TransMilenio, a Scalable Bus Rapid Transit System for Promoting Physical Activity

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ABSTRACT *Transport systems can play an important role in increasing physical activity (PA). Bogotá has been recognized for its bus rapid transit (BRT) system, TransMilenio (TM). To date, BRTs have been implemented in over 160 cities worldwide. The aim of this study was to assess the association between PA and the use of TM among adults in Bogotá. The study consists of a cross-sectional study conducted from 2010 to 2011 with 1000 adults. PA was measured using the International Physical Activity Questionnaire. In a subsample of 250 adults, PA was objectively measured using ActiGraph accelerometers. Analyses were conducted using multilevel logistic regression models. The use of TM was associated with meeting moderate-to-vigorous PA (MVPA). TM users were more likely to complete an average of >22 min a day of MVPA (odds ratio [OR] = 3.1, confidence interval [CI] = 95 % 1.4–7.1) and to walk for transportation for ≥150 min per week (OR = 1.5; CI = 95 % 1.1–2.0). The use of TM was associated with 12 or more minutes of MVPA (95 % CI 4.5–19.4, $p < 0.0001$). Associations between meeting PA recommendations and use of TM did not differ by socioeconomic status (p value = 0.106) or sex (p value = 0.288). The use of TM is a promising strategy for enhancing public health efforts to reduce physical inactivity through walking for transport. Given the expansion of BRTs, these results could inform the development of transport PA programs in low- to high-income countries.*

KEYWORDS *Physical activity, Walking, Transportation, Bus rapid transit*

INTRODUCTION

Physical inactivity (PI) is associated with at least 5.3 million deaths per year. If PI were decreased by 25 %, over 1.3 million deaths could be prevented every year¹ in mostly low- and middle-income countries.² Governments and health professionals are therefore being encouraged to promote physical activity (PA) and prevent noncommunicable diseases (NCDs).³

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Transportation infrastructure and active transport could play an important role in decreasing PI.^{4,5} Active travel modalities such as walking are associated with reductions in cardiovascular risk, type 2 diabetes, obesity, and cancer and improvement in overall fitness.^{6,7} Accumulating short periods of PA by walking for transportation contributes to meeting PA recommendations.^{6,8,9}

Studies on accessibility, the use of public transportation, and PA have shown inconsistent results. In addition, most studies have assessed only accessibility instead of use and have been conducted in cities in high-income countries.¹⁰ On the one hand, positive associations have been found between public transit accessibility and walking for transportation.¹¹ Specifically, walking for transport has been associated with accessibility to bus rapid transit (BRT) stations in Curitiba¹² and Bogotá,^{13,14} the use of trains in New Jersey,¹⁵ accessibility to transit stops in Atlanta,¹⁶ and in public transport use in Australia.¹⁷ On the other hand, studies assessing the perception of distance to public transit in 11 countries showed positive, negative, and null associations.¹⁸ Specifically, no studies relating the use of BRT by sex and socioeconomic status (SES) to PA, measured objectively, have been conducted in Latin America.

BRT and bus priority corridors have been implemented in 160 cities across the globe, with more than 4000 km serving 29 million passengers per day. Bus priority corridors include segregated lanes that are physically separated (e.g., by paint, curbs, or fences) from traffic and pedestrians.¹⁹ The BRT scalability process can be partly attributed to its low cost, rapid implementation, and impact on mobility.²⁰ The TransMilenio (TM) system in Bogotá is a BRT referent for planners and practitioners worldwide.²¹ Before 2000, the public transport services in Bogotá were offered by small-vehicle owners with little supervision by the city. Old public transportation buses do not have stops; instead, they drop and pick up passengers everywhere, and thousands of routes exist. The result of this situation was an ample supply of public transportation at a relatively low cost, though it has highly negative impacts on congestion, air pollution, and road traffic incidents. In response, the city implemented an organized system with BRT-segregated lanes and feeder routes, called TM, which was expected to contribute to mobility in the city by significantly decreasing traffic congestion and travel times.²² Several evaluations of the impact of the TM system have shown these benefits.^{20,23} According to Hidalgo et al.,²⁴ the first two phases, comprising 84 km of the BRT network and 663 km of feeder routes and serving 1.7 million passengers per day (in 2011), resulted in the equivalent of US\$3.1 billion in societal benefits from 2000 to 2008 (using a 12 % discount rate). These benefits came from travel-time savings for transit users, savings on the operation of traditional buses removed from service, and reductions in deaths and illnesses due to a reduction in air pollution and increased traffic safety.²⁴ However, these estimates did not include benefits from increasing PA.

