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Trends and patterns of work-related cyclist fatalities in Brazil, 2014–2022

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Bicycles are common mode of transport in countries with well-developed road infrastructure and traffic law enforcement. In Brazil, their use for economic activities, particularly on app-based deliveries, has surged. However, work-related cyclist fatalities (WRCFs) remain an understudied public health concern. This study characterizes WRCFs among individuals aged 10–69 in Brazil from 2014 to 2022, analyzing key demographic, occupational, temporal, and geographic trends. Using data from Brazil's Mortality Information System (MIS), we examined deaths classified under ICD-10 codes V10–V19 (pedal cyclist injured in transport accidents). Proportional mortality, mean age at death (MAoD), median, interquartile range and Years of Potential Life Lost (YPLL) were calculated. Of 6590 cyclist-related fatalities, 272 (4.1%) were confirmed as WRCFs. Most victims were male (87.1%), aged 29–58 years (68.3%), white (49.7%), had low education levels (<12 years, 82.4%) and were single (45.9%). Fatalities seem concentrated in the South/Southeast regions (71%), with 61.3% involving collisions with motor vehicles (ICD-10 codes V13–V14). The highest proportions of WRCFs occurred among industrial (42%) and sales/trade (30.9%) workers. The MAoD was 43.6 years, with a total of 8896.4 YPLL. Notably, work-related fatality classification was missing in 57% of cases, highlighting the need for improved death certificate reporting in the country. Enhancing data quality is essential to understanding the risks faced by workers, many of whom are engaged in precarious, informal employment without social protection.

Keywords Occupational accidents, Cyclists, Occupational mortality, Work-related accident, Mortality information system

According to the Brazilian Traffic Code (BTC), a bicycle is a human-powered vehicle propelled by pedals, consisting of two wheels, a seat and handlebars[1]. Originally invented in the eighteenth century by Karl Friederich von Drais in Germany, bicycle plays a fundamental role in human mobility, offering an accessible and efficient mode of transportation across diverse geographic contexts[2]. In the twenty-first century, its production and use expanded worldwide, driven by policies promoting active mobility, environmental sustainability, and employment opportunities, particularly through digital platforms that facilitate service provision. Today, an estimated 1 billion bicycles exist globally, with China, the United States, Japan and Germany leading in absolute fleet numbers[3,4]. In Brazil, there are approximately 75 million bicycles, equating to approximately 35 units per 100 inhabitants[2].

Widely used for leisure and physical activities, bicycles also serve as an essential mode of transportation for commuting. Their use offers numerous health benefits, including reduced morbidity risk[5], improved quality of life[6] and reduced premature mortality[7]. Despite these advantages and efforts to enhance cyclists' safety, such as traffic regulations and the development of dedicated urban cycling infrastructure, both recreational and work-related cyclists continue to face a high risk of accidents, including temporary or permanent injuries and in severe cases, death[4].

A work-related accident (WRA) refers to an acute event causing bodily injury or functional impairment to a worker while performing work-related task. A typical WRA occurs during professional activities, whereas a commuting WRA takes place during travel between home and workplace[8]. In Brazil, between 2014 and 2022, the notifiable injuries information system recorded 13,916 WRAs involving cyclists aged 10–69 years, classified under codes V10–V19—cyclists injured in a collision, of the International Classification of Diseases (ICD-10)[9]. Among these cases, 78% involved male cyclists and 80% were commuting WRA. Studies based on primary data examining the profile of Brazilians who use bicycles for work-related activities have reported a WRA prevalence

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of 5–10% within periods of less than 12 months[10,11]. A national study of Brazilian delivery cyclists, most of whom were engaged in digital platforms, reported a 40% prevalence of WRAs within the past 12 months, highlighting the occupational vulnerabilities faced by this group [12].

Over the past decade, a growing number of studies have evaluated the factors contributing to cyclist accidents[13]. Key causes include poor road or cycle path conditions, non-compliance with traffic regulations, lack of essential bicycle equipment like bells, reflective jackets and rearview mirrors, and adverse weather conditions[4,11,13]. Conversely, the use of personal protective equipment (PPE), particularly helmets, has been shown to reduce the risk of cyclist mortalities [14]. Despite the increasing research on cyclist accidents[15–19] and the characteristics of cyclist fatalities[3,20,21], studies examining their morbidity and mortality from a work perspective remain scarce. This gap is especially relevant in the context of app-based delivery work, which has expanded rapidly in recent years. The surge of the online food delivery sector, driven largely by digital platforms, has created new income opportunities for cyclists. However, these workers constitute a highly vulnerable group of road users, given their constant exposure to traffic, performance-based pay structure and lack of formal labor protections. These factors collectively heighten the daily risk faced by gig-economy workers[12,22].

Given this context, and the limited research at the intersection of cycling, work and mortality, this study aims to analyze and characterize cyclist fatalities in transport accident, particularly those that are work-related in Brazil from 2014 to 2022. Specifically, it examines deaths records of cyclists aged 10–69 who were involved in collisions while cycling for work-related purposes, focusing on their sociodemographic characteristics, occupational groups and geographic distribution to inform future interventions.

Methods

Study design and population

This descriptive epidemiological study analyzes microdata from death records of cyclists injured in transport accident (CITA) in Brazil, focusing on individuals aged 10–69 years from 2014 to 2022. Death records were included if they contained information on the underlying cause of death, occupation and sociodemographic profile. Records were excluded if the occupation was listed as student, housewife, retired/pensioner, unemployed, prisoner or if occupational information was missing[23] (Fig. 1).

Glossary of key acronyms frequently used throughout the manuscript

- **General-CITA**: refers to all deaths from cycling injuries in transport accidents among individuals aged 10–69, regardless of occupational information.
- **BCO-CITA**: deaths due to cycling injuries in transport accidents, with a valid occupational code, as classified by the Brazilian Classification of Occupations (BCO).
- **WR-BCO-CITA**: subset of BCO-CITA classified as work-related.

