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Road Traffic Injuries and the Built Environment in Bogotá, Colombia, 2015–2019: A Cross-Sectional Analysis

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Abstract Nine in 10 road traffic deaths occur in low- and middle-income countries (LMICs). Despite this disproportionate burden, few studies have examined built environment correlates of road traffic injury in these settings, including in Latin America. We examined road traffic collisions in Bogotá, Colombia, occurring between 2015 and 2019, and assessed the association between neighborhood-level built environment features and pedestrian injury and death. We used descriptive statistics to characterize all police-reported road traffic collisions that occurred in Bogotá between 2015 and 2019. Cluster detection was used to identify spatial clustering of pedestrian collisions. Adjusted multivariate Poisson regression models were fit to examine associations between several neighborhood-built environment features and rate of pedestrian road traffic injury and death. A total of 173,443 police-reported traffic collisions occurred in Bogotá between 2015 and 2019. Pedestrians made up about 25% of road traffic injuries and 50% of road traffic deaths in Bogotá between 2015 and 2019. Pedestrian collisions were spatially clustered in the southwestern region of Bogotá. Neighborhoods with more street trees (RR, 0.90; 95% CI, 0.82–0.98), traffic signals (0.89, 0.81–0.99), and bus stops (0.89,

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0.82–0.97) were associated with lower pedestrian road traffic deaths. Neighborhoods with greater density of large roads were associated with higher pedestrian injury. Our findings highlight the potential for pedestrian-friendly infrastructure to promote safer interactions between pedestrians and motorists in Bogotá and in similar urban contexts globally.

Keywords Road traffic injury · Built environment · Latin America

Introduction

Road traffic injuries rank among the top causes of death globally [1]. In 2021, 1.19 million deaths were caused by traffic collisions, corresponding to a fatality rate of 15 per 100,000 individuals, comparable to that of malaria. An additional 20–50 million individuals sustain non-fatal injuries annually due to collisions, leaving long-lasting impacts on individuals' livelihood and well-being potential [2].

The global burden of road traffic injury is not distributed equally [1]. Approximately 92% of all road traffic deaths occur in low- and middle-income countries, despite these countries containing only 53% of all registered motorized vehicles. Middle-income countries bear the greatest burden, with an annual road traffic fatality rate of 20.1 deaths per 100,000 compared to 18.3 deaths per 100,000 in low-income countries and 8.7 deaths per 100,000 in high-income countries [3].

In Latin America, comprised mostly of middle-income countries, road traffic injuries are among the leading cause of death and disability [3]. While road-traffic death rates vary across the region, the regional rate has remained around 20 deaths per 100,000 individuals annually for the last few decades, with recent evidence indicating this rate is steadily growing [4, 5]. Already high road traffic injury and death rates may be exacerbated if adequate road safety infrastructure and policies fail to keep pace with the region's motorization rate [6].

Road traffic health burden is disproportionately distributed across road users. In Latin America, 54% of road traffic injuries occur among the most vulnerable road users—motorcyclists, cyclists, and pedestrians [3]. However, there is significant regional heterogeneity in the burden of road traffic injuries among road users. In Colombia, nearly 80% of traffic deaths occur among motorcyclists, cyclists, and pedestrians [5]. Despite passage of several national road safety laws within the last two decades, such as laws and regulations mandating motorcycle helmets and seatbelts and speed limits,[2, 7] road traffic injury and deaths in Colombia remain concentrated among motorcyclists, cyclists, and pedestrians [7, 8].

Road traffic injuries are predictable and preventable. Increasing the number of traffic calming built environment features (e.g., raised crosswalks, narrower lanes) and diversifying land use (e.g., mixed, commercial) have been shown to mitigate traffic injury burden and facilitate safe active-living environments in high-income countries [9, 10, 11]. Yet despite the disproportionate burden of traffic injury in middle-income settings, few studies have examined built environment correlates of road traffic injury in these settings, including in Latin America.

We examined road traffic collisions in Bogotá, Colombia, that occurred between 2015 and 2019, and assessed the association between neighborhood-level built environment features and motor vehicle collisions involving pedestrians, pedestrian injuries, and pedestrian deaths.

Methods

Setting

This study was conducted in Bogotá, the capital city of Colombia, whose estimated within-city-limits population as of 2018 was 7.2 million people [12]. The urban region of the capital spans 380 km [2]. Bogotá is known for its active transit innovations, including Ciclorrutas de Bogotá, among the

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most extensive bicycle paths in the world [13]; Ciclovías, an open streets program for pedestrians and cyclists [14]; the TransMilenio, a bus rapid transit service [15, 16]; and TransMiCable, a cable car system linking communities to mass transit services [17, 18].