We hypothesized that PA for transport could be associated with TM use possibly because TM is the fastest mode of transport, it has fixed stations, and its implementation is related to built-environment transformations. A commercial speed of 28 km/h allows for major time savings, especially on long trips,²⁴ as a result of the combination of dedicated lanes with large stations with level access to the buses through multiple doors and overtaking lanes that are used by a combination of express and local services. TM construction is also associated with improved walking infrastructure (pedestrian bridges and wider sidewalks).²⁵ These factors together may attract users to walk longer distances to access BRT stations rather than other available modes of transportation.

In 2012, TM was expanded to 106 km, and in 2013, TM was moving close to two million passengers per day.¹⁹ The initial plans included the construction of 388 km of BRT corridors, with an 85 % spatial coverage of the city by 2016 (if a 500-m influence zone on each side of the corridors is assumed).²³ The plan is advancing at a slower pace than originally envisioned, as only 27 % of the system planned in 2000 was in operation by 2013. Currently, Bogotá has three public transit systems that coexist. TM is a BRT with exclusive corridors, stations, and feeder routes. SITP is a centralized bus system generally lacking any priority corridors with stops and transfers to BRT, and the old public transportation buses that stop everywhere do not take a payment card and are not connected to TM. Nevertheless, TM is expected to continue expanding over the upcoming years, by adding 34 km to the system over the next 3 years, with complementary investments in rail transit and cable cars.²⁶ Therefore, the aim of this study is to assess the association between the use of TM and PA using a cross-sectional study.

METHODS

Setting

The study was conducted in Colombia's capital city, Bogotá, which has an estimated population of 7.4 million²⁷ and a motorization rate of 163 vehicles per 1000 inhabitants.²⁸ In Bogotá, 41 % of the trips that are 15 min or longer are made using public transport, 28 % are made on foot, 14 % are by automobile, 5 % are by bicycle, and the remainder uses other modes of transportation.²⁸

Study Design

The cross-sectional study was conducted in 2010–2011 as part of the Colombian component of IPEN (International Physical Activity Environment Network), a collaborative network of researchers studying the associations between PA and the built environment in 12 countries.²⁹ The study used a multistage stratified sampling design. Bogotá has 120 official neighborhoods that are roughly equivalent to census tracts in size. First, a representative sample was taken of 30 neighborhoods that were stratified by socioeconomic status of low (strata 1–2), medium (strata 3–4), or high (5); the average slope of the terrain (≤ 10 and ≥ 10 %); proximity to TM stations (≤ 500 and ≥ 500 m); and public park provision (≤ 6 % of total land devoted to parks; ≥ 6 % of total land devoted to parks) (see Fig. 1).¹³ Next, five blocks were randomly selected within each neighborhood, and within each block, 10 households were randomly selected. In each household, one adult was systematically surveyed. If the selected adult did not answer the survey, then a replacement adult was chosen from the next house.

Data Collection

The survey data were collected through face-to-face interviews with subjects who lived in the household for at least 1 year, were between 18 and 74 years old, and had no physical or cognitive disabilities. All of the protocols and questionnaires were reviewed and approved by the Institutional Review Board of the Universidad de los Andes in Bogotá.

FIG. 1 The fitted model for each group (users and nonusers of TM [2010–2011]) used a Poisson distribution with a logarithmic link function. The MVPA minutes were calculated for each time of day using accelerometer data. The sample included 466 days for TM users and 1359 days for non-TM users.

Physical Activity Measurements

Subjective Physical Activity Measurements PA was measured using the long version of the International Physical Activity Questionnaire (IPAQ),³⁰ a validated self-report measurement tool.³¹ The PA dimension assessed was walking for transport (meeting the weekly PA recommendation of ≥ 150 min/week vs. walking ≤ 150 min/week).

Objective Physical Activity Measurements Objective measures provide a more accurate measurement of PA frequency and intensity, particularly when walking. PA was also measured objectively in a subsample of 250 participants from the study. The inclusion criteria for this analysis were the same as those used for the questionnaire with one addition, that is, having no plans to travel in the next week. These participants, who were evenly distributed by neighborhood, were asked to wear accelerometers (model GT3X ActiGraphTM, Pensacola, CA) 12 h a day for 7 days, except when sleeping, showering, or swimming.