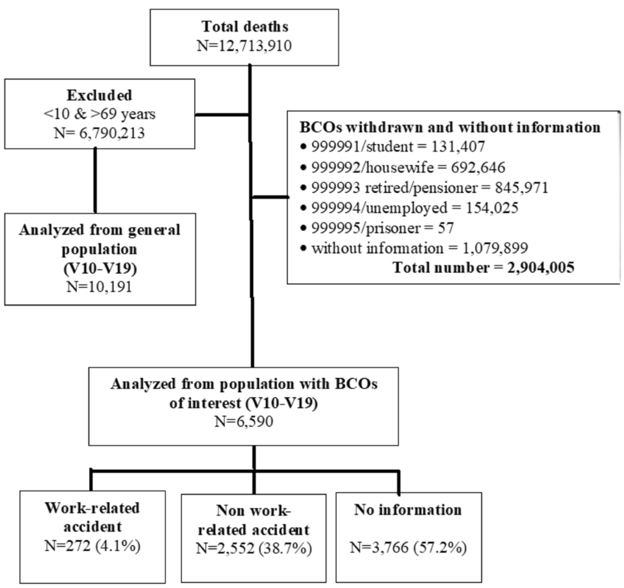

Fig. 1. Process of constructing the database (ICD-10 codes V10–V19)†, Brazil, 2014–2022. BCO—Brazilian Classification of Occupations. †ICD-10 codes V10–V19: V10—Cyclist injured in collision with pedestrian or animal; V11—Cyclist injured in collision with other pedal cycle; V12—Cyclist injured in collision with two- or three-wheeled motor vehicle; V13—Cyclist injured in collision with car, pick-up truck or van; V14—Cyclist injured in collision with heavy transport vehicle or bus; V15—Cyclist injured in collision with railway train or railway vehicle; V16—Cyclist injured in collision with other nonmotor vehicle; V17—Cyclist injured in collision with fixed or stationary object; V18—Cyclist injured in a non-collision transport accident; and V19—Cyclist injured in other or unspecified transport accidents.

- **NonWR-BCO-CITA**: subset of BCO-CITA classified as not work-related.
- **MissingWR-BCO-CITA**: subset of BCO-CITA with missing or ignored/unrecorded information regarding work-relatedness.

Data collection and processing
All mortality data were obtained from the Mortality Information System (MIS), which is based on standardized Death Certificates (DCs). Completion of the DC is mandatory for all deaths in the country and is performed by physicians in accordance with procedures and guidelines established by the Brazilian Ministry of Health[24]. The MIS has an estimated national coverage of approximately 95%, making it the primary official source of mortality data in Brazil.

Over the past two decades, the completeness of information recorded on DCs has improved significantly, with sociodemographic variables now reaching around 95% completeness. Studies have also documented improvements in the quality of cause-of-death data, including notable reductions in the proportion of deaths classified under ill-defined causes. Despite some regional disparities, the MIS is considered nationally representative and serves as a key instrument for public health surveillance and epidemiological research in Brazil[25].

The dataset is publicly accessible and made available by the Department of Informatics of the Unified Health System (known as DATASUS in Brazil) accessible at https://datasus.saude.gov.br. To identify relevant outcome, all records from field 40 of the DC (CAUSABAS) were considered, following the guidelines of Death Certificate Manual[24]. Records were selected based on ICD-10 codes V10–V19, which define CITA under Chapter XX—external causes of morbidity and mortality. See Fig. 1's footnote for code definitions.

WR-BCO-CITA data were extracted from field 49 of the DC, a field specifically designated for external causes of death. This field offers three response options: (1) Yes, (2) No, or (9) Ignored[24]. In our analysis, any records for which this field was left blank were classified as "Ignored."

The usual occupation, documented in field 14, represents the type of work the deceased predominantly engaged in during their productive life[24]. To classify occupations, this study applied the Brazilian Classification of Occupations (BCO)[26], categorizing workers into ten broad occupational groups based on the first digit of the recorded field.

To characterize the profile of deaths, various demographic and contextual variables were analyzed. These include gender; age range; race/color; education level; marital status; medical assistance; macroregions of Brazil; municipality typology, place of occurrence; BCO codes and triennium—see Table 1 for details on how the variables were categorized.

Data analysis
To analyze the profile of death records across variables and comparison groups, absolute values and corresponding frequencies were calculated. We calculated Proportional Mortality (PM) using:

$$PM = \frac{Di}{D_t} \cdot 100$$

where: D_i is the total number of deaths in the category of interest in the period; D_t is the total number of deaths in the variable of interest in the period.

The mean age of death (MAoD) was calculated using:

$$MAoD = \frac{\sum A_i}{D_t}$$

where: $\sum A_i$ is the sum of ages at deaths in the category of interest in the period; D_t is the total number of deaths in the variable of interest in the period.

To calculate the Years of Potential Life Lost (YPLL), we used a method previously described[27]. Briefly, we calculated the difference between the mean age of the variable of interest (A_i) and the corresponding life expectancy (LE), multiplied by the total number of deaths in that group (d_i). We applied a single general value for LE, 76.3 years in 2018, based on national estimates from the Brazilian Institute of Geography and Statistics (IBGE)[28]. The LE estimate is derived from complete mortality tables, which incorporate data from the 2010 Demographic Census, infant mortality estimates, and official death records disaggregated by sex and age. The projections are periodically updated and used for national population projections for the period 2010–2060. Although it would be possible to use age- or sex-specific LE values, we opted for a general national estimate to enhance comparability across subgroups and reduce the influence of demographic variations during the study period using:

$$YPLL_{total} = \sum (LE - A_i) \cdot d_i$$

where: LE is the life expectancy; A*i* is the mean age of the variable of interest in the period; d_i is the total number of deaths in that group in the period.

We calculated percentage distribution of YPLL (%YPLL) using:

