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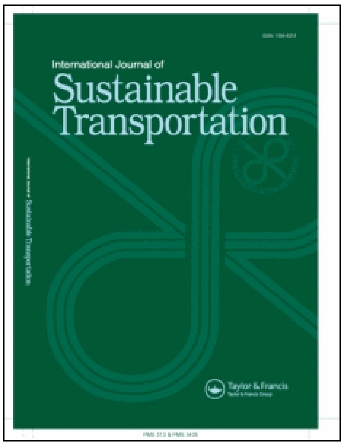

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Influences of Built Environments on Walking and Cycling: Lessons from Bogotá

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ABSTRACT

Bogotá, Colombia, is well known for its sustainable urban transport systems, including an extensive network of bike lanes and set-aside street space for recreational cyclists and pedestrians on Sundays and holidays, called *Ciclovía* ("cycleway"). This paper examines how such facilities along with other attributes of the built environment—urban densities, land-use mixes, accessibility, and proximity to transit—are associated with walking and cycling behavior as well as Ciclovía participation. We find that whereas road facility designs, like street density, connectivity, and proximity to Ciclovía lanes, are associated with physical activity, other attributes of the built environment, like density and land-use mixtures, are not. This is likely because most neighborhoods in built-up sections of Bogotá evolved during a time when non-automobile travel reigned supreme, meaning they are uniformly compact, mixed in their land-use composition, and have comparable levels of transport accessibility. Thus facility designs are what sway nonmotorized travel, not generic land-use attributes of neighborhoods.

Key Words: built environment, cycling, health, physical activity, transit, walking

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1. BOGOTÃ'S PROGRESSIVE TRANSPORTATION SYSTEM

Bogotá, the Andean capital of Colombia and home to some 7 million inhabitants, is internationally recognized for advancing sustainable transport. Much has been written about what many consider to be the gold standard of Bus Rapid Transit (BRT)—the 55 km TransMilenio system (Hook, 2004; Skinner, 2004; Cervero, 2005; Wright and Hook, 2007). Equally impressive has been Bogotá's world-class network of bikeways. The US$180 million that the city spent on bikeways from 1990 to 2002 was about half the amount the entire United States spends annually on cycling infrastructure (Hook, 2004).

Currently, Bogotá has 291.3 km of dedicated bicycle paths, called *Cicloruta.* The Dutch-advised long-range plan calls for the figure to double over the next 30 years. World-class bicycle facilities are even found in open agricultural fields on the city's fringes, introduced to promote cycling over motorized travel in soon-to-urbanize settings and to ingrain a "bicycle consciousness" in the minds of the young and carless (Peñalosa, 2002).

The combination of an extensive bikeway network and hospitable environment have encouraged cycling. Perched in a high plateau in the Andes Mountains, Bogotá enjoys a mild equatorial climate. Moreover, three-quarters of daily trips in the city are less than 10 km in length, a distance that bicycles can sometimes cover faster than cars given the city's traffic-snarled streets. From 1996 to 2003, the share of trips made by bicycle in Bogotá increased from 0.58% to 4.4% (Cervero, 2005). Though high by Latin American standards, bicycle use in Bogotá still lags well behind some of the world's great cycling cities, like Copenhagen and Amsterdam, where bicycles account for more than a quarter of all trips (Beatley, 2000; Rietveld and Daniel, 2004) and as high as half of all non-walk trips shorter than 4 km (Rietveld, 2000). Also, there remain significant deterrents to cycling in Bogotá, including the city's high elevation (2600 m), two rainy seasons, air pollution, and concerns over traffic safety.

To further promote cycling and leisure activities, the city closes 121 km of main roads for seven daylight hours on Sundays and holidays. Called *Ciclovía* ("cycleway"), these car-free corridors are reserved exclusively for cyclists, runners, skaters, and strollers. The city also tends to the needs of pedestrians. Under the leadership of a series of progressive, reform-minded mayors, including Enrique Peñalosa and Antansa Mockus, significant sums of public funds went to enhance public squares, open pocket parks, and to create more attractive streetscapes. From 2001 to 2003, the city's green area per inhabitant jumped from 2.5 to 4.1 m^2 per inhabitant, approaching the goal of 8 m^2 per resident set for 2013 (Instituto Distrital para la Recreación y el Deporte, 2006). Bollards have also been installed throughout the city core to physically prevent motorists from parking on sidewalks and bikeways. To enhance access to TransMilenio busway stations, a network of pedestrian overpasses, sidewalks, and bikeways, many embellished with attractive landscaping and brickwork, have been built.

2. RESEARCH FOCUS

This paper probes the question of how the built environment, including density, land-use mix, and elements of design (including bikeway and sidewalk facilities), influence walking and cycling in Bogotá as well as Ciclovía participation. The transportation and environmental benefits of walking and cycling are self-evident in traffic-choked and heavily polluted cities of the developing world. There are also, however, potential public health benefits. According to the World Health Organization (2005), 80% of all deaths due to chronic diseases like heart failure and stroke occur in low and middle income countries. Despite the health benefits of physical activity, the majority of adults living in Bogotá are physically inactive. A recent national survey found that fewer than half of adults in Bogotá meet minimum daily recommendations for physical activity (Instituto Colombiano de Bienestar Familiar, 2005). Significant shares of women, minimally educated residents, and those living in the poorest and most disadvantaged neighborhoods rarely walk or bike for leisure and recreational purposes.

In the developed world and particularly the United States, a substantial body of research suggests built environments are significant predictors of nonmotorized travel (Handy et al., 2002; Frumpkin, et al., 2004). A study in the San Francisco Bay Area, for example, found that factors like density, land-use, and street connectivity had moderate effects in promoting walking and bicycle travel for trips less than 5 miles in length, although personal and household attributes were stronger predictors (Cervero and Duncan, 2003). Research that directly measured physical activity using Atlanta as a case context found that measures of land-use mix, residential density, and street intersection density were positively related to minutes of moderate physical activity per day (Frank et al., 2005). Research further shows that grid street networks can increase biking and walking by reducing trip distances, offering alternative pathways, and slowing automobile travel (Frank and Engelke, 2001). A recent analysis in North Carolina revealed communities designed for "active transportation" had the strongest influence on bicycling and walking for at least 150 minutes per week among lower-income individuals (Aytur et al., 2007).

Do such relationships between the built environment and time spent walking and cycling also hold for cities in the developing world, such as Bogotá? Despite economic progress in recent years, many of Bogotá's residents struggle on a daily basis to make ends meet—over half of the city's households live below the poverty level. For many, walking and cycling are likely a necessity, regardless of urban environments. Thus the premise that the design of cityscapes significantly influences physical activity might not hold for significant segments of society in cities like Bogotá. And if it does, the relationships established in modern advanced societies might be fundamentally different in poorer urban settings. Studies show that poorer individuals tend to walk less for leisure and recreation in developing countries, such as in Brazil (see Hallal et al., 2005), however, few studies have examined factors that influence walking and cycling for utilitarian activities (e.g., going to work or shopping) in developing countries.