In accordance with the IPEN study protocol, all accelerometer data were stored in 60-s epochs and were scored using MeterPlus 4.2 based on Freedson's cutoff points for adults.³² The intensity of moderate-to-vigorous activity corresponded to ≥ 1952 counts per minute. The results were considered valid if the participants wore the accelerometer for at least 10 h per day for 5 days. If not, they were asked to re-wear the device for the days needed to comply with the measurement requirements. An hour was considered invalid if any time zero PA was recorded for 60 min. The cutoff point used with the accelerometer data, which served as the objective PA outcome for this study, was an average moderate-to-vigorous physical activity (MVPA) per day of more than 22 min, equivalent to meeting the weekly PA recommendation of ≥ 150 min/week.

Independent Variables

Main Exposure To assess the association between PA and use of TM, the participants were asked whether they had used TM within the last 7 days. Those who reported using the TM within the last 7 days were classified as users of TM.

Individual Covariates To account for characteristics that may influence PA,³³ we assessed individual variables, including sex, age, marital status, education, monthly household income, neighborhood SES, occupation over the last 30 days, years of residency in the neighborhood, and motorcycle and car ownership, as potential confounders. The study also evaluated the modes of transportation and minutes spent on each mode (public bus, TM, feeder bus, car, taxi, motorcycle, and others) over the previous 7 days. Additionally, we used the variable time of day to study the curvilinear relationship among MVPA minutes per hour of TM users and nonusers (using accelerometer data).

Neighborhood-Level Covariates The built-environment (BE) characteristics were the slope of the terrain; the presence of public park(s); proximity to TM, which was calculated as having a TM station within a 500-m buffer around the centroids of

each of the selected city blocks among the sampled neighborhoods; and walkability index.

In line with the IPEN protocol, geographic units were classified according to the walkability score derived as a function of the z -score of four variables, which was calculated using the following function:

$$WS = 2 \cdot Z_{id} + Z_{nrd} + Z_{lum} + Z_{rfar}$$

³⁴where WS is the walkability score; Z_{id} is the intersection density (i.e., the connectivity of the street network measured as the ratio of the number of intersections with three or more legs to the land area of the administrative unit); Z_{nrd} is the net residential density (i.e., ratio of residential units to the land area devoted to residential use); Z_{lum} is the land-use mix (diversity of land-use types per block), whose normalized scores ranged from 0 (single use) to 1 (an even distribution of area across several use types, including residential, retail, entertainment, office, institutional); and Z_{rfar} is the retail floor-area ratio (i.e., the ratio of retail building floor area to retail land area). According to the walkability index, neighborhoods were classified into high and low walkability using the median split. The data for BE characteristics were collected from Bogotá's Planning Department, its Cadaster's 2010 digital map, the Corporation of Universities in the Center of Bogotá, and the Universidad Jorge Tadeo Lozano. All of the GIS variables were generated using ArcGIS 9.3 (ESRI, Inc., Redlands, CA, USA).

Statistical Analyses

Statistical Analysis Our analytic strategy involved four steps. First, we evaluated the relation between accessibility and TM. Second, we conducted bivariate analyses to assess the association between ≥ 150 min/week of walking for transportation and sociodemographic characteristics, BE characteristics, and transportation patterns. Third, we evaluated the collinearity between independent variables using Spearman correlation coefficients and variance inflation factors (VIF). Finally, we employed a multilevel multivariate logistic model to measure the association between TM and walking for transportation for ≥ 150 min/week. To assess interactions by sex and SES, the terms sex*TM use and SES*TM were included in the multivariable models. For the main effects for all of the models and the interaction effects, we used p values of 0.05 and 0.10 to determine statistical significance.