$$\%YPLL = \left(\frac{YPLL_i}{YPLL_{total}}\right) \cdot 100$$

Variables	General-CITA n = 10,191 n	%	BCO-CITA n = 6590 N	%	p-value†
Gender					**< 0.001**
Female	1079	10.6	491	7.5	
Male	9108	89.4	6098	92.5	
Missing data	4	0.0	1	0.0	
Age range					**< 0.001**
10–14	448	4.4	5	0.1	
15–18	616	6.1	117	1.8	
19–23	656	6.4	367	5.6	
24–28	623	6.2	419	6.4	
29–33	667	6.5	475	7.2	
34–38	828	8.2	597	9.0	
39–43	943	9.2	707	10.7	
44–48	1040	10.3	796	12.1	
49–53	1103	10.8	813	12.3	
54–58	1209	11.8	919	13.9	
59–63	1046	10.2	775	11.8	
64–69	1012	9.9	600	9.1	
Race/color					**< 0.001**
White	4285	42.0	2778	42.2	
Black	661	6.5	446	6.7	
Yellow	17	0.2	13	0.2	
Mixed	5015	49.2	3239	49.1	
Indigenous	45	0.4	18	0.3	
Missing data	168	1.7	96	1.5	
Education level					**< 0.001**
None	650	6.4	456	6.9	
1–3	1793	17.5	1268	19.2	
4–7	2943	28.8	1933	29.3	
8–11	2316	22.7	1581	24.0	
≥ 12	443	4.5	340	5.2	
Missing data	2046	20.1	1012	15.3	
Marital status					**< 0.001**
Single	5525	54.2	3324	50.4	
Married	2485	24.4	1872	28.4	
Widower	227	2.2	141	2.1	
Legally separated	660	6.5	501	7.6	
Stable union	528	5.2	400	6.1	
Missing data	766	7.5	352	5.3	
Medical assistance					**< 0.001**
No	3196	31.4	2095	31.8	
Yes	4709	46.2	3123	47.4	
Missing data	2286	22.4	1372	20.8	
Macroregions of Brazil					**< 0.001**
North	694	6.8	402	6.1	
Northeast	2201	21.6	1454	22.1	
Central-west	1298	12.7	884	13.4	
South	2261	22.2	1630	24.7	
Southeast	3737	36.7	2220	33.7	
Municipality typology					**0.026**
Remote rural	106	1.0	58	0.9	
Adjacent rural	1393	13.7	878	13.3	
Remote intermediary	65	0.6	28	0.4	
Adjacent intermediary	687	6.7	436	6.6	
Continued					

Variables	General-CITA		BCO-CITA		p-value†
	n = 10,191		n = 6590		
	n	%	N	%	
Urban	7897	77.6	5173	78.4	
Missing data	43	0.4	17	0.3	
Place of occurence					**< 0.001**
Hospital	5204	51.1	3397	51.5	
Other health establishment	220	2.2	148	2.2	
Homestead	110	1.1	72	1.1	
Public road	4241	41.5	2724	41.3	
Others	402	4.0	245	3.7	
Missing data	14	0.1	4	0.1	
BCO codes††					**< 0.001**
Armed forces	–	–	30	0.4	
Public officials	–	–	170	2.6	
Sciences and arts	–	–	214	3.2	
High school technician	–	–	497	7.5	
Administrative services	–	–	185	2.8	
Sales and trade services	–	–	1351	20.5	
Agricultural	–	–	1446	21.9	
Industrial services 1	–	–	2102	31.9	
Industrial services 2	–	–	182	2.8	
Repairs and maintenance	–	–	413	6.3	
Triennium					**< 0.001**
2014–2016	3363	33.0	2040	31.0	
2017–2019	3381	33.2	2179	33.1	
2020–2022	3447	33.8	2371	36.0	

Table 1. Proportional mortality of cyclists aged 10–69 years injured in transport accidents (ICD-10 codes V10–V19), classified by general-CITA and BCO-CITA in Brazil, 2014–2022 (n = 10,191). Data source: Mortality Information System (MIS), Department of Informatics of the Unified Health System (DATASUS), Brazilian Ministery of Health. International Classification of Diseases, 10th revision (ICD-10), codes V10-V19 (see Fig. 1 for a complete description). †Chi-square test for heterogeneity. Values in bold are statistically significant ($p < 0.05$). ††Brazilian Classification Occupation—10 major groups[26]. General-CITA: all deaths due to cycling injuries in transport accidents, regardless of occupational information. BCO-CITA: deaths due to cycling injuries in transport accidents, with a valid occupational code.

where: $YPLL_i$ is the YPLL in the category of interest in the period; $YPLL_{total}$ is the total YPLL in the variable of interest in the period.

The %YPLLratios were calculated using the %YPLL values for %WR-BCO-CITA values as numerator and the %BCO-CITA as reference (denominator) using:

$$\%YPLLratio = \frac{\%YPLL_{exposure}}{\%YPLL_{reference}}$$

where: $\%YPLL_{exposure}$ is the %YPLL in the exposure category; $\%YPLL_{reference}$ is the %YPLL in the reference category.

The 95% confidence interval (95% CI) for the ratio between proportions was calculated assuming a log-normal distribution. Specifically, the natural logarithmic transformation of the ratio (lnR) was used, and the confidence limits were obtained by adding and subtracting 1.96 times the estimated standard error using:

$$IC_{95\%} = \left[e^{In(R) - 1.96\sqrt{\frac{1}{a} + \frac{1}{b}}}, e^{In(R) + 1.96\sqrt{\frac{1}{a} + \frac{1}{b}}} \right]$$

where: R is the %YPLLratios in the exposure and reference categories; a is the number of YPLL in the exposure category; b is the number of YPLL in the reference category; *e* is the base of the natural logarithm.

The MAoD, median and 25th and 75th percentiles were calculated. Comparisons of median age at death across categories were performed using nonparametric tests: the Mann–Whitney test for independent binary variables, and the Kruskal–Wallis test for independent polytomous variables, with the Dunn's post-test and Bonferroni correction. The choice of these tests was based on the verification of variance heterogeneity in the continuous variable of age at death, using the Anderson–Darling test. When applied to general-CITA cases between 2014 and 2022 among individuals aged 10–69, regardless of occupational information, and for WR-BCO-CITA, the distribution was found to be nonparametric ($p < 0.05$). Data ignored for work accidents underwent predictive mean imputation with robust sensitivity (Supplementary material 1).

Notably, given the descriptive nature of the study, inferential analyses and formal hypothesis testing were unnecessary. Similarly, it is important to note that, although the original dataset included all deaths recorded in Brazil between 2014 and 2022, the final analytical sample represents only its subset. This reduction resulted from the exclusion of individuals under 10 and over 69 years of age, as well as records lacking valid BCO codes[23]. To evaluate variations in the proportional distribution of deaths across different variable categories, the chi-square test for heterogeneity was applied. The full code for data construction and processing is available at: https://doi.org/10.5281/zenodo.14927296 [29]. All data processing and analysis were performed using R software (version 4.4.2, R Project for Statistical Computing).