Another possibility is that in the absence of a strong tradition of comprehensive urban planning or strict enforcement of land-use regulations (like zoning), many cities in the developing world have evolved so as to accommodate both foot and bicycle travel. With only around one in five Bogotá households in possession of a car, compact, mixed-use development that allows many destinations to be quickly and conveniently reached by foot is more the rule than the exception.

Consequently, there might not be enough variation in the density, land-use mix, and urban design profiles of neighborhoods in cities like Bogotá to discernibly influence travel choices. Instead, sociodemographic factors, like income and car ownership levels, might be far stronger determinants of travel. In Bogotá's case, the presence of specific facilities, like Cicloruta pathways or dense street networks in some neighborhoods but not others, could at the margin explain travel behavior. We were prepared for such outcomes in our analysis.

To date, relatively little research has been conducted on the connection between built environment and nonmotorized transport outside of first-world countries. This paper aims to help fill this gap. In the sections that follow, we begin by discussing our research design for studying the influence of Bogotá's built environment on walking and cycling and Ciclovía program. We then present three models: one on walking for utilitarian (i.e., non-recreational) purposes; one on cycling for utilitarian purposes; and one on Ciclovía (i.e., mainly recreational) participation. The paper concludes with discussions on the policy implications of the research findings.

3. RESEARCH DESIGN AND METHODS

This section first reviews the sampling approach for selecting neighborhoods and households to study how built environments are associated with walking and cycling in Bogotá and Ciclovía participation. This is followed by a discussion of the survey instrument used to compile primary data, the variables selected to express built environments, and our overall modeling approach.

3.1. Sampling Approach

Because the data on built environments needed to carry out the research would be prohibitively expensive and time consuming to compile for the entire city of Bogotá, we opted for a multistage stratified sampling approach instead. The city of Bogotá has designated 120 official neighborhoods, roughly equivalent to census tracts in size. Based on a power test, a representative sample of 30 neighborhoods was randomly selected. We first grouped all neighborhoods by four variables: socioeconomic status (SES), average slope of terrain, proximity to TransMilenio stations, and public park provision. The stratifying variables were chosen because walking and cycling were thought to vary across these dimensions. A previous study found the share of trips by biking or walking made by Bogotá residents differed by topography and sociodemographic characteristics (Gomez, et al., 2005). Moreover, theory holds and research reveals that physical activity levels are influenced by accessibility to parks (Humpel et al., 2002; Bedimo-Rung et al., 2005) and that Bogotá households assign value to living within walking distance of TransMilenio stations (Rodríquez and Targa, 2004; Rodríquez and Mojica, 2008). In examining histograms of these variables across all neighborhoods in Bogotá, the following cut points were identified for the four stratifying variables:

- Socioeconomic status (SES): low (strata 2), medium (strata 3–4), and high (5);
- Average slope (≤10% and >10%);
- Proximity to TransMilenio (≤500 m and >500 m); and

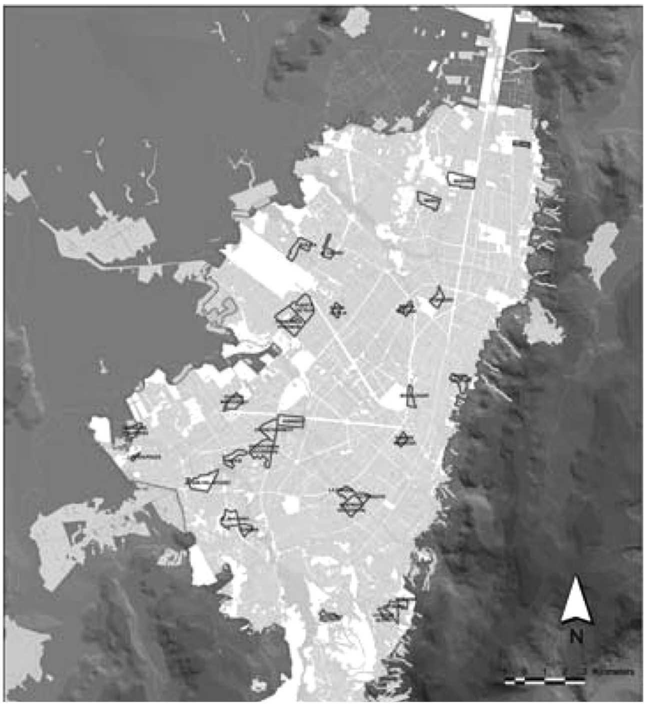

Figure 1. Locations of 30 selected neighborhoods in Bogotá.

- Public-park provisions (≤6% of total land devoted to parks; >6% of total land devoted to parks).

Once neighborhoods were sorted into groups, individual neighborhood cases were randomly selected using proportional weighted sampling. This yielded 30 representatively sampled neighborhoods, shown in Figure 1.

In the second sampling stage, five city blocks were randomly selected from all blocks within each selected neighborhood. Ten households were then randomly selected in each block. Households were included in the sample as long as there was at least one adult member who had resided in the neighborhood for a year or more. Selected households were then contacted to schedule a time to conduct interviews. All household members 18 years of age and above were later interviewed. In all, 1500 of 2000 individuals originally contacted and asked to participate in the study responded to the survey, yielding a response rate of 66.7%.

3.2. Survey Instrument

To obtain information on bicycling and walking activities among the sampled households, data from an adapted version of the IPAQ (International Physical Activity Questionnaire) survey were compiled. IPAQ was developed as an instrument for cross-national monitoring of self-reported physical activity. Research on the use of IPAQ in 12 different countries found it to be a reliable and valid instrument for compiling self-reported physical activity data (Craig et al., 2003). For our study, the long version of IPAQ was culturally adapted and evaluated through a cognitive interview technique. The Bogotá version included a diary table for each physical activity dimension expressed in minutes of duration per day. The physical activity dimensions included walking for transport (i.e., for utilitarian purposes such as going to work, school, or for groceries); biking for transport; and Ciclovía participation over the previous 4 weeks (which included four Sundays and one holiday).

The validity of the responses to the modified IPAQ questionnaire was tested using Uniaxial Computer Science and Application, Inc., accelerometers (CSA model 7164) for a subsample of the study population. From among 300 adults selected randomly from eligible households, 160 agreed to wear an accelerometer. However, only 41 of these used the accelerometer for at least 5 days and 600 or more minutes. The Spearman correlation coefficient between self-reported IPAQ responses and objective accelerometer measures was 0.42 ($p = 0.006$), which is comparable with the median value obtained by the IPAQ validation in 12 other countries (Craig et al., 2003). The reliability, assessed through test–retest procedures 1 week after the first IPAQ survey was administered, was 0.69 ($p < 0.001$), which is lower than that reported in the pooled analysis of the other 12 nations (Craig, et al., 2003).

All the questionnaires were administered through face-to-face interviews for which respondents had already given verbal consent. Only adults who wore accelerometers signed a consent form and received a report for recording their physical activity levels. Participants also received a tee-shirt as a small token of appreciation for participating in the study. All the protocols and questionnaires were reviewed and approved by the Institutional Review Board of the Universidad de los Andes in Bogotá, Colombia.

