.77	2.19	24.77	93.47	246
Buffalo, NY	0.52	16.23	1.86	26.51	86.95	284
Chicago, IL	0.56	15.23	1.76	26.59	80.98	2041
Cincinnati, OH	0.65	14.26	1.61	27.28	95.93	546
Dallas, TX	0.72	12.21	1.42	26.51	88.89	501
Denver, CO	0.56	14.92	1.75	25.67	89.92	429
Des Moines, IA	0.43	15.43	1.94	26.99	78.28	591
Detroit, MI	0.45	13.92	1.84	27.84	79.65	501
District of Columbia	0.69	15.39	1.65	26.27	81.57	1951
Duluth, MN	0.43	17.18	2.03	26.29	90.20	163
Fort Worth, TX	0.67	14.47	1.61	26.63	78.54	378
Gary, IN	0.49	12.54	1.71	27.76	94.02	402
Grand Junction, CO	0.55	16.15	1.82	25.79	114.59	125
Green Bay, WI	0.35	13.77	2.04	26.56	76.38	157
Houston, TX	0.51	14.42	1.78	27.31	78.27	728
Indianapolis, IN	0.40	15.65	2.02	27.04	92.79	731
Kansas City, MO-KS	0.51	14.33	1.78	26.12	71.47	701
Las Vegas, NV	0.28	11.53	2.13	26.60	103.80	880
Los Angeles-Long Beach, CA	0.48	16.94	1.94	26.87	95.79	958
Louisville, KY	0.65	14.32	1.61	27.05	52.30	368
NYC, NY	0.76	13.70	1.49	25.75	76.79	486
Nashville, TN	0.44	14.56	1.89	26.49	67.61	230
New Orleans, LA	0.58	13.21	1.63	26.83	65.59	389
Oakland, CA	0.45	15.14	1.91	26.08	102.34	199
Oklahoma City, OK	0.37	14.73	2.03	26.90	74.14	1278
Omaha, NE	0.52	15.11	1.81	26.63	72.73	1121
Philadelphia, PA	0.62	14.21	1.64	27.55	86.31	310
Phoenix, AZ	0.34	11.04	1.94	26.21	82.04	805
Providence, RI	0.63	16.79	1.78	26.32	82.53	2319
San Diego, CA	0.28	15.14	2.28	26.53	106.08	367
San Francisco, CA	0.71	14.22	1.56	24.75	93.23	99
Virginia Beach, VA	0.38	17.35	2.13	27.37	108.09	262
Waterloo-Cedar, IA	0.34	15.50	2.14	27.10	71.83	129

Both San Diego, California, and Las Vegas, Nevada, had low road connectivity scores, but both cities had higher average physical activity scores. A connectivity index close to 0.3 suggests a triangle-like road system, where T-shaped intersections and dead-end streets are fairly common. Even though neighborhood road systems in San Diego and Las Vegas are not well connected, residents there might be more likely to either work out in a gym (Las Vegas) or walk in neighborhood (San Diego). New York City and Boston had higher road connectivity scores. A connectivity index close to 0.7 suggests a Manhattan network system. Since the dimensions of a single grid is about 300 × 300 meters (or 9 100-meter grids), an index close to 7 is very high. If an even larger grid were used, the index could be higher. Regardless of the scale used, a higher road connectivity score apparently is associated with less physical activity, because both New Yorkers and Bostonians tend to engage in less physical activity than the average. One problem with categorizing physical activity simply as moderate or vigorous is that no distinction is made between outdoor and indoor physical activities. In addition, such categorization seems to reflect only purposeful leisure-time physical activity, and it does pick up many incidental daily activities, such as running errands and shopping at a local store.

It seems counterintuitive that Boston, Dallas, and New York had greater outdoor amenability than San Diego or Virginia Beach, but the Shannon indices suggest that this is the case. If the vertical dimension of a city could be added to our analysis, the Shannon index would have a different meaning. In the context of this study, however, there appears to be no relationship between the Shannon index and physical activity scores without controlling other individual characteristics.