Ethical aspects

This study used publicly available and non-identifiable microdata from DATASUS, a unit of the Ministry of Health responsible for developing and managing health information systems. DATASUS makes microdata publicly accessible only after removing all potentially identifiable information, such as names, unique identification numbers (e.g., CPF—Cadastro de Pessoa Física and RG—Registro Geral) and residential or workplace addresses, thereby ensuring that the datasets are fully anonymized. As such, the study is exempt from assessment by a Research Ethics Committee and registration on Plataforma Brasil, the national electronic system for registering research involving human beings in Brazil in accordance with the Resolution No. 674 of May 6, 2022[30,31].

Results

Between 2014 and 2022, a total of 12,713,910 deaths were recorded in Brazil. For this analysis, 6,790,213 records involving individuals younger than 10 years or older than 69 years were excluded, resulting in 10,191 deaths from V10–V19—general-CITA. Subsequently, 2,904,005 records without BCO of interest or missing data were excluded, totaling 6590 deaths attributed to BCO-CITA. Of this, 272 (4.1%) were classified as WR-BCO-CITA and 2552 (38.7%) as NonWR-BCO-CITA. Notably, 3766 (57.2%) were classified as missingWR-BCO-CITA (Fig. 1).

Table 1 presents the proportional mortality distribution of general-CITA and BCO-CITA by variables of interest. In both groups, the majority of deaths occurred among men, accounting for 89.4% of general-CITA deaths and 92.5% of BCO-CITA deaths. Age distribution patterns showed a positive correlation between both CITA groups, with the highest proportions in the 44–58 age range and declining after age 58. In terms of race/color, Mixed individuals represented 49.2% of general-CITA deaths and 49.1% of BCO-CITA. Education level analysis revealed that individuals with not more than 11 years of schooling comprised a major proportion of deaths in both groups, accounting for 75.4% of general-CITA deaths and 79.4% of BCO-CITA. Regarding marital status, single individuals had the highest death rates in both categories, making up 54,1% of general-CITA deaths and 50.4% of BCO-CITA. The proportion of individuals who had received medical assistance was 46,2% among general-CITA deaths, compared to 47.4% among BCO-CITA deaths. Geographically, the Southeast (36.7%) and South (22.2%) macroregions together accounted for 58.9% of general-CITA deaths. Among BCO-CITA deaths, the Northeast ranked third (22.1%), behind the Southeast (33.7%) and South (24.7%). Urban municipalities concentrated approximately 78% of deaths in both groups. Regarding the place of death, hospital was the most frequent location, accounting for 51% in both groups while public roads accounted for 41%. Analysis of occupational history in BCO-CITA deaths showed that highest proportional mortality occurred among workers in the industrial services, agricultural, and sales/commerce sectors. Specifically, industrial service workers accounted for the highest (31.9%), while workers in Armed forces reported the lowest (0.4%). Temporally, both groups showed increased representation during the COVID-19 pandemic, with 33.8% of general-CITA deaths and 36% of BCO-CITA occurring during this period. Table 1 also includes information on missing/ignored data. The application of the chi-square test for heterogeneity demonstrated a statistically significant difference ($p < 0.05$) in the distribution of deaths across all variables when comparing general-CITA deaths with those classified as BCO-CITA (Table 1).

Table 2 summarizes deaths classified as BCO-CITA stratified by work related and variables of interest. Between 2014 and 2022, Brazil recorded 272 WR-BCO-CITA deaths. The victims were predominantly men (87.1%), aged between 29 and 58 years (68.3%), of White race/color (49.6%), with 4–11 years of education (64.3%) and single marital status (45.9%). Among these cases, 102 (37.5%) did not receive medical assistance. By region, 103 deaths (37.9%) occurred in the South and 90 deaths (33.1%) occurred in the Southeast, together accounting for 71% of the cases. Urban municipalities were the location for 85.3% of recorded WR-BCO-CITA deaths. While 51.1% of deaths occurred in hospitals, 116 victims (42.6%) died on public roads. In terms of occupation, 100 (42%) worked in industrial services, 84 (30.9%) in sales and commerce and 23 (8.5%) in agriculture. The number of WR-BCO-CITA deaths showed a slight increase over time, with 80 cases recorded in the first three-year period, 93 in the second and 99 in the third (2020–2022). Markedly, among the 6590 BCO-CITA, 3766 (57.1%) lacked information on WRAs (Table 2).

However, results from the sensitivity analysis conducted to estimate the probable number of unrecorded WR-BCO-CITA indicated that 248 of the unclassified cases were likely WR-BCO-CITA (Supplementary material 1). This adjustment would raise the total estimated number of WR-BCO-CITA to 520, increasing the proportion from 4.1 to 7.9%. Notably, the sociodemographic distribution and patterns observed in the descriptive analyses remained consistent, suggesting robustness in the trends initially identified.

Table 3 summarizes PM due to BCO-CITA stratified by work-related and ICD-10 subgroups, V10-V19. Among the 6590 BCO-CITA deaths, 3208 (48.7%) resulted from collisions with cars, pick-ups or vans (V13)