3.3. Variables and Modeling Approach

We adopted an ecological approach to modeling walking and bicycling behavior, expressing minutes of nonmotorized travel per weekday as a function of both built and natural environment attributes as well as socioeconomic, attitudinal, and policy variables (Sallis et al., 2006). For modeling purposes, levels of walking and cycling for utilitarian (e.g., non-recreational or leisure) purposes was treated as a binary variable. Specifically, we measured whether sampled adults walked or biked for utilitarian purposes at least 30 minutes per day for at least 5 days during the previous week.

Predictor variables fell into two categories: (1) those related to individuals and their households; and (2) those related to neighborhoods. Attributes of individuals (e.g, age, gender) and their households (e.g., SES [socioeconomic status], car ownership levels) were obtained from responses to the IPAQ survey. Attributes of neighborhoods pertained mainly to land-use and built environment variables and were obtained from the Cadastre Department of the City of Bogotá using Geographic Information Systems (GIS) tools.

For expressing built environments, we adopted and extended the "3D" model—density, diversity, and design—first advanced by Cervero and Kockelman (1997). Two additional "Ds" were added: distance to transit and destination accessibility, the former acknowledging how the presence of TransMilenio busway services might induce walking as a form of access and egress, and the latter expressing the degree of accessibility to activities outside of one's neighborhood. Of course, these are not unrelated variables as, after all, dense environments also tend to be diverse in their land-use makeups, often have pedestrian-oriented designs, tend to be relatively accessible to other locations, and have high levels of transit services. Because these "5Ds" are effectively overlapping Venn diagrams (Fig. 2), with a fair amount of intercorrelation among manifest variables, we first measured 39 different built-environment variables and applied factor analysis to capture common variance. The 39 variables fell into one of the 5D categories. Table 1 lists the candidate variables considered for model entry for each of the 5Ds. For the "Design" dimension, for instance, variables for neighborhood buffers included those related to amenities (e.g., park area), street design (e.g., proportion of intersections that are 3, 4, or 5 way; street network density; street connectivity indices; route directness indices; share of blocks that are quadrilateral), and pedestrian safety (e.g., accident rates).

All built-environment variables were measured for (1) 500-m buffer-rings (using straight-line distances) around the centroids of each of the randomly selected city blocks among the 30 sampled neighborhoods; and (2) larger geographic territories, comparable in size with census tracts, which extended approximately 1000 straight-line meters beyond the perimeters of sampled neighborhoods (Fig. 3). The smaller 500-m buffers captured attributes of built environments immediate to one's residence, whereas the larger 1000-m peripheral buffers reflected attributes over a longer distance for which people might be willing to occasionally walk or bicycle, such as to community parks and shopping centers. Among the 30 sampled neighborhoods, the average size of these extended peripheral buffers was 604.6 hectares, with a fairly moderate degree of variation (standard deviation = 123.6 hectares).

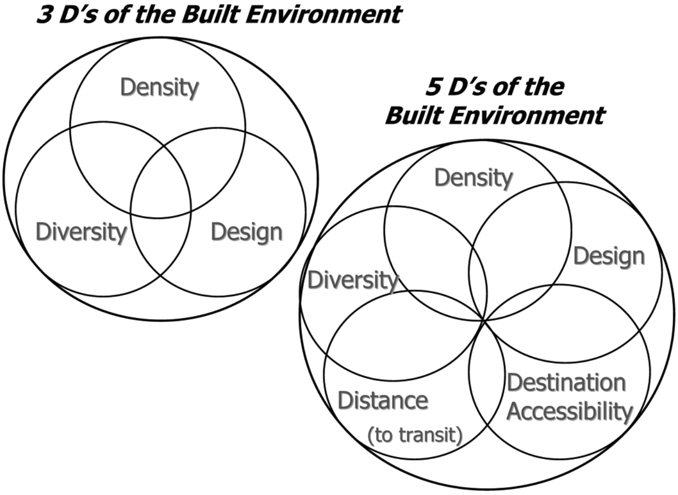

Figure 2. **Expanding from three to five "Ds" of built environments: Density, diversity, design, destination accessibility, and distance to transit.**

Table 1. Candidate variables for five built environment dimensions, measured at the neighborhood (500 m) and extended neighborhood (1000 m around perimeter) scales

Dimension	Candidate variables
Density	Dwelling units per hectare; % of land area occupied by buildings; average building floor height; plot ratio (building m^2/land m^2)
Diversity	Entropy index of land-use mix (0–1 scale); proportion of buildings vertically mixed; proportion of total floor space in buildings with 2+ uses
Design: *Amenities*	Public park area as % of total land area; average park size (hectares); % of road links with median strips; traffic light density (traffic lights/street length); tree density (trees/street length)
Design: *Site and street design*	Average lot size (m^2); quadrilateral lots as % of total; percent of blocks with contained housing and access control; street density (street area/land area); proportion of intersections with: 1 point (cul de sac), 3 points, 4 points, 5+ points; bike-lane density (lineal meters of bike lane/lineal meters of streets); route directness (0–1 scale measuring shortest street distance/straight-line distance between neighborhood centroid and 8 compass points); connectivity index (intersection nodes/street links); number of bridges; Ciclovia two-way length (lineal meters)
Design: *Safety*	Number of pedestrian bridges; pedestrian accidents per year; average automobile speeds on main streets; deaths (all types) in traffic accidents per year; number of reported crimes per year
Destination Accessibility	Number of: public schools; hospitals; public libraries; shopping centers (>500 m^2); churches; banks
Distance to transit	Number of TransMilenio (BRT) stations; shortest network distance to closest TransMilenio station; number of feeder TransMilenio stations

In all, 90 city blocks and their associated 500 m buffers were used to capture built-environment variables; these 90 blocks contained 1285 adult residents who responded to the IPAQ survey. This is less than the original sample (30 neighborhoods × 5 blocks/neighborhood = 150 blocks) because, to achieve adequate statistical power, blocks with fewer than 10 individuals were combined (based on proximity matching among blocks sharing the same buffer). The within-block sample size sizes ranged from 10 to 27 adult residents, with a mean of 14. For the larger scale units of analysis (1000 m from the periphery of neighborhoods), 27 observations were obtained that contained 1315 adult members who completed surveys. Among the 27 extended areas, sample sizes ranged from 31 to 61 surveyed individuals with a mean of 49.