Road Traffic Collision, Injury, and Death Data

Georeferenced police-reported collisions occurring between 2015 and 2019 were provided by the *Secretaría Distrital de Movilidad* of Bogotá. Person-level information for each collision was recorded, including the road user type of each individual involved (i.e., driver, motorcyclists, passenger, cyclist, or pedestrian) and whether those individuals sustained any injuries or died due to the collision. We aggregated individual-level data to the collision-level, deriving summary variables to indicate whether the collision resulted in any pedestrian injuries or fatalities. Collisions were assigned to traffic analysis zones (in Spanish: *Zonas de Análisis de Transporte*, ZATs) to match the geographic scale of the pedestrian volume data (see below). We use ZATs to approximate neighborhoods. Collisions that were missing geographic identifiers, road user information, or outside Bogotá's city limits were excluded from this analysis.

Built Environment Data

Street segment-level built environment features were provided by the Capital District of Bogotá and OpenStreetMap and aggregated to ZATs. We included eight features: traffic signals per intersection, street trees per road, pedestrian signals per traffic signal, pedestrian bridges per area, intersections, large road density, bus stop density, and bicycle lane length, which are described in Table 1.

Additional Covariates

Neighborhood socioeconomic status (NSES) and population density were included as covariates in analytic models.

Neighborhood Socioeconomic Status

The multidimensional poverty index (in Spanish: *Índice de Pobreza Multidimensional*, IPM) was used to measure NSES. This poverty index was developed by the National Planning Department (in Spanish: *Departamento Nacional de Planeación*, DNP) and is managed by the National Administrative Department of Statistics (in Spanish: *Departamento Administrativo Nacional de Estadística*, DANE) [19]. The index captures five dimensions of poverty: household education conditions, conditions of children and youth,

Table 1 Description and distribution of built environment features

Built environment features	Description	Source	Year last updated	Median (IQR)
Traffic signals per intersection	The number of traffic signals divided by the number of intersections	IDECA	2022	0.004 (0.00–0.02)
Street trees per road	The number of street trees per total road length (m)	MGN	2022	0.04 (0.01–0.08)
Pedestrian signals per traffic signal	The number of pedestrian signals per the number of traffic signals	IDECA	2022	1.00 (0.8–1.0)
Pedestrian bridge density	Number of pedestrian bridges per area (km^2)	IDECA	2020	0.0 (0.0–3.3)
Intersections	The total count of intersections	MGN	2020	80.0 (37.0–142.5)
Large road density	Length of roads in meters divided by the intersections area in square kilometers (m/km^2)	IDECA	2020	24,129 (14,494–29,803)
Bus stop density	The number of bus stop stations per the total area (km^2)	IDECA	2021	19.54 (9.8–29.3)
Bicycle lane length	Number of bicycle lanes per road length (m)	IDECA	2020	0.007 (0–0.07)

Abbreviations: *MGN*, Marco Geoestadístico Nacional; *IDECA*, Infraestructura de Datos Espaciales para el Distrito Capital health, employment, and access to public services and housing conditions, measured with 15 indicators using household data collected as part of the National Survey of Quality of Life (Encuesta Nacional de Calidad de Vida). Households that are deprived in at least a third of the 15 indicators are considered multidimensionally poor. DANE uses this definition to measure of the proportion of households that meet the multidimensionally poverty definition for every census block in Bogotá. An aggregated version of the 2018 measure was used to represent socioeconomic disadvantage in our analyses. Specifically, the census block-level data were aggregated up to the ZAT using an area-weighted average approach. ZAT boundaries were overlaid with the census block administrative boundaries and then assigned the weighted average of the block-level proportion of households that meet the multidimensional poverty definition of nested census blocks.

Population Density

Population density was included as a covariate to further account for residual confounding due to any measurement error in pedestrian volume data. Population counts were obtained from DANE. Using an area-weighted average approach, block-level population counts from 2018 were used and aggregated to the ZAT-level.

Pedestrian Volume

Data on pedestrian traffic volume was extracted from the 2019 mobility survey (in Spanish: *Encuesta de Movilidad 2019*). We computed the pedestrian volume per ZAT by accounting for the starting and ending points of all journeys conducted on foot, using public transport, and utilizing other transportation modes where travelers indicated engaging in a first-mile/last-mile walking leg. When a trip originates from or concludes within a specific ZAT, we categorized the commuter as a pedestrian within that corresponding ZAT.