Multivariate analysis. I first ran a model that included the road and land-use indices—(model 1); I then dropped the road and land-use variables and added the Shannon index as the key area-level explanatory variable (model 2). The results for both models are shown in Table 2. In both models, the results for the demographic and behavioral risk factors were consistent with the literature. The age, sex, and race/ethnicity of the respondents to the 2003 BRFSS survey were also important demographic factors. The physical activity decreased with age, and males engaged in more physical activity than did females. Most minority groups (i.e., Asian, Black, and Hispanic) tended to engage in less physical activity, and physical activity increased with educational level. As expected, smokers had a higher level of physical activity, as did persons who ate more servings of fruits and vegetables per day.

None of the three variables that represented outdoor amenability to physical activity—road connectivity, mixed land use, and population density—were significant in model 1. Several explanations could be offered for the non-significant results for the road-connectivity and land-use variables. It is possible that there was some spatial mismatch in a particular area. The ISS photographs typically cover a part of a county, but the survey data may cover the entire area or a different part of the county. It is possible that there is no direct relationship between these indices and physical activity. It is noteworthy that the Shannon index was significant in model 2. Presumably, as suggested by Lynch (1981.), the more complex the combined land use and road system, the greater the physical activity.

Table 2. Multilevel regression on BMI and physical activity

	Model I			Model II		
Individual variables	Estimate	Error	t Value	Estimate	Error	t Value
Intercept	66.9769	19.3112	3.47*	27.6349	17.5787	1.57
Age (18-29)**						
Age 30-44	-8.7808	1.8505	-4.75*	-8.7883	1.8505	-4.75*
Age 45-64	-16.1527	1.8663	-8.65*	-16.1598	1.8663	-8.66*
age 65-74	-25.6303	2.9451	-8.7*	-25.6418	2.945	-8.71*
age 75 or older	-50.8325	3.2427	-15.68*	-50.8386	3.2426	-15.68*
Sex (Male)	22.5497	1.4085	16.01*	22.5466	1.4085	16.01*
Race/ethnicity (White)						
Black	-4.8239	2.2042	-2.19*	-4.7633	2.2036	-2.16*
Asian	-22.2135	3.3292	-6.67*	-22.1685	3.3283	-6.66*
Hispan	-4.6968	2.1312	-2.2*	-4.6832	2.1306	-2.2*
Other races	17.6372	3.1253	5.64*	17.6376	3.1251	5.64*
Education (< high school)						
High School	4.9743	1.283	3.88*	4.9701	1.2829	3.87*
Associate Degree	5.4863	2.6272	2.09*	5.4739	2.6271	2.08*
College or higher	0.3139	2.6164	0.12*	0.3231	2.6162	0.12*
Fruit/veget Servings/day	3.4979	0.321	10.9*	3.5006	0.321	10.91*
Current smokers	6.0563	1.7742	3.41*	6.0536	1.7742	3.41*
City-wide variables						
intersection/road-segment ratio	-27.5512	16.3993	-1.68			
mixed landuse index	1.0315	1.1104	0.93			
Shannon index				22.1429	9.261	2.39*
Population density	0.06391	0.1812	0.35	0.0635	0.1698	0.37

* significant at P<0.05
**category in the parentheses is the referent

CONCLUDING REMARKS

In this project, I explore the feasibility of using ISS photographs to assess the built environment of urban areas. In contrast to previous remote-sensing studies, which tend to focus on a single city or a portion of a city, I used images of 39 U.S. cities. And in contrast to previous health-promotion studies on the built environment, which tend to rely on survey respondents' responses to evaluate road connectivity or mixed land use for a single study site, I examined the built environments of multiple cities based on ISS photos. Although none of the citywide indicators was statistically significant by itself, the composite measure of the Shannon index was significant. Consequently, leisure-time physical activity seems to be positively associated with the urban complexity scale.

A truly representative Shannon index for a city also requires vertical measures, which I could not evaluate because of the lack of oblique-view data. The oblique view is important, especially for its ability to capture a vertical dimension. Oblique view is more intuitive to visualization. For cities located near a mountain or a hill, the oblique view can be a better source of information source than a three-dimensional model. It is suggested implicitly in the literature on remote sensing that the oblique view is inferior because people tend to correct the distortion caused by the view. Three-dimensional views also are distorted; using an oblique photograph sidesteps artificial distortion by a computer algorithm.