Variables	Work-related			p-value†
	Yes = 272	No = 2552	Missing data = 3766	
	n (%)	n (%)	n (%)	
Gender				**0.015**
Female	35 (12.9)	212 (8.3)	244 (6.5)	
Male	237 (87.1)	2340 (91.7)	3521 (93.5)	
Missing data	0 (0.0)	0 (0.0)	1 (0.0)	
Age range				0.277
10–14	0 (0.0)	3 (0.2)	2 (0.2)	
15–18	7 (2.7)	48 (1.9)	62 (1.6)	
19–23	21 (7.7)	132 (5.2)	214 (5.7)	
24–28	16 (5.9)	156 (6.1)	247 (6.5)	
29–33	22 (8.1)	209 (8.2)	244 (6.5)	
34–38	28 (10.3)	217 (8.5)	352 (9.3)	
39–43	36 (13.2)	278 (10.9)	393 (10.4)	
44–48	36 (13.2)	308 (12.1)	452 (12.0)	
49–53	31 (11.4)	297 (11.6)	485 (12.9)	
54–58	33 (12.1)	363 (14.2)	523 (13.9)	
59–63	28 (10.3)	287 (11.2)	460 (12.2)	
64–69	14 (5.1)	254 (9.9)	332 (8.8)	
Race/color				0.006
White	135 (49.7)	1093 (42.8)	1550 (41.2)	
Black	26 (9.5)	162 (6.2)	258 (6.8)	
Yellow	2 (0.7)	5 (0.2)	6 (0.2)	
Mixed	109 (40.1)	1257 (49.4)	1873 (49.7)	
Indigenous	0 (0.0)	8 (0.3)	10 (0.3)	
Missing data	0 (0.0)	27 (1.1)	69 (1.8)	
Education level				**< 0.001**
None	7 (2.6)	204 (8.0)	245 (6.5)	
1–3	42 (15.4)	468 (18.3)	758 (20.1)	
4–7	80 (29.4)	761 (29.8)	1092 (29.0)	
8–11	95 (35.0)	673 (26.4)	813 (21.7)	
≥ 12	9 (3.3)	141 (5.5)	190 (5.0)	
Missing data	39 (14.3)	305 (12.0)	668 (17.7)	
Marital status				0.008
Single	125 (45.9)	1277 (50.0)	1922 (51.0)	
Married	105 (38.6)	723 (28.3)	1044 (27.7)	
Widower	2 (0.8)	55 (2.2)	84 (2.2)	
Legally separated	15 (5.5)	187 (7.3)	299 (7.9)	
Stable union	16 (5.9)	188 (7.4)	196 (5.2)	
Missing data	9 (3.3)	122 (4.8)	221 (6.0)	
Medical assistance				0.578
No	102 (37.5)	959 (37.6)	1034 (27.5)	
Yes	137 (50.4)	1182 (46.3)	1804 (47.9)	
Missing data	33 (12.1)	411 (16.1)	928 (24.6)	
Macroregions of Brazil				**< 0.001**
North	32 (11.8)	220 (8.6)	150 (4.0)	
Northeast	23 (8.4)	597 (23.4)	834 (22.1)	
Central-west	24 (8.8)	247 (9.7)	613 (16.3)	
South	103 (37.9)	766 (30.0)	761 (20.2)	
Southeast	90 (33.1)	722 (28.3)	1408 (37.4)	
Municipality typology				**< 0.001**
Remote rural	3 (1.1)	35 (1.4)	20 (0.5)	
Adjacent rural	22 (8.1)	421 (16.5)	435 (11.5)	
Remote intermediary	3 (1.1)	17 (0.7)	8 (0.2)	
Adjacent intermediary	12 (4.4)	205 (8.0)	219 (5.8)	
Urban	232 (85.3)	1869 (73.2)	3072 (81.6)	

Continued

Variables	Work-related			p-value†
	Yes = 272	No = 2552	Missing data = 3766	
	n (%)	n (%)	n (%)	
Missing data	0 (0.0)	5 (0.2)	12 (0.4)	
Place of occurence				0.362
Hospital	139 (51.1)	1168 (45.7)	2090 (55.5)	
Other health establishment	3 (1.1)	48 (1.9)	97 (2.6)	
Homesstead	2 (0.8)	28 (1.1)	42 (1.1)	
Public road	116 (42.6)	1214 (47.5)	1394 (37.0)	
Others	12 (4.4)	92 (3.6)	141 (3.7)	
Missing data	0 (0.0)	2 (0.2)	2 (0.1)	
BCO codes††				**< 0.001**
Armed forces	2 (0.8)	13 (0.6)	15 (0.5)	
Public officials	5 (1.8)	70 (2.7)	95 (2.5)	
Sciences and arts	9 (3.3)	87 (3.4)	118 (3.1)	
High school technician	12 (4.4)	179 (7.0)	306 (8.1)	
Administrative services	12 (4.4)	71 (2.8)	102 (2.7)	
Sales and trade services	84 (30.9)	498 (19.5)	769 (20.4)	
Agricultural	23 (8.5)	667 (26.1)	756 (20.1)	
Industrial services 1	100 (36.8)	765 (30.0)	1237 (32.8)	
Industrial services 2	17 (6.2)	64 (2.5)	101 (2.7)	
Repairs and maintenance	8 (2.9)	138 (5.4)	267 (7.1)	
Triennium				0.989
2014–2016	80 (29.4)	744 (29.2)	1216 (32.3)	
2017–2019	93 (34.2)	868 (34.0)	1218 (32.3)	
2020–2022	99 (36.4)	940 (36.8)	1332 (35.4)	

Table 2. Proportional mortality of cyclists aged 10–69 years injured in transport accidents (ICD-10 codes V10–V19), classified by BCOs of interest (BCO-CITA) in Brazil, 2014–2022 (n = 6590). Data source: Mortality Information System (MIS), Department of Informatics of the Unified Health System (DATASUS), Brazilian Ministry of Health. International Classification of Diseases, 10th revision (ICD-10), codes V10-V19 (see Fig. 1 for a complete description). †Chi-square test for heterogeneity. Values in bold are statistically significant ($p < 0.05$). ††Brazilian Classification Occupation-10 major groups[26]. BCO-CITA: deaths due to cycling injuries in transport accidents, with a valid occupational code.

and with heavy transport vehicles or buses (V14). This proportion was higher among WR-BCO-CITA deaths, representing 61.3% (167/272). Similarly, 43 (15.9%) cases were classified as unspecified transport accidents (V19). Among the 3766 missingWR-BCO-CITA deaths, higher proportions were observed in collision involving cars, pick-ups or vans (31.9%) (V13), unspecified transport accidents (18.5%) (V19) and in non-collision transport accidents (16.9%) (V18) (Supplementary material 2).

Table 4 presents the median age at death and interquartile range for BCO-CITA and WR-BCO-CITA, stratified by variables of interest. The median age at death was 47 years for BCO-CITA and 45 years for WR-BCO-CITA. In general, median ages for WR-BCO-CITA were lower than those for BCO-CITA, except for the groups with higher education, the Northeast region, public officials, industrial services 2, and subgroup code V10. Statistical analyses using the Mann–Whitney U and Kruskal–Wallis tests showed statistically significant differences ($p < 0.05$) across all variables in the BCO-CITA group, except municipal typology. However, when the same tests were applied to the WR-BCO-CITA group, significant differences were observed only for education level and marital status.