Statistical Analysis

First, summary statistics were derived to describe traffic collision characteristics and information about road user trends over the observation period. Second, maps were used to display information about the geographic distribution of pedestrian-involved collisions over the observation period. The Gi* statistic was used to test for statistically significant local clustering of collisions [20]. Positive Gi* z-scores indicate clustering of high values (more collisions than expected) and negative Gi* z-scores indicate clustering of low values (less collisions than expected), with the magnitude indicating strength of clustering. Positive z-scores ≥ 2.56 were characterized as "very hot," ≥ 1.96 as "hot," and ≥ 1.65 as "somewhat hot," corresponding to alpha levels 0.01, 0.05, and 0.10, respectively. Similarly, negative z-scores were characterized as "very cold" (z-score ≤ -2.56), "cold" (z-score ≤ -1.96), and "somewhat" (z-score ≤ -1.65), also corresponding to alpha levels 0.01, 0.05, and 0.10, respectively. Characterized Gi* z-scores were mapped to visualize clustering of pedestrian collisions, injuries, and fatalities.

Third, adjusted Poisson regression models were fit to examine the association between each of the eight standardized built environment features listed above and pedestrian injuries and fatalities. Due the complex and co-occurring nature of built environment features, we explored several adjustment strategies for each built environment feature in relation to pedestrian injuries and fatalities (Table s1). All models included population density and NSES. The total number of pedestrian trips for each ZAT was used as the model offset. All built environment features were mean-standardized before fitting models, such that a one-unit difference in the built environment feature corresponds to a one standard deviation difference in the density of the feature. Effect estimates were exponentiated to be interpreted as the relative difference in injury or fatality rates for a standard deviation difference in the mean-standardized built environment feature (rate ratio, RR). Sandwich estimators were used to construct robust standard errors and corresponding 95% confidence intervals (95% CI). All data management and analyses were conducted using R 4.2.1. Data available on GitHub: https://github.com/aquistbe/BEPIDL.

Results

Between 2015 and 2019, 173,443 police-reported traffic collisions occurred involving 374,078 individuals in Bogotá (Table 2). Most collisions involved automobile drivers, followed by motorcyclists and then pedestrians. Thirty-three percent of all collisions over the observation period resulted in at least one injury, and 1% resulted in at least one death. Observed counts corresponded to an average annual crude rate of 226.2 road traffic injuries and 7.5 road traffic deaths per 100,000 individuals, based on Bogotá's 2018 population (Table 2) [12].

Proportion of traffic injuries varied by road user type (Fig. 1). Pedestrians and motorcyclists bore the greatest burden of traffic injury (average proportion: pedestrian injury, 24.9%; motorcyclist injury, 29.6%) and death (average proportion: pedestrian death, 48.2%; motorcyclist injury, 27.6%) over time, despite drivers making up the largest proportion of road user types involved in collisions during the obversion period. In more recent years, a greater proportion of injuries involving motorcyclists occurred compared to other road user types (32% injuries among motorcyclists compared to 20% among pedestrians in 2019). Pedestrians experienced the highest proportion of road traffic deaths, making up 50% of all traffic-related fatalities throughout the observation period.

With regard to pedestrian traffic injury specifically, the average annual rate of pedestrian collisions over the 5-year period was 23.3 collisions per 100,000 active transport trips. The average annual rate for pedestrian collisions resulting in injury and death was 21.8 collisions resulting in injuries and 1.6 collisions resulting in deaths for every 100,000 active transport tips, respectively. The average annual rates by ZAT indicate geographic heterogeneity in burden of pedestrian injury (Fig. 2). This was further confirmed in our cluster detection analysis. Hot spot analyses revealed pedestrian road traffic injuries and deaths occurring between 2015 and 2019 were significantly spatially clustered (Fig. 3). A greater number of collisions were observed than expected in the southwestern region of the city, whereas a lower number of collisions were observed than expected in the northern and southern parts of the city.

The strongest and most consistent associations between neighborhood-built environment features and pedestrian safety were observed with street tree density

Table 2 Descriptive characteristics of traffic collisions in Bogotá, Colombia, between 2015 and 2019