In order to compute odds ratios for choice models, the built-environment variables were generally converted to binary or three-category ordinal variables. This

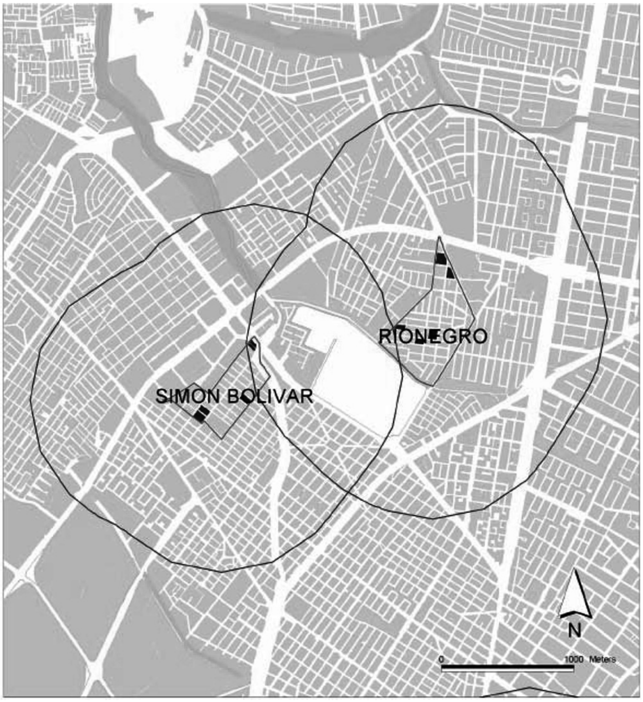

Figure 3. Example of 1000-m buffers around the peripheries of two sampled neighborhoods in Bogotá: Simon Bolivar and Rio Negro.

enabled the relative importance of different dimensions of the built environment (i.e., among the 5 "Ds") in explaining walking and bicycling choices to be compared (effectively removing the influences of measurement scales). The cut points used to categorize built-environment variables were based on tertiles or noticeable breaks in the distribution of values (as revealed by histograms). We also examined continuous measures of built environment variables using smoothed LOESS curves (e.g., robust, locally weighted regression; see Selvin, 2001), which aided in the selection of inflection points to categorize built-environment variables.

3.4. Modeling Approach

As an analysis guided by a combination of theory and exploration, a sequential approach to model building was followed. First, models that contained key control variables related to sociodemographic attributes of respondents and their households as well as attitudinal variables were initially used. Control variables with unadjusted probability values of 0.15 or below, which showed minimal signs of multi-collinearity, and whose coefficient signs matched *a priori* expectations were retained in initial models. Next, we examined whether neighborhood-scale built-environment variables added significant statistical explanatory power to person- and household-level control variables. Because of the high intercorrelations of the 39 built-environment variables (shown in Table 1) we initially tried to extract new latent variables representing each of the "5 Ds" (density, diversity, design, destination accessibility, and distance to transit) using factor analysis. After inputting factor scores for extracted factors into multilevel models, it became evident after several preliminary modeling efforts that limited numbers of the original built-environment variables yielded more interpretable and statistically better-fitting results than did factors. We opted for a backward elimination process to select built-environment variables for model inclusion using an alpha level of 0.10 to reduce the chance of eliminating important variables. Thus built-environment variables that added significant marginal explanatory powers to the control variables, were minimally correlated with each other, and that provided interpretable results consistent with theory were retained. The models that were chosen and that are presented in this paper represent the combinations of statistically significant control variables and representations of the 5Ds that were interpretable, minimally intercorrelated, and consistent with theory.

In the sections that follow, best-fitting models are presented for predicting (1) utilitarian walking (e.g., to work, school, or retail establishments); (2) utilitarian cycling; and (3) Ciclovía usage for recreational-leisure activities. Thus the first two models examine purposeful travel by foot and bicycle, based on the availability of data from IPAQ. In contrast, the third model gets at factors influencing recreational travel, specifically on reserved Ciclovía lanes. Collectively, we believe these analyses provide wide-ranging insights into the influences of built environments on walking and cycling travel in Bogotá.

For each model, we present statistics that reveal data structure, statistical significance, and goodness-of-fit. Summary statistics are presented for each sequential modeling phase: an intercept-only model; a "reduced model" with only person- and household-level control variables; and a "full model" with both control variables and neighborhood-level built-environment variables. The tau statistic discloses variance of the estimated value of the dependent variable between blocks, with higher values denoting large variation in explanatory variables, including built-environment attributes, among neighborhoods. The intra-class correlation (ICC) statistic measures the relative variation in the estimated dependent variable between and within blocks; high ICC values indicate individuals living in the same neighborhoods share built environment attributes. We also present the proportional reduction in error (PRE) for each sequential modeling step, with higher values indicating better statistical fits. In contrast, low values of the deviance statistic denote improved statistical fits. Lastly, a chi-square statistic is shown that compares model significance of the intercept-only and reduced models compared with the full model.

Table 2 presents descriptive statistics for the dependent variables and all explanatory variables that entered the best-fitting predictive models. For example, around 27% and 15% of the sample walked or biked, respectively, 30 minutes or more per weekday for utilitarian purposes, like going to work or shopping. Explanatory variables with particularly high variation among sampled neighborhoods (based on standard deviation statistics relative to means) included Ciclovía length, presence of a nearby TransMilenio station, car ownership, education, slope, and death rates, in addition to the three dependent variables. We note other attributes of the sample that are not presented in the table. More than half the respondents

Table 2. Descriptive statistics for dependent and explanatory variables that entered predictive models

	Mean	Standard deviation
Dependent variables		
Walking for utilitarian purposes for 30 minutes or more per day (0–1)	0.267	0.499
Bicycling for utilitarian purposes for 30 minutes or more per day (0–1)	0.154	0.361
Ciclovía use in the past four weeks (0–1)	0.098	0.298
Built-environment variables		
Connectivity index (nodes/links); 500 m buffer	2.453	0.362
Street density (road km/land area km^2); 500 m buffer	0.224	0.062
Street density (road km/land area km^2); 1000 m buffer	0.211	0.051
Ciclovía length (meters); 500 m buffer	219.1	442.2
Park density (park area/land area); 500 m buffer	0.066	0.047
TransMilenio station (0–1); 500 m buffer	0.145	0.436
TransMilenio station (0–1); 1000 m buffer	0.287	0.436
Socioeconomic variables		
Age 35 to 65 years (0–1)	0.569	0.495
Cars in household (no.)	0.208	0.406
Bicycles in household (no.)	0.558	0.497
Know how to ride bicycle (0–1)	0.675	0.468
Education (years)	0.295	0.456
Male (0–1)	0.353	0.478
Socioeconomic status (0 = 1 to 2; 1 = 3 to 5)	0.505	0.500
Other variables		
Slope of land (%); 500 m buffer	4.872	5.013
Slope of land (%); 1000 m buffer	5.602	7.620
Death rates in traffic accidents (fatalities per year; all accidents); 1000 m buffer	1.474	1.921
See others jogging/cycling in neighborhood (1 = no; 5 = high)	2.528	1.075

reported having a partner (57%) and 3 of 10 had worked or studied during the previous month. Also, walking and cycling for utilitarian purposes was more prevalent than for leisure and recreation. The mean time spent walking for work, shopping, and other utilitarian purposes over the prior 7 days was 120 minutes (standard deviation = 154 minutes). Fifteen percent of the respondents who knew how to ride a bicycle reported cycling for at least 30 minutes over the previous week and 10% indicated they had walked or cycled taken part in Ciclovía.