Subsample of Adults with Objective Physical Activity Measures For the subsample of adults who wore accelerometers ($N=250$), the analytic strategy involved the following steps: (i) identifying the differences in sociodemographic characteristics between the overall sample and the accelerometer subsample; (ii) assessing the differences in MVPA minutes between TM users and nonusers; (iii) evaluating effect modification by sex and SES, through the interaction terms sex*TM use and SES*TM use included in the multivariable models; and (iv) comparing MVPA minutes throughout the day between users and nonusers. These comparisons were conducted using the generalized additive model (GAM) function of the MGCV package in R version 3.0.1 (R Foundation for Statistical Computing) with a smooth covariate function of the covariate (time of day) for each group. A GAM was used because this model can estimate complex curvilinear relationships of unknown form among a dependent variable, a set of covariates, and/or smooth functions of a set of

covariates. A detailed description of the GAM is available elsewhere.³⁴ The covariate “time of day” is a measure that is derived from the accelerometer-based PA measures. The accelerometer data allows the calculation of the MVPA minutes that a participant has during the different hours of a day. We used a smooth function of this covariate because we are interested in understanding the curvilinear relationship among the MVPA minutes per hour of TM users and nonusers and the time of day. We fitted the GAM to the data using a Poisson distribution with a log link function and used thin-plate regression splines to estimate a smooth function.³⁵ The model structure used for users and nonusers was

$$\text{Log}\{u_i\} = f(x_i) + \epsilon_i$$

where $u_i = E(y_i)$ and $y_i \sim \text{Poisson}$. y_i is the MVPA minutes throughout the day, x_i is the time of day, f is a smooth function of the covariate x_i represented using a thin-plate regression spline basis, and ϵ_i are i.i.d. $N(0, \sigma^2)$ are random variables.

RESULTS

Subjective PA

Individual Characteristics The survey was administered to 1000 participants, with an overall response rate of 56.6 %. Of these 1000 participants, 63.7 % were female. The mean age was 41.1 (SD 14.52), 34.3 % were single, 53.1 % were married or partnered, and 12.6 % were divorced, separated, or widowed. In terms of education, 39.0 % had a technical, college, or graduate degree. Nevertheless, 47.6 % of the participants reported a household income of less than US\$350 per month, and 49.0 % reported living in a low-SES area. Forty-eight point three percent of the sample reported being employed, and 48.1 % named “working” as their principal activity in the last 30 days. The mean length of residence in the neighborhood was 15.5 years (SD 12.6). The sociodemographic characteristics resemble Bogotá’s characteristics in terms of neighborhood SES. However, the participants in the study were more likely to be female, married, more educated, and older (Table 1).

Transportation Characteristics Although 31.9 % of the participants reported family car ownership, with 15.4 % having two or more cars, the most frequently used mode of transportation over the last 7 days was public bus (68.1 %), followed by car (33.2 %) and TM (29.3 %). The median minutes and days per week for use of each mode of transportation were 240 min over 3 days for the bus, 180 min over 2 days for the car, and 120 min over 2 days for TM (Table 2).

Association between accessibility to TM and TM use Among the 23.9 % of those who live in a block within 500 m of a TM station, 46 % reported using TM. Among the 76.1 % of those who live farther than 500 m from a TM station, 23.8 % reported using TM. Participants with accessibility to TM were more likely to report using TM (odds ratio [OR] 2.0, 95 % confidence interval [CI] 1.4–2.8). Furthermore, TM users were more likely to live more than 500 m from a station. In fact, of the 29.3 % of TM users, 61.8 % live more than 500 m from a station.

Association between Walking for Transportation and TM Use Approximately half of the participants reported walking ≥ 150 min/week for transportation (Table 1).

TABLE 1 Sociodemographic and neighborhood characteristics, physical activity outcomes, and modes of transportation

	General population (<i>n</i> = 1000)			Accelerometer subsample (<i>n</i> = 250)		
	<i>n</i>	%	SD	<i>n</i>	%	SD
Sociodemographic characteristics						
Sex						
Male	363	36.3		170	68.0	
Female	637	63.7		80	32.0	
Age, years						
18–30	298	29.8		28	11.2	
31–40	185	18.5		48	19.2	
>40	517	51.7		174	69.6	
Marital status						
Single	343	34.3		51	20.4	
Married/partnered	531	53.1		151	60.4	
Divorced/separated/widow	126	12.6		48	19.2	
Education level						
Less than elementary and elementary	189	18.9		68	27.2	
High school	421	42.1		100	40.0	
Technical/college/graduate	390	39.0		82	32.8	
Other (looking for a job and retired)	83	8.3		19	7.6	
Monthly household income						
Less than US\$350	435	47.6		142	59.2	
US\$350–1000	350	38.3		73	30.4	
More than US\$1000	129	14.1		25	10.4	
Neighborhood SES						
1–2 strata	493	49.3		136	54.4	
3–5 strata	507	50.7		114	45.6	
Principal activity during the last 30 days ^a						
Working	481	48.3		131	52.4	
Working and studying or studying	152	15.3		11	4.4	
Home activities	280	28.1		89	35.6	
Other (looking for a job and retired)	83	8.3		19	7.6	
Years of residency in the neighborhood						
Mean	1000	15.5	12.6	250	19.2	12.6
Physical activity and health outcomes						
Walking ≥150 min for transportation per week				MVPA ^c ≥22 min per day		
Yes	509	50.9		164	65.6	
No	491	49.1		86	34.4	
Body mass index						
Underweight or normal	484	48.4		96	38.4	
Overweight	405	40.5		117	46.8	
Obese	111	11.1		37	14.8	
Transportation characteristics						
Family car ownership						
Yes	319	31.9		65	26.0	
No	681	68.1		185	74.0	