Year	Overall	2015	2016	2017	2018	2019
Collision-level						
Total collisions, *N*	173,443	31,341	34,988	35,171	36,953	34,990
Road user type, *N* (%)‡						
Drivers	158,857 (92)	28,644 (91)	32,188 (92)	32,541 (93)	33,732 (91)	31,752 (91)
Passengers	17,085 (10)	3156 (10)	3136 (9)	3115 (9)	3776 (10)	3902 (11)
Pedestrians	19,672 (11)	4170 (13)	4052 (12)	3725 (11)	4013 (11)	3712 (11)
Motorcyclists	42,331 (24)	7532 (24)	8306 (24)	8005 (23)	9302 (25)	9186 (26)
Cyclists	10,096 (5)	1485 (5)	1749 (5)	1859 (5)	2375 (6)	2628 (8)
Injuries, *N* (%)	57,278 (33)	10,837 (35)	10,676 (31)	10,517 (29)	12,717 (34)	12,531 (36)
Deaths, *N* (%)	2624 (2)	529 (2)	566 (2)	538 (2)	499 (1)	492 (1)
Individual-level						
Total individuals, *N*	374,078	67,899	75,035	75,639	79,861	75,644
Road user type, *N* (%)						
Drivers	273,023 (73)	49,427 (73)	55,689 (74)	56,613 (75)	57,675 (72)	53,619 (71)
Passengers	24,369 (7)	4495 (6)	4375 (6)	4527 (6)	5509 (7)	5463 (7)
Pedestrians	21,321 (6)	4488 (6)	4396 (6)	4078 (5)	4357 (5)	4002 (5)
Motorcyclists	45,068 (12)	7977 (12)	8801 (12)	8524 (11)	9894 (12)	9872 (13)
Cyclists	10,297 (3)	1512 (2)	1774 (2)	1897 (3)	2426 (3)	2688 (4)
Injuries, *N* (%)	81,448 (22)	14,697 (22)	14,511 (19)	14,899 (20)	18,864 (24)	18,477 (24)
Deaths, *N* (%)	2697 (1)	544 (1)	586 (1)	547 (1)	515 (1)	505 (1)

‡Note: collisions involve multiple road users; therefore, percentages reported for each road user are greater than 100% when summed

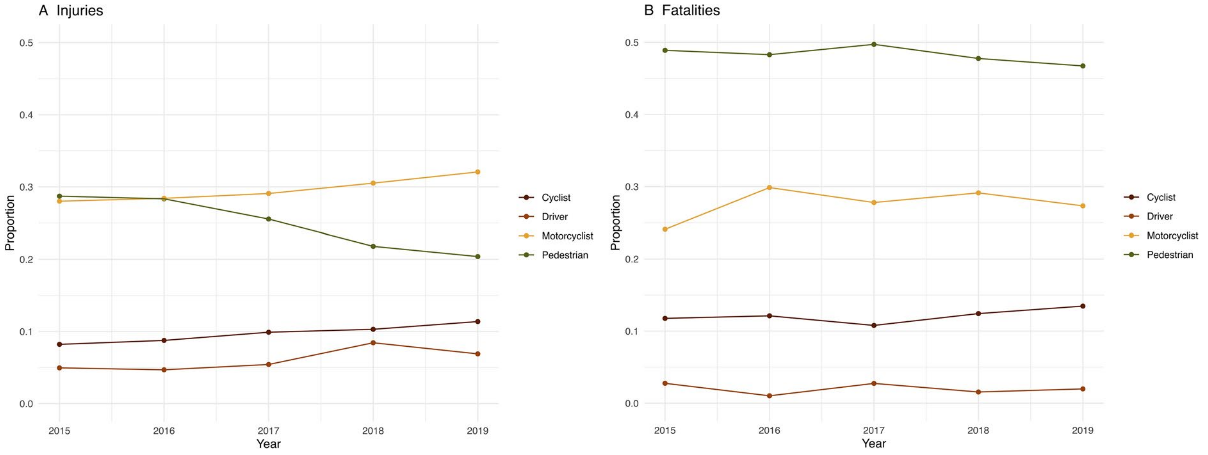

Fig. 1 Distribution of traffic-related injuries (**A**) and fatalities (**B**) by road user type in Bogotá between 2015 and 2019.‡ ‡Passenger injury and deaths were included in the calculation of proportions but not visualized above since the data did not distinguish between cars versus motorcycle passengers, road users with different risk profiles