Several factors, we note, limit our ability to draw inferences from the sample. One, this is a cross-sectional study, therefore we cannot infer causality in a strict sense. Second, an issue that frequently comes up when modeling how built-environments influence behavior is self-selection. Do those who like to walk move to communities that are better suited for walking (Boarnet 2004)? Our study cannot rule out selection bias. Surveyed households represented neither the poorest nor wealthiest households in Bogotá, however most had modest incomes by global standards, and thus likely weigh factors other than opportunities to walk or bike when making residential location choices (e.g., factors like availability and affordability of housing). Moreover, the vast majority of sampled households had lived in their residences for a fairly long time, moving in well before improvements such as Cicloruta bikeways were introduced. The mean length of time sampled adults had lived in their current residence was 14.4 years (standard deviation = 11.6 years).

4. FACTORS INFLUENCING WALKING FOR UTILITARIAN PURPOSES

How does the built environment influence walking for utilitarian purposes, such as going to school or work, grocery shopping, or visiting a doctor, in Bogotá? A model was estimated that predicted whether someone walked more than 30 minutes per day over 5 weekdays (150 minutes) or not, expressed in binary (0–1) terms. Because the amount of weekday walking was highly skewed toward zero and there was a large gap between zero and the rest of the categories (i.e., relatively little walking for utilitarian purposes), we opted to dichotomize the variable (and thus avoid problems with a non-normally distributed dependent variable), using 30 minutes per weekday as a cut point. This 30 minute per weekday threshold was chosen in part because public health officials recommend this as a minimal daily amount of moderate-level physical activity, as reported by the U.S. Surgeon General and World Health Organization (Sallis et al., 2006). Also, predictor variables were expressed in categorical form (i.e., nominal or ordinal) in order to compute odds ratios that reflect the comparative explanatory power, free from the influences of measurement units. A best-fitting model for predicting whether someone walked 30 minutes or more per weekday for utilitarian purposes is presented in Table 3 for the 500-m buffer around the centroid of sampled block (hereafter referred to as "neighborhood-scale analysis"). This is followed by the model shown in Table 4 for the larger 1000-m buffer around the perimeter of the sampled neighborhoods (hereafter referred to as "extended-neighborhood analysis").

Because variables were measured at two levels (i.e., for individuals and neighborhoods), multilevel modeling (MLM) was used whenever the intraclass correlation (i.e., between-neighborhood variation in utilitarian walking) was above 0.03. At the neighborhood-scale level, for example, the intraclass correlation of walking 30 minutes or more per weekday was 0.065 indicating that 6.5% of the variation in reported walking is attributable to between-neighborhood differences. Overall, individual and built-environment variables accounted for 41.4% of the variation in walking at the block level. These values are high enough to justify MLM estimation (reflecting the degree of hierarchical clustering of different level variables, not the model fits). Using ordinary least squares (OLS) under such conditions violates the assumption of independence, yielding biased parameter estimates (Raudenbush et al., 2004). In addition, penalized quasi-likelihood (PQL) estimation was used in estimating the hierarchical models. PQL produces approximate Bayes estimates

Table 3. Walking for utilitarian purposes at neighborhood scale: Hierarchical nonlinear model for predicting walking for utilitarian purposes (30 minutes or more per weekday = 1; <30 minutes per weekday = 0). Level 1 (person respondents) = 1285; level 2 (500 m buffer around centroid of respondent's block) = 90

	Coefficient	***t* statistic**	**p value**	**Odds ratio (OR)**	**95% CI OR**
Built-environment variables (level 2)					
Street density (road km/land area km^2): low (<0.20)	—	—	—	1.00	—
Street density (road km/land area km^2): medium (0.20–0.25)	0.370	1.921	0.058	1.45	0.99–2.12
Street density (road km/land area km^2): high (>0.25)	0.402	1.683	0.096	1.49	0.93–2.40
Connectivity index: low (<2.5)	—	—	—	1.00	—
Connectivity index: medium (2.5–2.6)	0.692	3.908	0.001	2.00	1.41–2.84
Connectivity index: high (>2.6)	0.791	3.432	0.001	2.21	1.40–3.49
Socio-economic control variables (level 1)					
Age: young (18–35)	—	—	—	1.00	—
Age: non-young (>35)	0.349	3.216	0.002	1.42	1.15–1.76
Socioeconomic status (low: 1–2)	—	—	—	1.00	—
Socioeconomic status (medium: 3–4)	−0.496	−2.187	0.029	0.61	0.39–0.95
Cars in household (no)	—	—	—	1.00	—
Cars in household (yes)	−0.335	−2.136	0.033	0.72	0.53–0.97
Landscape control variables (level 2)					
Slope of land (<4%)	—	—	—	1.00	—
Slope of land (4% or more)	−0.858	−2.969	0.004	0.42	0.24–0.75
Constant	−1.440	−6.648	0.000	0.24	—

Summary Statistics.

Tau: Intercept-only model (0.227); reduced model (0.241); full model (0.133).

ICC: Intercept-only model (0.065); reduced model (0.068); full model (0.039).

PRE from intercept-only model: reduced model (0.266); full model (0.414).

Deviance: Intercept-only model (3848.1); reduced model (3836.1); full model (3814.1).

Significance of full model compared with: Intercept-only model ($X^2 = 33.89$, df = 8; p = < 0.001); reduced model ($X^2 = 21.89$; df = 5; p = 0.001).

of the randomly varying level 1 (person-level) coefficients, generalized least square estimates of the level 2 (area-level) coefficients, and approximate maximum-likelihood estimates of the variance and covariance parameters (Snijders and Bosker, 1999). Lastly, because interactions between built-environment variables and control variables (at the person- and household-levels) were not large or significant enough to affect coefficient estimates, all hierarchical models assumed a random-intercept form.

Table 4. Walking for utilitarian purposes at extended-neighborhood level: Hierarchical nonlinear model for predicting walking for utilitarian purposes (30 minutes or more per weekday = 1; <30 minutes per weekday = 0). Level 1 (person respondents) = 1315; level 2 (1000 m buffer around perimeter of respondent's neighborhood) = 90

	Coefficient	*t* statistic	p value	Odds ratio (OR)	95% CI OR
Built-environment variables (level 2)					
Street density (road km/land area km^2): <0.20	—	—	—	1.00	—
Street density (road km/land area km^2): $\geq$0.20	0.539	3.069	0.006	1.71	1.19–2.46
TransMilineo station: None	—	—	—	1.00	—
TransMilenio station: $\geq$1	0.541	3.056	0.006	1.72	1.19–2.47
Socioeconomic control variables (level 1)					
Age: young (18–35)	—	—	—	1.00	—
Age: non-young (>35)	0.325	2.912	0.004	1.38	1.11–1.72
Cars in household (no)	—		—	1.00	—
Cars in household (yes)	−0.331	−1.910	0.056	0.72	0.51–1.01
Constant	−1.749	−8.243	0.000	0.17	—

Summary Statistics.

Tau: Intercept-only model (0.173); reduced model (0.169); full model (0.087).

ICC: Intercept-only model (0.050); reduced model (0.049); full model (0.026).

PRE from intercept-only model: reduced model (0.442); full model (0.486).

Deviance: Intercept-only model (3927.4); reduced model (3917.6); full model (3906.5).