The calculations of YPLL, %YPLL and %YPLL ratio are presented in Table 5 stratified by BCO-CITA versus WR-BCO-CITA and variables of interests. During the analyzed period, a total of 200,336 YPLL were recorded for all 6590 deaths, while WR-BCO-CITA cases accounted for 8894 YPLL. A consistent pattern in the distribution of %YPLL was observed for both BCO-CITA and WR-BCO-CITA cases. The proportions of YPLL were concentrated among male cyclists (91.4% vs. 86.3%), single individuals (62.3% vs. 56.1%) who had received medical assistance (58.1% vs. 55.8%). Equally, individuals from urban municipalities (78.9% vs. 84.9%), deaths occurring in hospitals (49.8% vs. 51.6%), workers in service and industrial sectors/group 1 (31.5% vs. 36%), deaths occurring during 2020–2022 triennium (35.6% vs. 36.5%) and classified under code V13—cyclist injured in collision with automobile, pick-up or truck (33.4% vs. 32.8%) prevailed. Among WR-BCO-CITA, higher %YPLL values were observed among White race/color workers (48.3%), with 8–11 years of education (46%) and residing in the Southeast region (38.6%). The highest %YPLL ratios WR-BCO-CITA/BCO-CITA were observed among women (1.59), Yellow individuals (3.00), residents of the North (1.75) and Southeast (1.58) regions, residing in remote intermediary municipalities (2.40) and industrial service workers 2 (2.20).

ICD-10 codes	BCO-CITA			
	Total	Work-related		
	n = 6590	Yes = 272	No = 2552	Missing data = 3766
	n (%)	n (%)	n (%)	n (%)
V10	28 (0.4)	2 (0.7)	14 (0.5)	12 (0.3)
V11	46 (0.7)	1 (0.4)	23 (0.9)	22 (0.6)
V12	850 (12.9)	32 (11.8)	358 (14.0)	460 (12.2)
V13	2147 (32.6)	88 (32.3)	856 (33.5)	1203 (31.9)
V14	1061 (16.1)	79 (29.0)	374 (14.7)	608 (16.1)
V15	10 (0.1)	–	4 (0.2)	6 (0.2)
V16	12 (0.2)	–	6 (0.2)	6 (0.2)
V17	215 (3.3)	7 (2.6)	92 (3.6)	116 (3.1)
V18	1049 (15.9)	20 (7.3)	391 (15.3)	638 (16.9)
V19	1172 (17.8)	43 (15.9)	434 (17.1)	695 (18.5)

Table 3. Proportional mortality of cyclists aged 10–69 years injured in transport accidents, classified by BCOs of interest (BCO-CITA) and by ICD-10 Chaper XX subgroups V10–V19, in Brazil, 2014–2022 (n = 6590). Data source: Mortality Information System (MIS), Department of Informatics of the Unified Health System (DATASUS), Brazilian Ministery of Health. International Classification of Diseases, 10th revision (ICD-10), codes V10-V19 (see Fig. 1 for a complete description). BCO-CITA: deaths due to cycling injuries in transport accidents, with a valid occupational code.

Discussion

The descriptive analyses provided insights into the demographic, occupational, temporal and geographic profile of cyclist fatalities among individuals aged 10–69 years who used bicycles for work-related activities in Brazil between 2014 and 2022. During this period, 6590 BCO-CITA deaths were recorded, of which 272 (4.1%) were classified as WR-BCO-CITA. The median age at death was 47.0 years, with fatalities predominating occurring among men aged 29–58 years, of white race/color, with lower education levels, single and employed in the industrial, service or commercial sectors. Most cases were concentrated in the South and Southeast regions, particularly in urban municipalities. Collisions with motor vehicles (ICD-10 codes V13 and V14) accounted for 48.7% of these fatalities. Of the total YPLLs due to BCO-CITA (200,336 years), 8894 YPLLs were attributed to WR-BCO-CITA. Although records of BCO-CITA fatalities increased over the three-year periods, a significant proportion (57.1%) of DCs lacked information on the association between fatalities and WRAs, suggesting potential underreporting or gaps in data collection.

The observed patterns of general-CITA and BCO-CITA fatalities, predominantly among males and those with low education levels align with international findings. An international review conducted in the Netherlands[32] reported that men face higher traffic risks, possibly due to risk behaviors and greater use of bicycles for long-distance commuting. Similarly, a systematic review by Pucher and Buehler[33] showed that individuals with lower education levels often possess limited access to road safety information and are less likely to use PPE. The lower median age at death among women and individuals with low to intermediate education levels further highlights gender and class disparities, aligning with findings by Heesch et al.[34] in Australia. These findings underscore the need for targeted interventions, such as improved cycling infrastructure and educational programs for vulnerable groups, to reduce the increasing number of traffic accidents, as well as the high proportion of observed YPLL. This aligns with the recommendations of Teschke et al.[35] from a case–control study in Canada involving 690 injured cyclists and Aldred et al.[36] from a longitudinal study in the United Kingdom with 1500 cyclists, both advocating for enhanced infrastructure and tailored safety education to mitigate cycling-related risks.

The median age at death among WR-BCO-CITA cases was 45 years (IQR: 34–55 years), highlighting the precocity of these fatalities. Notably, the age dropped to 41 years (IQR: 31–51 years) among female workers. These findings align with previous studies which reported variations in the median age at death among cyclists involved in traffic accidents, typically ranging from 32 to 50 years[37,38]. A meta-analysis[39] encompassing 18 studies on cycling accident risks and sociodemographic factors suggests that young and middle-aged adults are at higher risk of being involved in bicycle accidents. A potential explanation is that younger individuals, due to greater physical vigor, may cycle at higher speeds, increasing the severity of accidents. Additionally, young workers are more often engaged in activities that require cycling in high-traffic environments, such as app-based delivery services, thereby increasing their exposure risk. Also, the lack of PPE and lower adherence to traffic laws among younger cyclists may also contribute to their higher fatality rates. However, it is important to emphasize that these are plausible hypotheses rather than definitive conclusions, given the limitations of DC data used in this study. To establish these associations more robustly, further epidemiological research, particularly analytical studies such as case–control investigations, is needed.