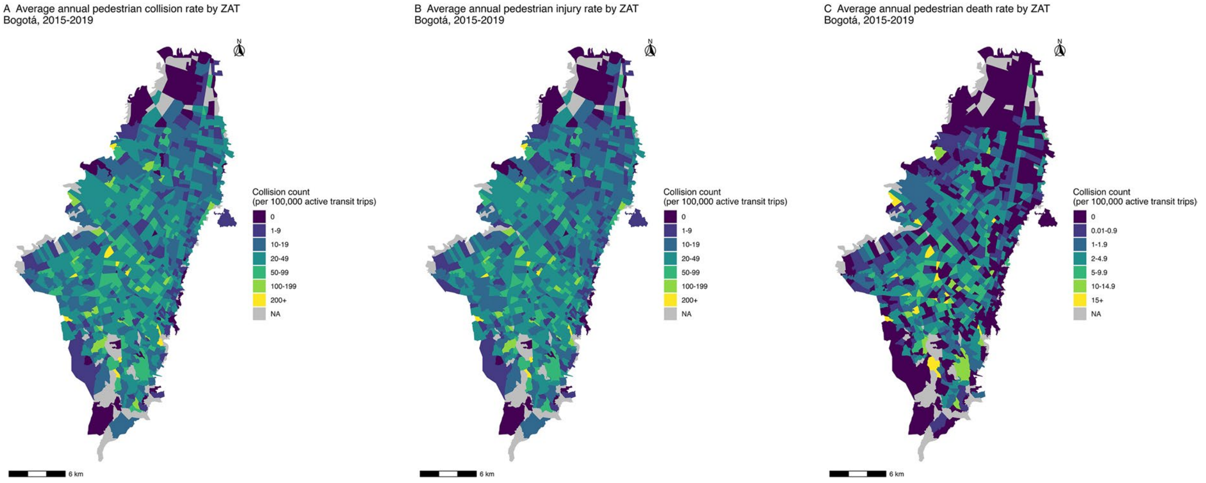

Fig. 2 Geographic distribution of traffic-related pedestrian collisions (**A**), resulting in injuries (**B**), and fatalities (**C**) in Bogotá between 2015 and 2019

and large road density (Fig. 4, Table s2). Specifically, higher street tree density was associated with lower rates of pedestrian injury (RR, 0.83; 95% CI, 0.77, 0.88) and deaths (RR, 0.89; 95% CI, 0.81, 0.99). Conversely, large road density was associated with higher rates of pedestrian injury (RR, 1.30; 95% CI, 1.21, 1.41) and deaths (RR, 1.24; 95% CI, 1.11, 1.39). Higher traffic signal density and bus stop density and pedestrian road traffic deaths were associated with fewer pedestrian deaths (traffic signal density RR, 0.90; 95% CI, 0.82, 0.98; bus stop density RR, 0.89; 95% CI, 0.82, 0.97). Both features were not significantly associated with pedestrian injuries at the neighborhood level. Of note, neighborhood density of pedestrian signals, pedestrian bridges, intersections, and bicycle lanes was also not associated with pedestrian traffic injury or death.

Discussion

In this study, we used data from Mobility Secretariat (in Spanish: *Secretaría Distrital de Movilidad*)

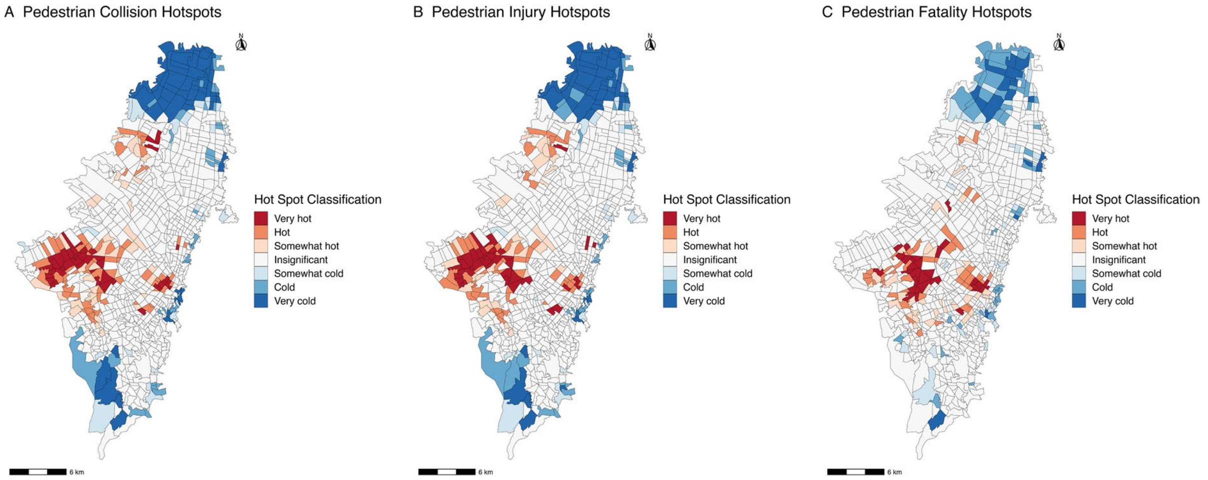

Fig. 3 Hot spot analysis results for pedestrian collisions (**A**), injuries (**B**), and fatalities (**C**) in Bogotá between 2015 and 2019