Significance of full model compared with: Intercept-only model ($X^2 = 20.88$, df = 4; p = 0.001); reduced model ($X^2 = 11.10$; df = 2; p = 0.004).

4.1. Neighborhood-Scale Analysis of Utilitarian Walking

For the neighborhood-scale model (shown in Table 3), two built-environment variables—street density and connectivity index—were significant predictors, marginally adding explanatory power to the control variables. (As defined previously in Table 2, street density was calculated as roadway kilometers divided by land area [km^2] within 500 m of the centroid of neighborhoods. The connectivity index was calculated as the number of nodes [i.e., intersections and dead-ends] divided by the number of road links within 500-m buffers. The larger the index, the higher the connectivity.) A high connectivity value indicates there are many route opportunities for traversing through a road network, though this is only the case in a fine-grained road network. A fine-grained grid network has high values on both the street density and street connectivity variables.

From Table 3, street connectivity was the strongest predictor among built-environment variables. A high connectivity index (over 2.6) increases the odds of walking 30 minutes or more per weekday for utilitarian activities by 2.21 relative to a low index (under 2.25). A dense street network also increases the likelihood of walking, though less so than connectivity (and, we note, the variable was not statistically significant at the 0.05 probability level). All else being equal, someone living in a neighborhood with a dense street network (>0.25 road km/land area km^2) was 49% more likely to walk 30 minutes or more per weekday than someone residing in a sparse street network setting (<0.20).

It is noteworthy that only two aspects of the "Design" component of the 5 Ds entered the model. None of the measures of density, diversity, distance to transit, or destination accessibility provided significant marginal explanatory power when expressed at the neighborhood scale.

Table 3 also shows that walking for work, shopping, and other utilitarian purposes was highest for Bogotá residents at the midstages of the life cycle and older (i.e., 35 years and higher). A steeper topography, cars in the household, and a higher socioeconomic standing appeared to discourage utilitarian walking, controlling for other factors.

The summary statistics shown in Table 3 reveal model improvement over the three sequential modeling phases. Potential biasing effects due to nonindependence of person-level variables are reduced through MLM as revealed by the declining tau and ICC statistics from the intercept-only to the reduced model to the full model steps. Moreover, the full model containing built-environment variables reduce errors in predicting outcomes relative to the intercept-only model by 41%. Lastly, the deviance statistic is lowest for the full model, and based on the chi-squared statistic, the full model is statistically more significant than the intercept-only model.

4.2. Extended-Neighborhood Analysis of Utilitarian Walking

When expressing built-environment variables at the larger sector scale, a leaner model (i.e., with fewer predictor variables) was obtained (Table 4). Whereas street density again was a significant predictor (expressed as a simpler low-high dichotomous variable), street connectivity was not. Instead, a measure of another "D" variable—"distance to transit"—emerged as a significant predictor at the sector scale. Specifically, having one or more TransMilenio busway stations within the 1000-m buffer of one's neighborhood periphery increased the odds of walking 30 minutes or more per day for utilitarian purposes by 72% relative to those living in an area without a TransMilenio station. Thus, though Bogotá's celebrated TransMilenio busway confers numerous environmental and mobility benefits, it also appears to provide a public health benefit—specifically, inducing more walking per day, controlling for socio-economic factors like age and car ownership. This finding conforms with recent research by Rundle et al. (2007) showing body mass index (BMI) was negatively associated with bus-stop and rail-station densities in New York City. Lastly, the socioeconomic controls shown in Table 4 had similar influences on utilitarian walking as with the neighborhood-scale analysis shown in Table 3.

Again, summary statistics reveal improvements through hierarchical estimation of the full model relative to the intercept-only and reduced models. The full model reduces estimation errors by nearly 50% relative to the intercept-only model, which based on the chi-square output is statistically significant at the 0.001 probability level.

5. FACTORS INFLUENCING BICYCLING FOR UTILITARIAN PURPOSES

A parallel analysis was carried out on factors influencing bicycle use for utilitarian purposes. Given the appreciable amount of investment made in

Table 5. Bicycling for utilitarian purposes at extended neighborhood level hierarchical nonlinear model for predicting walking for utilitarian purposes (30 minutes or more per weekday = 1; <30 minutes per weekday = 0). Level 1 (person respondents) = 830; level 2 (1000-m buffer around perimeter of respondent's neighborhood) = 27

	Coefficient	***t* statistic**	**probability**	**Odds ratio (OR)**	**95% CI OR**
Built environment variables (level 2)					
Street density (road km/land-area km^2): low (<0.20)	—	—	—	1.00	—
Street density: medium-high (0.20 or more)	0.689	3.024	0.007	1.99	1.24–3.19
Street safety (level 2)					
Death rates in traffic accidents (fatalities per year): 0–10	—	—	—	1.00	—
Death rates in traffic accidents (fatalities per year): >10	−0.746	4.098	0.001	0.47	0.32–0.69
Socioeconomic control variables (level 1)					
Woman	—	—	—	1.00	—
Male	1.955	9.924	0.000	7.07	4.80–10.40
Age: young (18–35)	—	—	—	1.00	—
Age: mid-lifecycle and senior (>35)	−0.570	3.184	0.002	0.56	0.40–0.80
Education level (high school or less)	—	—	—	1.00	—
Education level (post-high school)	−0.477	2.052	0.041	0.62	0.39–0.98
Cars in household (no)	—	—	—	1.00	—
Cars in household (yes)	−0.854	3.665	0.000	0.43	0.27–0.67
Landscape control variable (level 2)					
Slope: ≤3%	—	—	—	1.00	—
Slope: >3%	−1.736	3.858	0.001	0.18	0.07–0.45

Summary Statistics

Tau: Intercept-only model (0.446); reduced model (0.510); full model (0.100).

ICC: Intercept-only model (0.119); reduced model (0.134); full model (0.029).

PRE from intercept-only model: reduced model (0.661); full model (0.806).

Deviance: Intercept-only model (2314.6); reduced model (2296.4; full model (2,205.9).

Significance of full model compared with: Intercept-only model ($X^2 = 108.0$, df = 6; $p < 0.001$); reduced model ($X^2 = 90.5$; df = 3; $p \leq 0.001$).

dedicated bicycle lanes (Cicloruta programs) in Bogotá, we expected the accessibility to these facilities to have a significant bearing on cycling behavior. For expressing built environment attributes that might influence cycling, we opted to examine relations at the extended-neighborhood level (i.e., for the buffer area 1000 m around the perimeter of each sampled household's neighborhood). This produced a geographic area that was, on average, around six times larger than the 500-m buffers used to study utilitarian walking.