TABLE 1 Continued

	General population (<i>n</i> = 1000)			Accelerometer subsample (<i>n</i> = 250)		
	<i>n</i>	%	SD	<i>n</i>	%	SD
Number of cars per household ^a						
0	681	68.1		185	74.0	
1	268	26.8		57	22.8	
2 or more	49	4.9		8	3.2	
Family motorcycle ownership						
Yes	100	10.0		17	6.8	
No	900	90.0		233	93.2	
Mode of transportation used ^b						
Public bus	681	68.1		181	72.4	
TransMilenio	293	29.3		65	26.0	
Feeder bus	104	10.4		30	12.0	
Car	332	33.2		83	33.3	
Taxi	290	29.0		84	33.6	
Motorcycle	53	5.3		10	4.0	
Other	79	7.9		11	4.4	

SD standard deviation

^aThe total does not add to 1000 due to missing data

^bThe total is more than 1000 because it is a multiple answer question

^cMean

Bivariate analysis results indicated that users of TM were more likely to walk for transport ≥ 150 min/week (OR 1.5, 95 % CI 1.1–1.9). Spearman correlation coefficients did not show correlations above 0.35, and VIF were all less than 1.5 for the variables used in the analysis. Additionally, the results of multilevel multivariate analysis showed that users of TM were more likely to report walking for transport ≥ 150 min/week than were nonusers (57.6 vs. 48.1 %; adjusted OR 1.5, 95 % CI 1.1–2.0). We did not find an effect modification by SES (*p* value = 0.106) or sex (*p*

TABLE 2 Minutes and days per week using each mode of transport

	General population (<i>n</i> = 1000)			Accelerometer subsample (<i>n</i> = 250)		
	<i>n</i>	Median	<i>p</i> ₂₅ – <i>p</i> ₇₅	<i>n</i>	Median	<i>p</i> ₂₅ – <i>p</i> ₇₅
Minutes per week using each mode of transportation among users						
Public bus	681	240	120–600	181	210.0	105–540
TransMilenio	293	120	60–360	65	120.0	60–180
Feeder bus	104	40	20–100	30	30.0	15–60
Car	333	180	60–480	83	180.0	85–390
Taxi	290	55	30–120	84	40.0	30–90
Motorcycle	53	90	40–360	10	200.0	40–360
Days per week using each mode of transportation among users						
Public bus	681	3	2–6	181	3.0	1–6
TransMilenio	293	2	1–4	65	1.0	1–3
Feeder bus	104	2	1–3	30	1.0	1–3
Car	333	2	1–4	83	2.0	1–4
Taxi	290	1	1–2	84	1.0	1–2
Motorcycle	53	2	1–5	10	3.5	1–7

TABLE 3 Association between physical activity with use of TransMilenio (TM)