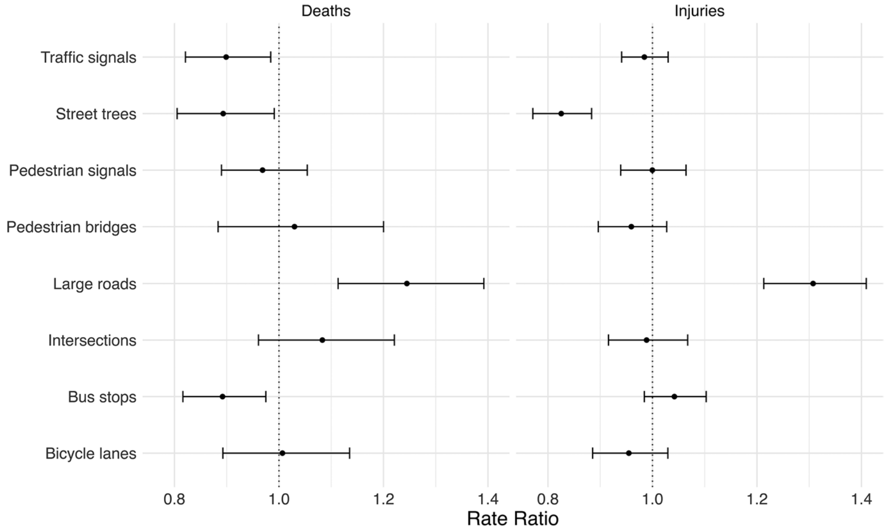

Fig. 4 Associations between built environment features and traffic-related pedestrian collisions. Data are RR (95% CI) from adjusted multivariable Poisson models

Bogotá to characterize road traffic collisions between 2015 and 2019 and examine built environment correlates of pedestrian road traffic injuries and deaths in a large city in Latin America. The average annual injury rate of road traffic collisions in Bogotá during our observation period was 226.2 traffic-related injuries and 7.5 traffic-related deaths per 100,000 population. Of these injuries and deaths, we found that pedestrians were overrepresented compared to other road users, and that these pedestrian-involved collisions were concentrated in specific regions within the city. As observed in many high-income settings, built environment infrastructure considered friendly to pedestrians, such as traffic signals and street trees, was associated with fewer pedestrian injuries, whereas features that facilitate high speeds (i.e., large road density) were associated with more pedestrian-involved collisions per estimated pedestrian. We also found built infrastructure intended to promote pedestrian safety, such as pedestrian signals and pedestrian bridges, to be unassociated with traffic-related pedestrian injury or death.

In the context of other efforts quantifying road traffic burden in Bogotá, rates of road traffic injury and death presented in this analysis underscore important progress and remaining challenges in improving road safety in Bogotá. In 1999, the traffic-related mortality rate for Bogotá was 23 deaths per 100,000 population [21]. This figure significantly contrasts with our current findings that report the average annual traffic-related mortality rate to be 7.5 deaths per 100,000 population between 2015 and 2019, indicating a substantial reduction in road traffic-related fatalities in the city. Our rate aligns with the most recent pedestrian mortality rate reported by the Bogotá's Mobility Secretariat in 2022 (7 per 100,000 population) [22]. Many road safety-related and civic culture policies and interventions have been implemented over the last two decades that likely in part explain the lower traffic-related mortality rate observed in our analysis. For example, the passing of the National Road Safety Plan in Colombia in 2011 led to the development of several traffic regulations, including heightened regulations on drunk driving [23, 24], distracted driving [25], and speeding [26], and the adoption of alternative forms of travel (e.g., TransMileno) [16, 27]. Moreover, stricter regulations on schools surroundings and civic culture campaigns led to a decrease of pedestrian collisions including kids to near zero [28]. However, despite reductions in traffic-related mortality in Bogotá, we do not observe the same reductions in injury rates. The traffic-related injury rate for Bogota in 1999 was 202 injuries per 100,000; this is comparison to our current findings of an average annual injury rate of 226 injuries per 100,000 population. Based on these findings, we hypothesize that policies and intervention aimed to reduce traffic-related injury likely contributed to reducing the severity of collisions but may not have been equally effective at reducing the incidence of collisions, resulting in lower rates of fatal collisions but not collisions resulting in injury.