The characterization of BCO-CITA and WR-BCO-CITA fatalities by occupation in this study was made possible by the "Usual occupation" field in the DC[24]. To facilitate comparison, workers were grouped into the ten major occupational categories based on BCO[26]. The proportional mortality distribution by WR-BCO-CITA and occupation showed that 43% of victims were from the industrial sector, 30.9% from the sales and commerce sector and 8.5% from the agricultural sector. These findings align with previous study indicating that workers

Variables	BCO-CITA = 6590		WR-BCO-CITA = 272	
	Median (25th–75th)	p-value††	Median (25th–75th)	p-value††
Gender		**< 0.001**		0.283
Female	42.0 (32.0–52.0)		41.0 (31.0–51.0)	
Male	48.0 (36.0–57.0)		45.0 (34.0–55.0)	
Race/color		**< 0.001**		0.269
White	49.0 (37.0–58.0)		47.0 (34.0–55.0)	
Black	45.0 (34.0–55.0)		38.5 (32.0–50.0)	
Yellow	60.0 (40.0–63.0)		49.5 (44.7–54.2)	
Mixed	47.0 (35.0–56.0)		42.0 (34.0–55.0)	
Indigenous	40.5 (25.2–52.7)		–	
Education level		**< 0.001**		**0.001**
None	55.0 (47.0–61.0)		52.0 (38.5–54.5)	
1–3	52.0 (42.0–60.0)		48.5 (43.0–56.7)	
4–7	48.0 (37.0–57.0)		46.0 (38.0–55.2)	
8–11	40.0 (29.0–52.0)		40.0 (28.5–50.5)	
≥ 12	43.5 (34.0–54.0)		55.0 (34.0–58.0)	
Marital status		**< 0.001**		**< 0.001**
Single	41.0 (30.0–51.0)		39.0 (26.0–47.0)	
Married	54.0 (45.0–61.0)		50.0 (40.0–59.0)	
Widower	60.0 (56.0–65.0)		57.0 (56.0–58.0)	
Legally separated	55.0 (47.0–60.0)		55.0 (46.5–61.0)	
Stable union	45.0 (35.0–54.0)		40.0 (33.0–54.2)	
Medical assistance		**< 0.001**		0.269
No	46.0 (35.0–56.0)		43.0 (32.0–54.7)	
Yes	49.0 (37.0–58.0)		46.0 (36.0–54.0)	
Macroregions of Brazil		**< 0.001**		0.562
North	47.0 (35.0–58.0)		44.5 (38.7–57.2)	
Northeast	48.0 (36.0–57.0)		49.0 (41.0–53.5)	
Central-west	48.0 (38.0–58.0)		41.5 (36.0–48.0)	
South	46.0 (34.0–56.0)		42.0 (32.0–54.7)	
Southeast	49.0 (36.2–57.0)		46.0 (31.0–55.0)	
All Brazil	47.0 (36.0–57.0)		45.0 (34.0–54.0)	
Municipality typology		0.277		0.573
Remote rural	45.5 (31.5–55.5)		37.0 (33.5–48.5)	
Adjacent rural	48.0 (37.0–58.0)		46,5 (32,3–58,7)	
Remote intermediary	45.0 (33.5–52.2)		39,0 (36,5–43,5)	
Adjacent intermediary	48.0 (35.0–57.0)		39.5 (22.0–51.0)	
Urban	47.0 (36.0–57.0)		45.0 (35.0–54.0)	
Place of occurence		**< 0.001**		0.336
Hospital	49.0 (38.0–58.0)		46.0 (35.0–54.0)	
Other health establishment	46.0 (33.0–56.0)		56.0 (49.0–56.5)	
Homestead	52.0 (44.0–58.0)		32.5 (27.2–37.7)	
Public road	45.0 (34.0–56.0)		41.0 (32.7–54.2)	
Others	49.0 (36.0–57.0)		49.5 (38.7–58.7)	
BCO codes†††		**< 0.001**		0.423
Armed forces	43.5 (30.0–50.5)		39.0 (29.5–48.5)	
Public officials	52.0 (38.0–60.0)		53.0 (41.0–61.0)	
Sciences and arts	45.0 (36.0–54.0)		50.0 (34.0–56.0)	
High school technician	46.0 (36.0–56.0)		39.5 (30.5–47.2)	
Administrative services	37.0 (25.0–50.0)		34.5 (26.5–46.5)	
Sales and trade services	46.0 (34.0–56.0)		45.0 (32.0–52.0)	
Agricultural	51.0 (40.0–59.0)		48.0 (41.0–56.5)	
Industrial services 1	48.0 (37.0–57.0)		45.5 (37.0–55.2)	
Industrial services 2	45.5 (35.2–54.7)		47.0 (31.0–54.0)	
Repairs and maintenance	43.0 (30.0–55.0)		38.0 (34.7–53.7)	
Triennium		**0.001**		0.166
Continued				

Variables	BCO-CITA = 6590		WR-BCO-CITA = 272	
	Median (25th–75th)	p-value††	Median (25th–75th)	p-value††
2014–2016	46.0 (34.0–56.0)		41.5 (33.0–51.0)	
2017–2019	48.0 (37.0–57.0)		46.0 (36.0–55.0)	
2020–2022	48.0 (37.0–57.0)		45.0 (33.0–56.0)	
Subgroups V10–V19†		**< 0.001**		0.069
V10	47.0 (38.5–57.2)		29.0 (23.5–34.5)	
V11	48.0 (40.0–56.0)		40.0 (40.0–40.0)	
V12	52.0 (41.0–60.0)		51.0 (46.7–58.2)	
V13	46.0 (35.0–56.0)		44.0 (33.5–52.0)	
V14	45.0 (33.0–55.0)		41.0 (32.0–54.5)	
V15	43.0 (28.7–51.5)		–	
V16	30.0 (23.5–43.0)		–	
V17	42.0 (31.0–54.0)		55.0 (30.0–58.5)	
V18	49.0 (39.0–58.0)		45.5 (32.2–53.2)	
V19	47.0 (35.0–57.0)		42.0 (34.0–53.5)	

Table 4. Median age at death of cyclists aged 10–69 years involved in transport accidents (ICD-10 codes V10–V19), classified by BCOs of interest (BCO-CITA and WR-BCO-CITA), in Brazil, 2014–2022 (n = 6590). Data source: Mortality Information System (MIS), Department of Informatics of the Unified Health System (DATASUS), Brazilian Ministery of Health. †International Classification of Diseases, 10th revision (ICD-10), codes V10-V19 (see Fig. 1 for a complete description). ††Mann–Whitney and Kruskal–Wallis tests were used. Values in bold indicate statistical significance ($p < 0.05$). †††Brazilian Classification of Occupation – 10 major groups[26]. 25th–75th percentiles (interquartile range): Measure of dispersion. BCO-CITA: deaths due to cycling injuries in transport accidents, with a valid occupational code. WR-BCO-CITA: subset of BCO-CITA classified as work-related.

in these sectors frequently use bicycles as a means of transportation to work[2]. Although additional occupational details were not available in the DC, it is plausible that industrial workers primarily used bicycles for commuting, classifying their deaths as commuting accidents. Workers in the sales and trade sector may have been engaged in delivery services, such as food delivery, a common practice in Brazil[12], potentially categorizing their deaths as typical work-related accidents. While studies on cyclist fatalities in Brazil exist, few have specifically examined the victims' economic activities[3,12,21]. Globally, there is also a notable gap in studies on the relationship between bicycle use and specific occupations, such as postal workers, armed forces personnel and app delivery workers. Despite improvements in the quality of occupational data in information systems, certain crucial details, like the use of PPE at the time of the accident, the condition of the bicycle and others contextual factors remain absent. To enable more comprehensive analyses of workers' health and safety, it is essential to incorporate these data fields into the official reporting systems.