Variable	Unadjusted OR (95 % CI)	Adjusted OR ^a (95 % CI)	Adjusted <i>p</i> value
Cross-sectional study (<i>n</i> = 995)			
Walking ≥150 min for transport and use of TM during the last 7 days	1.5 (1.1–1.9)	1.5 (1.1–2.0)	0.004
Women (<i>n</i> = 635)			
Walking ≥150 min for transport and use of TM during the last 7 days	1.3 (0.9–1.9)	1.4 (0.9–2.2)	0.110
Men (<i>n</i> = 360)			
Walking ≥150 min for transport and use of TM during the last 7 days	1.7 (1.1–2.6)	2.1 (1.2–3.9)	0.009
Low SES (<i>n</i> = 490)			
Walking ≥150 min for transport and use of TM during the last 7 days	1.3 (0.9–1.9)	1.1 (0.7–1.9)	0.560
High SES (<i>n</i> = 505)			
Walking ≥150 min for transport and use of TM during the last 7 days	1.6 (1.1–2.3)	2.0 (1.3–3.1)	0.003
Accelerometer data (<i>n</i> = 249)			
Average MVPA ≥22 min per day and use of TM during the last 7 days	3.3 (1.6–6.9)	3.1 (1.4–7.1)	0.001
Women (<i>n</i> = 169)			
Walking ≥150 min for transport and use of TM during the last 7 days	3.8 (1.6–9.0)	3.5 (1.3–9.3)	0.010
Men (<i>n</i> = 80)			
Walking ≥150 min for transport and use of TM during the last 7 days	2.0 (0.5–8.3)	1.7 (0.4–8.0)	0.470
Low SES (<i>n</i> = 135)			
Walking ≥150 min for transport and use of TM during the last 7 days	4.0 (1.4–11.4)	4.2 (1.2–15.4)	0.029
High SES (<i>n</i> = 114)			
Walking ≥150 min for transport and use of TM during the last 7 days	2.9 (1.0–7.9)	2.5 (0.8–7.8)	0.107

OR odds ratio, MVPA moderate-to-vigorous physical activity measured with accelerometers

^aAdjusted for sex, age, occupation, education level, reported body mass index, use of car, walkability, and study design stratifying variables (socioeconomic status, slope of terrain, public park provision, and proximity to TM)

value = 0.288) (Table 3).

Subsample of Adults with Objective Physical Activity Measures

Individual Characteristics In this subsample, 68 % were female, and the mean age was 48.1 years (SD 13.4) (data not shown). The subsample of adults who wore accelerometers was older than the complete sample, less educated, and with a lower SES.

Physical Activity Patterns Among these adults, 65.6 % averaged more than 22 min of MVPA per day. Twenty-six percent were TM users, and 74 % were nonusers. TM users, however, had more minutes than nonusers did, with a median of 38.4 vs.

28.0 min a day and an average 12-min difference in MVPA minutes (95 % CI 4.5–19.4, $p < 0.0001$) (Fig. 2). TM users were also more likely to average over 22 min of MVPA daily (87.7 vs. 59.4 %; unadjusted OR = 3.3, 95 % CI 1.6–6.9; adjusted OR = 3.1, 95 % CI 1.4–7.1). Additionally, the results show that, by women and a low-SES population, TM users were also more likely to average over 22 min of MVPA daily, but there was no effect modification by SES (p value = 0.590) or sex (p value = 0.620) (Table 2).

Figure 2 shows the curvilinear relationship among estimated minutes of MVPA per daily hour of TM users and nonusers. The results of the GAM show that TM users had more estimated minutes of MPVA than nonusers did (Fig. 2). Further, the results of the estimated minutes of MVPA are consistent with the peak transportation hours (6:15–7:15, 11:45–12:45, and 17:30–18:30 hours) in Bogotá. The largest differences in the MVPA minutes among TM users and nonusers occur at peak transportation hours (Fig. 2).²⁸

DISCUSSION

Our analyses showed a positive association between accessibility to TM and TM use and between walking for transportation and TM use. Adults who use TM were more likely to walk for transport, with nearly 6 of every 10 TM users walking at least 150 min/week and reporting a median MVPA per day of 38.4 min. Likewise, the average difference in daily MVPA minutes between users and nonusers was 12 min, signaling that TM offers a potential health co-benefit. This co-benefit did not differ by sex or SES. This is the only study that we are aware of that establishes a positive association between the use of BRT and meeting PA requirements in a middle-low-income country. This positive association may be relevant globally due to the high prevalence of NCDs² and the worldwide growth of BRT as a mass transit mode.²⁰

The BRT in Bogotá has shown multiple positive externalities, including decreased air pollution, carbon emissions, and automobile accidents, and has improved urban environments for walking.²⁴ Our study also underscores an additional positive externality, namely, walking for transportation. This behavior, we hypothesized, is positively associated with TM use because TM is one of the fastest BRT systems in the world. In New York, BRT users walk more than bus users but less than subway users,³⁶ and in Australia, the mode of the public

FIG. 2 Sampling design. Thirty representative neighborhood samples, SES, and TM distribution in Bogotá.

transport trip is the most important determinant of walking distance.³⁷ These factors may attract users to walk longer distances to access BRT stations compared with other modes of transportation. In fact, in our sample, TM users were more likely to live farther than 500 m from a TM station.