Furthermore, the burden of road traffic injury is disproportionately placed among pedestrians. Despite only making up 11% of road users involved in collisions, we find that pedestrians made up about 25% of road traffic injuries and 50% of road traffic deaths in Bogotá between 2015 and 2019. This is significantly higher than reported global and regional proportions, where about 23% of road traffic deaths were reported among pedestrians, and higher than national estimates that report 26% of traffic-related deaths occurring among pedestrians [29]. Additionally, pedestrian-involved collisions, especially those leading to fatalities, exhibit a clear spatial pattern within the city. Pedestrian collisions were found to be concentrated along main corridors, large roadways, and transit lines in central and southern Bogotá, aligning with previous studies demonstrating similar spatial patterns of collisions [21, 26, 30]. Specifically, higher concentration of collisions was found in the Kennedy, Fontibón, Suba, Los Mártires, and Santa Fé localities. Studies contribute this spatial patterning to high speeds of vehicles along these corridors and the heightened risk of pedestrian exposure to road traffic at transit intersections, leading to persistently elevated collision rates and their severity in these areas [26].

Regarding built environment features, we found that neighborhoods with a higher density of traffic signals, street trees, and bus stops had lower rates of pedestrian injury, whereas neighborhoods with a greater density of large roads observe higher rates. Traffic signals and street trees can serve as traffic-slowing built environment features that reduce the risk and severity of pedestrian collisions [10]. A higher concentration of traffic signals on street networks may help reduce speeding by drivers while simultaneously creating safer crossing opportunities for pedestrians, thus minimizing the probability of collisions. Street trees have been linked with lower rates of road traffic collisions due to their "visual narrowing" effects that cause drivers to perceive lower speeds and exercise greater caution [31, 32]. This added visual complexity also increases drivers' attention and alertness, reducing the likelihood of a pedestrian collision.

Bus stop density was associated with lower rates of traffic-related pedestrian deaths, but not significantly associated with pedestrian injury. Areas surrounding bus stops are likely congested due to frequent stops by buses and trams. Consequently, motor vehicle speeds may be slower such that if a collision occurred, it would likely not result in a fatality. Other studies have found cities with a bus rapid transit system, subway, or similar mass transit tend to have lower risk of pedestrian deaths [4]. Prevailing hypotheses suggest that this reduction is due to more road users using those systems rather than driving, reducing risk of motor vehicle–pedestrian collisions [4, 33]. Though bus stop density was not significantly associated with pedestrian injury in our analysis, others have found bus stop density to be associated higher pedestrian injury, but this relationship may depend on the volume of motorists on the road [34, 35]. Despite reduction in motor vehicle speed, risk of pedestrian-motor vehicle collisions is likely higher around bus stops due to higher pedestrian traffic that often coincides with the presence of a transit stop. While this is also true in Bogotá, the mix of shared and exclusive bus lanes along with variation in bus stop design features confers various levels of protection for pedestrians [36, 37], likely contributing to the non-significant finding for the association between bus stops and pedestrian injury in our analysis. Our results suggest that locations with bus stops may need additional countermeasures to reduce pedestrian injuries.

We also did not observe significant associations between density of pedestrian bridges, pedestrian signals, intersections, and bicycle lanes, and pedestrian injury. Pedestrian bridges are intended to reduce risk for pedestrians by reducing pedestrian flow in areas designed for motor vehicles; however, findings about their utility in actually reducing pedestrian injury and death are mixed [38, 39, 40, 41]. Inconclusive findings could be attributed to the difficulty of distinguishing pedestrian risk from pedestrian activity, along with variations in bridge design and the adjacent environment, that correspond to heterogeneity in observed effects [42, 43, 44]. Future research assessing pedestrian bridges at finer geographic scales, such as at the street segment-level, and differentiating between those with and without protective characteristics can better inform how pedestrian bridges are related to pedestrian safety.

Pedestrian signals and intersections were not significantly associated with a reduction in either pedestrian injury or fatality, consistent with other studies examining these features in relation to pedestrian safety [34, 45]. In a study that explore pedestrian perceptions of walkability [43], participants consistently voiced concerns about the prevailing lack of respect for traffic rules and yielding to pedestrians by motor vehicle drivers, especially regarding pedestrian crosswalks and traffic control signs. For example, despite pedestrian signals indicating a safe crossing, participants expressed hesitancy due to the perceived risk of drivers not adhering to signals and continuing to drive particularly when executing right and left turns. This qualitative insight complements quantitative data and emphasizes the complex interactions between pedestrians and drivers, which can significantly impact pedestrian safety. It is important to note these findings do not suggest that pedestrian signals should not be used. In Bogotá and other LMIC cities, they are often the only visible signal to pedestrians to cross the road. Instead, our findings suggest that intersections could be improved such that crossing pedestrians are more visible to turning drivers and to reduce conflicts between turning drivers and pedestrians. Some potentially effective interventions include implementing leading pedestrian intervals to allow pedestrians to begin crossing the street before adjacent traffic [46, 47], or providing more opportunity for pedestrian visibility by slowing drivers down using curb extensions, for example [11, 48].