Table 5 presents the best-fitting multilevel model for predicting cycling for utilitarian purposes, revealing model improvements from an intercept-only form, to a reduced model with only person-level control variables, to a full model that includes built-environment variables. For this analysis, we only included adults who reported that they know how to ride a bike, which reduced the sample size to 830 adults. The only built-environment variable that added significant marginal explanatory power to control variables was street density. The model reveals that a Bogotá resident is nearly twice as likely to cycle for utilitarian purposes 30 minutes or more per weekday in a setting with relatively high street densities (i.e., road km/land-area km ≥ 0.20) than in a low street density setting. Surprisingly, bike-lane density (i.e., bike-lane km/land-area km^2) did not significantly influence utilitarian cycling. Neither did a variable capturing bike-lane completeness nor any of the other remaining 36 built-environment variables that were candidates for model entry. The absence of variables related to cycling infrastructure is partly due, we believe, to the small sample. The coefficient of the bike-lane density variable was positively related to utilitarian cycling, however the small sample size rendered this variable statistically insignificant, thus it is excluded from the final model. Follow-up research based on a larger sample is needed to better evaluate the influence of Bogotá's bike lanes and other cycling infrastructure on bicycle travel.

Table 5 shows that high fatality levels was a significant deterrent to utilitarian cycling in Bogotá. The odds ratio drops by more than 50% if fatalities per year (motorists and nonmotorists) exceed 10 (versus under 10). Cycling to work, school, shopping, and other non-recreational activities is lower for women and drops with age, car ownership, and education level. Steep topography also deters cycling, consistent with the findings of other researchers (Troped et al., 2001). Although we did not use it as an explanatory variable in Table 5 because of missing observations, the strongest single correlate of utilitarian cycling is the availability of a bike in a household. Increasing bicycle ownership or access could very well promote utilitarian cycling at least as much as building cycleways or making other changes to the built environment.

6. FACTORS INFLUENCING CICLOVÍA USE

As noted, Bogotá has one of the longest standing and most extensive programs for closing off major thoroughfares to cars on Sundays and national holidays, giving them over to cyclists, runners, strollers, in-line straters, and any other form of "nonmotorized" movement. Bogotá's Ciclovía initiative has since been mimicked in other cities of Latin America, including Rio de Janeiro and Santiago. On Sundays, Ciclovía is the largest linear park in the world. Surveys reveal around half of Ciclovía users are on bicycle or roller-skates and the other half are on foot (moving at a variety of speeds).

Applying the same modeling approach used to predict utilitarian walking and cycling, we investigated the degree to which the 5 Ds of the built environment influenced Ciclovía use. The specific question asked on the IPAQ questionnaire was: "Have you used Ciclovía within the past four weeks"? Because the intraclass correlation for Ciclovía use among study areas was low (0.030) and statistically insignificant, multilevel modeling was unnecessary. Instead, a logistic regression equation was estimated using the maximum likelihood techniques. Because of the general willingness of cyclists and recreationists to travel longer distances, built-environment variables were expressed for 1000-m buffers around the perimeters of sampled neighborhoods (i.e., at the extended-neighborhood level), as in the previous analysis.

Table 6 presents the best-fitting model for predicting Ciclovía activities. The rho-square Nagelkerke statistic, interpreted similar to the traditional R-square statistic in a multiple regression model, reveals a moderate fit that is statistically significant (based on the chi-square statistic).

Table 6 shows that bicycle facilities clearly matter. Having 1000 m or more of Ciclovía lanes within one's extended neighborhood increases the odds of using Ciclovía at least once a month relative to having no Ciclovía lanes nearby. This aligns with the findings of other research showing that proximity to trails and bikeways induces cycling and other forms of physical activity (Vernez Moudon et al., 2005; Krizek and Johnson, 2006; Tilahun et al., 2007).

The only other built-environment-related variable with reasonably good predictive powers that entered the model captured the presence of public parks. However, park density worked against Ciclovía use. Evidently, having a lot of public parks nearby reduces the need to exercise by using Ciclovía streets. As with the other two analyses of nonmotorized transport, Table 6 is also notable for the absence of other built-environment variables—specifically those related to urban density, land-use mixture, distance to transit, or destination accessibility.

Statistical models are useful for understanding relationships between urban environments and travel, and so are simple comparisons. Figure 4 contrasts two neighborhood settings. The neighborhood shown in the lower left-hand panel averaged fairly high Ciclovía participation among adult residents—it also had a central Ciclovía pathway and comparatively few public parks nearby. By contrast, the neighborhood shown in the lower right-hand panel had relatively little Ciclovía usage; despite having bikeways nearby, the presence of plentiful nearby public parks likely reduced the importance of Ciclovía as a recreational outlet.

Table 6 shows that a variable suggestive of an active neighborhood (i.e., "seeing others jogging and cycling in the neighborhood") induces Ciclovía use. Because people are known to socialize more and become more physically active in compact, mixed-use neighborhoods, this variable could be a proxy for walking-friendly places. Social support has been shown by others to be a significant determinant of physical activity over a range of diverse populations (Brownson et al., 2001; Ainsworth et al., 2007). The significance of this variable also lends support to the arguments of Robert Putman regarding the importance of walking-friendly

Table 6. Use of Ciclovía in the past 4 weeks: Logistic regression model

Dependent Variable: Have you used Ciclovía within the past 4 weeks (1 = yes; 0 = no)	**Coefficient**	**Wald statistic**	**Probability**	**Odds ratio(OR)**	**95% CI OR**
Built environment variables					
Ciclovía length (meters): 0 m	—	—	—	1.000	—
Ciclovía length (meters): 1–999 m	0.565	3.73	0.053	1.759	1.41–2.19
Ciclovía length (meters): 1000+ m	0.780	4.364	0.037	2.181	1.85–2.57
Park density (park area/land area): low (<0.04)	—	—	—	1.000	—
Park density (park area/land area): medium (0.04–0.08)	−0.448	2.638	0.104	0.639	0.42–0.86
Park density (park area/land area): high (>0.08)	−0.722	3.882	0.049	0.486	0.36–0.61
Social capital					
See others jogging/cycling in neighborhood: no/little	—	—	—	1.000	—
See others jogging/cycling in neighborhood: medium-high	0.545	30.508	0.000	1.725	1.58–1.93
Socioeconomic control variables					
Woman	—	—	—	1.000	—
Male	0.742	12.708	0.000	2.099	1.92–2.26
Cars in household (no)	—		—	1.000	—
Cars in household (yes)	−0.714	7.324	0.007	0.490	0.41–0.57
Bicycles in households (no)	—	—	—	1.000	—
Bicycles in household (yes)	1.174	22.1978	0.000	3.235	2.88–3.53
Know how to ride bike (no)	—	—	—	1.000	—
Know how to ride bike (yes)	1.123	11.578	0.001	3.075	2.86–3.29
Landscape control variables					
Slope of Land (<4%)	—	—	—	1.000	—
Slope of Land (4% or more)	−0.567	4.028	0.045	0.567	0.36–0.77
Constant	−4.943	95.724	0.000	0.007	0.006–0.008

Summary Statistics
Chi- (probability) = 148.1 (0.000).
Rho-square (Nagelkerke) = 0.238.

places in encouraging community engagement (which one could argue Ciclovía usage is a form of) (Putman, 2000).