Unless they are planned or designed in advance, photographs taken by astronauts generally are not appropriate for a study of a single-site built environment nor are they appropriate for a study of infectious diseases, such as West Nile virus (Rogers et al., 2002). The ground resolution is usually sufficient for an infectious disease study, but an astronaut usually does not systematically take photographs of a city. This practice often leaves various holes in the landscape that are critical for studying the infectious environment. For a large-area study that requires a coarse ground resolution, an ISS photograph is a fine choice, because only one photograph is needed for each time period. Finer ground resolution requires that several photographs be taken, some from an azimuthal viewpoint from the ISS window. The latter requirement is problematic in the current ISS observations of the Earth.

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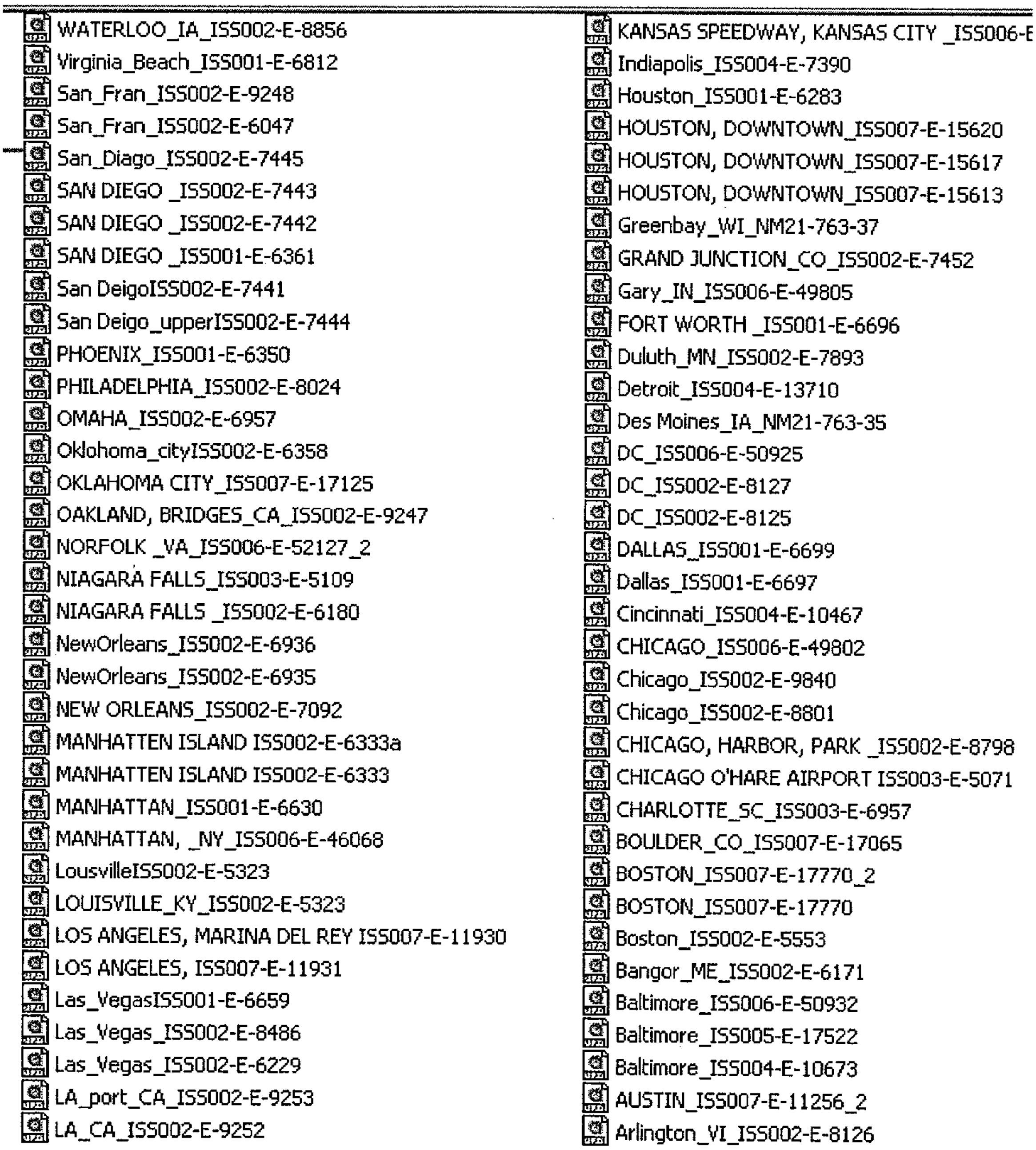
Appendix I. The final list of ISS photos used in the report



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