Finally, bicycle lanes were not associated with pedestrian safety, despite their potential to confer safer pedestrian environments by providing separation between bikers and pedestrians and motor vehicle traffic [11]. We hypothesize that this is due to the mix of types of bike lanes present in Bogotá. We could not distinguish between types of bike lanes, such as off-street bicycle lanes versus paint-delimited on-road bicycle lanes, for example, which offer various levels of protection for pedestrians [30, 49].

There are important limitations to our study to consider. Our outcome data were from reports of road traffic collisions made by the police at the same time of collisions; therefore, they do not include collisions where the police were not called and may also underestimate middle-and long-term injuries and deaths caused by the collision. These police reports, however, likely cover the most severe collisions due to police involvement, which have a more significant public health impact than vehicle-damage-only collisions. We examined outcomes aggregated over several years with built environment data that may not have matched the study period, thus there may be some measurement error. This study did not consider temporal and behavioral factors, such as construction, weather, speeding, and drunk driving. Because we examined neighborhood-level associations, our findings may not correspond to findings from studies at the intersection or segment-level or those that examine the entire city, region, or country. Neighborhood-level analyses, however, provide important evidence for city planners, traffic engineers, and public health officials to understand better areas in the city that may need more resources to improve road safety rather than just focusing on one intersection or road segment. We also adjusted for the role of NSES using interpolated data which may not represent the actual NSES of all city areas.

Despite the limitations, this study has several strengths. First, road traffic collisions used in our analysis were linked to data from the 2019 Mobility Survey to ascertain approximate pedestrian activity. This allows for more accurate estimates that considers population exposure to road traffic which is largely not accounted for in other traffic injury studies in low- and middle-income country settings and even in high-income settings. Second, few studies in Colombia and LMICs in general examine neighborhood-level built environment features in relation to pedestrian safety. The few existing studies provide either city-level or segment-level analysis of features, which may overlook important nuance needed to inform effective road safety interventions in cities, or focus on medical outcomes among the hospitalized. Furthermore, this is one of few studies that provide a comprehensive assessment of as many built environment features as featured in this study. Given the scarcity of evidence on neighborhood-built environment correlates of pedestrian injury outside high-income country settings, this study addresses a critical research gap where evidence is needed most. Finally, this study uses relatively recent collision data compared similar studies conducted in this region, resulting in findings that reflect recent neighborhood-road safety dynamics and can more readily be used to inform timely interventions.

Recommendations

Bogotá, along with many other urban areas in the Global South, is a city where active transport, in most cases, is a necessity [50]. As such, it is imperative to implement comprehensive strategies to improve road safety and prioritize the well-being of pedestrians and other vulnerable road users. Below are policy and research recommendations based on our findings to promote pedestrian road safety in Bogotá:

- *Invest in traffic calming built environment characteristics:* Invest in and evaluate features that reduce motor vehicle speeds (e.g., street trees).
- *Equity-based approach for road safety interventions:* Target the implementation and evaluation of pedestrian safety interventions in areas where pedestrian collisions are historically concentrated.
- *Consistent and standardized volume measurement:* Develop system for collecting consistent and standardized volume data for pedestrians, cyclists, motorcyclist, and drivers to improve evaluation of road safety interventions.
- *Leverage community-based groups to foster pedestrian-centric culture:* Allocate resources to support community-based interventions that foster a culture centered around pedestrian priorities (e.g., TransMiCable: community engaged transport intervention) [18].
- *Multisectoral approach for innovative solutions:* Encourage multisectoral and interdisciplinary collaborations to cultivate innovative ideas to address pedestrian road safety from various dimensions (e.g., urban health framework diagnostic tool) [51].

Conclusion

In conclusion, our study provides guidance not only for Bogotá but also for other major cities in Latin America and similar cities globally, on how the built environment at the neighborhood-level can impact pedestrian safety. Pedestrians in these cities typically represent the majority of trips in these cities via walking and mass transit use [52], but face disproportionately high risks of road traffic injuries and fatalities, with collisions concentrated in specific regions along major corridors and transit intersections. Even in these settings, road infrastructure often focuses on motor vehicle users and optimizing motor vehicle speed and traffic. While progress has been made through road safety policies and interventions in Bogotá, pedestrian safety remains an ongoing concern that demands continued investment and attention. Our findings highlight the importance of pedestrian-friendly infrastructure in promoting safer interactions between pedestrians and motorists in Bogotá and in similar settings. Improving pedestrian infrastructure benefits all road users and can significantly enhance physical health and promote sustainable mobility.

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