Our results are consistent with a study conducted in Curitiba, which found that a higher density of BRT stations was associated with walking at least 10 min per week.³⁸ Additionally, our results were consistent with Saelens et al.'s³⁹ estimate of a 12.4-min/transit-day difference between users and nonusers of public transport. Nonetheless, our results of walking time are lower than those reported by Besser and Dannenberg⁸ (19 min/transit day) as well as those reported by Freeland et al.⁹ (median total walk time for bus-only trips at 18.2 min per travel day). In this study, we show that TM users were more likely to walk at least 150 min/week and to average over 22 min of MVPA daily. The fact that most studies have assessed only the accessibility but not the use of public transportation and walking,¹⁰ and specifically the study conducted in Curitiba, which evaluated only accessibility and used a lower cutoff point, underscores the importance of assessing use instead of accessibility and using multiple thresholds in different settings.

Our estimates could be useful for conducting a sensitivity analysis to estimate the TM/PA promotion cost-benefit ratio over the 2000–2013 period. This value denotes the return in medical costs savings that are attributed to walking for transport for TM users for every dollar spent on the average annual TM costs. To calculate an estimate of the average annual TM costs, we discounted the sum of the average construction (71 %) and operational (29 %) costs in 2013 US dollars by assuming a 13-year period of TM usage (2000–2013). Considering the calculated costs, the number of users meeting PA recommendations, and the adjusted OR (Table 2), we estimated the health-care savings from transportation-related PA to be between 3 and 22 % of every dollar spent on TM costs. Each TM user has a difference of US\$10 per year in the expected value of medical costs savings that are attributed to meeting the PA recommendations by walking for transportation compared to a nonuser,⁴⁰ which corresponds to the portion of the direct health benefit for PA in Colombia that is attributed to PA in TM usage.⁴¹ By assuming an immediate change in PA behaviors after expanding the system to calculate the number of physically active users attributable to TM, we estimated an annual direct health benefit derived from PA and attributed between US\$3,310,278 and US\$22,068,518 to TM, which corresponds to approximately US\$2.63–US\$17.55 per user per year. This benefit represents between 1 and 5 % savings on the average annual medical costs per user. Future studies should include potential delay functions to obtain a better estimate of the PA attributable to TM expansion, because this consideration could decrease the cost-benefit ratio calculated by the end of the period.

Our study has several limitations. First, it is a cross-sectional study; therefore, we cannot conclude the direction of causality. To assess these associations, the projected BRTs such as that in Rio de Janeiro should leverage the natural experiment by measuring walking behaviors before and after BRT implementation. Future studies might also assess the multimodalities through which the interaction between BRT and active transport could be enhanced. Second, we do not have constructs in our survey to better understand preferences toward walking for transport. Third, the biases in the sample include a higher response rate among women than men and a skewed SES distribution toward the lower and middle SES. However, all of the models were adjusted by sex, and the sample focused on a low- to middle-SES population, which represents 90 % of the population. Finally, in terms of PA

measurement, because the IPAQ captures 10-min bouts and shorter transit trips are not captured, future research might also consider incorporating objective measures of PA, such as accelerometry, activity diaries, and global positioning systems (GPS), to more accurately measure walking.

As shown in the present study, TM users were more likely to report walking for transport ≥ 150 min/week than were nonusers and were thus more likely to meet physical activity recommendations. In addition, the objective measurement of PA with accelerometers showed an average difference of 12 MVPA minutes per day between TM users and nonusers, with the largest differences observed during peak transportation hours. Our study underscores the potential importance of BRT in increasing walking for transport. This study provides evidence of the benefit of incorporating considerations of increasing walking into public transportation planning to increase physical activity and prevent NCDs in the world's rapidly urbanizing cities.⁴

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COMPLIANCE WITH ETHICAL STANDARDS

All of the protocols and questionnaires were reviewed and approved by the Institutional Review Board of the Universidad de los Andes in Bogotá.

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