Among the other "control" variables in the model, Table 6 reveals that Ciclovía activities are higher for males and those who own a bicycle. It declines with cars in households and a steep terrain. Owning and knowing how to ride a bike were

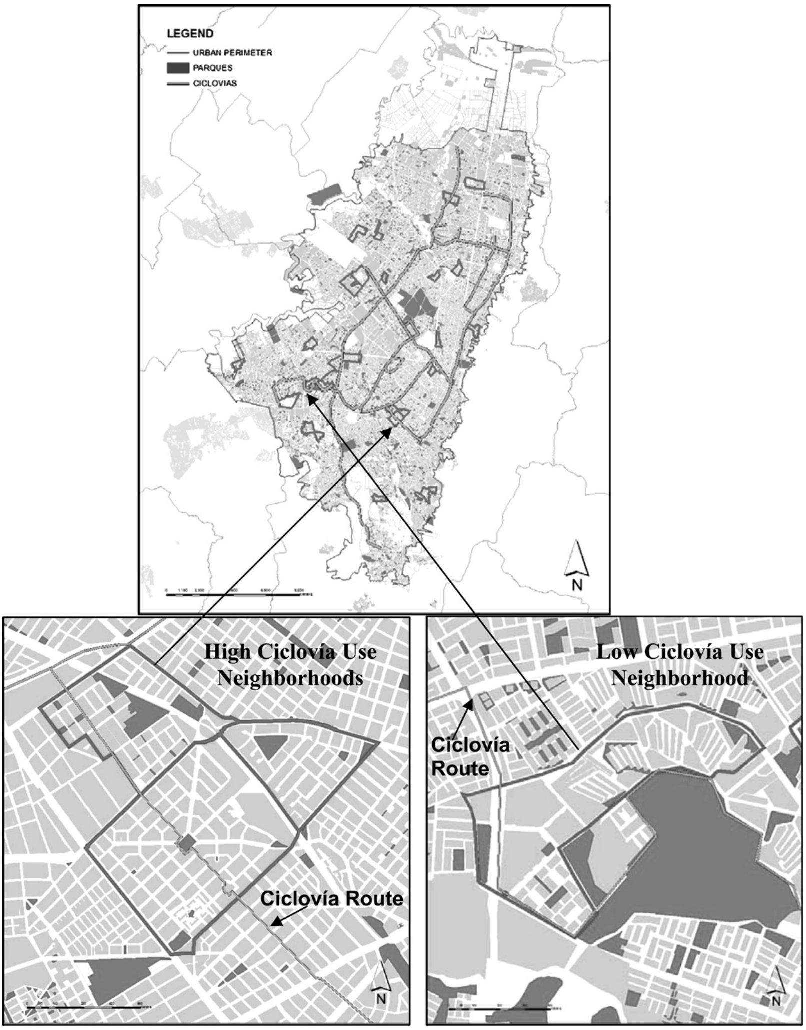

Figure 4. **Neighborhood comparisons of Ciclovía use. Top: Ciclovía routes and study neighborhood. Left bottom: High-use neighborhood (central bikeway and comparatively few parks). Right bottom: Low-use neighborhood (peripheral bikeways and plentiful park opportunities).**

the strongest predictors of Ciclovía usage. Thus, providing micro-credit for the purchase of bicycles as well as basic training on how to ride them might be one way to stimulate physical activity among Bogotá residents. Opening up more Ciclovía lanes throughout the city is another. However, based on the results of our study, changing the density and land-use pattern of the city would likely have a modest impact on recreational cycling, walking, and other Ciclovía activities.

7. CONCLUSION

Whereas in the developed world and notably the United States, density and diversity of land uses have been found in numerous studies to influence travel demand (Ewing and Cervero, 2001), this was not the case in Bogotá. Neither were the other "Ds"—destination accessibility and distance to transit (with the exception this latter factor had some influence on utilitarian walking when measured at the extended neighborhood level). This could reflect the fact that compact neighborhoods with mixes of housing, shops, and other uses are commonplace in Bogotá. Any Bogotá neighborhoods also have good access to transit stops and generally have comparable levels of accessibility to subregional destinations like shopping plazas, schools, and medical facilities. With little appreciable variation, the influences of density, land-use diversity, and the other "Ds" on non-motorized travel failed to achieve statistical significance.

What did have some influence on utilitarian travel were street designs—specifically, street density, and in the case of cycling, route connectivity as well. And for recreational activities, having reserved lanes for bicycles and foot travelers reasonably close to one's residence encouraged Ciclovía usage. Clearly, the most important leverage that urban designers and planners have over walking and cycling in Bogotá is in the design and (in the case of Ciclovía) regulation of streets. The configuration, connectivity, and density of streets matter. Other built-environment factors (e.g., urban densities, land-use mix, and destination accessibility) do not.

Our findings perhaps have the greatest implications for new-town development. Like most rapidly growing cities, Bogotá's periphery is rapidly being carved up into new subdivisions and tract housing. To promote active transportation (i.e., walking and cycling), particular attention should be given to street designs and layouts that create dense networks with high connectivity. Grid-street patterns and the platting of land into small blocks (e.g., 40 m × 40 m) produce dense, highly connected networks. The reality, however, is that most suburban development in Bogotá, especially subdivisions that cater to professional-class residents, are unabashedly car-oriented in their designs—superblocks with a sparse network of curvilinear streets. Of course, following the traditional patterns of the older, built-up parts of the city—specifically, compact, mixed-use development—is likely also important in encouraging nonmotorized travel. The fact that these variables did not show up as significant in our predictive models does not mean that their absence will have no influence on nonmotorized travel. It is the uniformly compact, mixed-use nature of the neighborhoods that we sampled in Bogotá that produced little statistical variation and thus non-significant results. But segregating activities by long distances and designing suburbs at very low densities, coupled with car-oriented street designs, would no doubt significantly reduce nonmotorized travel.

Our research also makes a case for extending the network of dedicated Ciclovía lanes on Sundays and holidays to many areas of the city, including newly suburbanizing ones. Whereas this might have little impact on traffic congestion or even air quality, the contributions toward promoting physical activity and a fit lifestyle could be significant. Ciclovía, we note, is hardly a novelty. It has been in existence since 1980. Moreover, it would be wrong to think of Ciclovía as an "amenity" or "frill." Just as motorists need safe and reliable facilities to drive, recreational cyclists, joggers, pedestrians, and in-line staters need lanes and areas dedicated to their activities.

As cities of the developing world increasingly mimic the car-oriented settlement patterns of modern, first-world cities, there becomes a greater likelihood that the same kinds of chronic diseases and obesity problems associated with physical inactivity in the United States and other car-based societies will arise. One study found that Chinese men averaged a weight gain of 1.82 kg within a year for every car they purchased versus a weight loss of 0.57 kg for each bicycle acquired (Bell et al., 2002). The public health implications of rapidly growing cities becoming more automobile-oriented in their designs need to be seriously weighed.

Whether our research findings are generalizable to other large cities in the developing world is an open question. We believe they are, although not everywhere. In hot, humid mega-cities of southeast Asia, some might avoid walking and cycling during much of the year regardless how pedestrian- and bike-friendly cities might be. In cities situated in more temperate climates like Bogotá, the insights gained from this research are likely more transferable. We hope similar research is conducted elsewhere to see if this indeed is the case.

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