Collisions with motor vehicles (ICD-10 codes V13 and V14) accounted for 48.7% of BCO-CITA fatalities and 61.3% of WR-BCO-CITA cases during the study period. These findings align with a national study conducted between 2001 and 2010, using the same data source (MIS), which examined bicycle-related fatalities in São Paulo, Brazil's largest city, with approximately 11.5 million inhabitants. That study found that more than 46.4% of cyclist deaths were classified under ICD codes V13 and V14, from 2000 to 2017[21]. The rapid expansion of São Paulo's fleet from 5 million in 2000 to 8 million in recent years[40], likely contributes to the high proportion of such collisions. A similar trend has been observed internationally. A study conducted in London, analyzing collisions between 2007 and 2011, found that 51% of cyclist fatalities involved trucks, while 28% involved cars[41]. The substantial difference in size and weight between bicycles and motor vehicles makes these collisions particularly dangerous, often leading in fatal or life-threatening injuries for cyclists. One important regulatory safeguard is Article 201 of the BCO, which mandates that motor vehicle drivers "maintain a minimum lateral distance of 1.5 m when overtaking cyclists, with failure to comply considered a medium-level infraction, subject to a fine"[42]. A more effective long-term solution lies in expanding dedicated cycling infrastructure, particularly in high-traffic urban areas and regions with substantial number of commuting cyclists. A 2023 study highlighted a negative correlation between increased cycling infrastructure and reduced cyclist mortality rates in São Paulo, reinforcing the critical role of urban planning interventions in enhancing general road safety[21].

The calculation of YPLL was based on a LE of 76.3 years for Brazil in 2018, representing the midpoint of the analysis period and is closely aligning with the average LE for the entire study period (76.1 years)[28]. As an indicator of premature mortality burden, YPLL has been widely used in studies on traffic fatalities[43–45], including analyses by specific vehicle types, such as motorcycles[46–48]. However, studies focusing on cyclists, both in general population and among workers, remains scarce, particularly in relation to YPLL estimation. During the study period, 6590 cyclist fatalities were recorded, resulting in 200,336 YPLL among BCO-CITA cases, with 8894 YPLL attributed to the 272 WR-BCO-CITA cases. Since YPLL is an absolute value, larger populations naturally yield higher values. The lack of reliable data on the total number of cyclists, both in the general population and among workers, limits the possibility of direct comparison between groups. To address

Variables	YPLL		%YPLL		%YPLL ratio: WR-BCO-CITA/BCO-CITA (95% CI)
	BCO-CITA	WR-BCO-CITA	BCO-CITA	WR-BCO-CITA	
Gender					
Female	17,135.9	1218.0	8.6	13.7	1.59 (0.70–3.59)
Male	182,940.0	7678.8	91.4	86.3	0.94 (0.70–1.26)
Race/color					
White	82,228.8	4293.0	41.6	48.3	1.16 (0.77–1.74)
Black	14,272.0	951.6	7.2	10.7	1.48 (0.60–3.62)
Yellow	301.2	53.6	0.2	0.6	3.0 (0.28–31.99)
Mixed	100,409.0	3586.1	50.7	40.4	0.79 (0.52–1.19)
Indigenous	651.6	–	0.3	–	–
Education level					
None	10,396.8	200.9	6.1	2.6	0.42 (0.11–1.51)
1–3	33,221.6	1146.6	19.6	15.1	0.77 (0.40–1.47)
4–7	58,376.6	2488.0	34.4	32.8	0.95 (0.59–1.52)
8–11	56,599.8	3496.0	33.4	46.0	1.37 (0.88–2.13)
≥ 12	11,084.0	263.7	6.5	3.5	0.53 (0.16–1.73)
Marital status					
Single	118,334.4	4812.5	62.3	56.1	0.90 (0.62–1.28)
Married	44,928.0	2835.0	23.7	33.9	1.43 (0.85–2.39)
Widower	2368.8	38.6	1.2	0.5	0.41 (0.05–3.31)
Legally separated	11,573.1	351.0	6.1	4.1	0.67 (0.21–2.09)
Stable union	12,640.0	534.4	6.7	6.2	0.92 (0.33–2.55)
Medical assistance					
No	65,992.5	3468.0	41.9	44.2	1.05 (0.69–1.60)
Yes	91,503.9	4370.3	58.1	55.8	0.96 (0.66–1.38)
Macroregions of Brazil					
North	12,180.6	950.4	6.1	10.7	1.75 (0.69–4.45)
Northeast	43,620.0	687.7	21.8	7.7	0.35 (0.16–0.77)
Central-west	25,636.0	811.2	12.8	9.1	0.71 (0.31–1.60)
South	70,152.0	3006.0	35.0	33.8	0.96 (0.60–1.53)
Southeast	48,737.0	3429.9	24.3	38.6	1.58 (0.96–2.61)
Brazil	200,336.0	8894.4	–	–	–
Municipality typology					
Remote rural	1850.2	102.0	0.9	1.1	1.22 (0.17–8.69)
Adjacent rural	25,988.8	668.8	13.0	7.5	0.57 (0.24–1.35)
Remote intermediary	918.4	108.0	0.5	1.2	2.4 (0.30–19.12)
Adjacent intermediary	13,341.6	462.0	6.7	5.2	0.77 (0.26–2.23)
Urban	157,776.5	7540.0	78.9	84.9	1.07 (0.79–1.46)
Place of occurence					
Hospital	99,871.8	4475.8	49.8	51.6	1.03 (0.70–1.52)
Other health establishment	4736.0	73.8	2.4	0.9	0.37 (0.06–2.21)
Homestead	1857.6	87.6	0.9	1.0	1.11 (0.15–8.09)
Public road	86,623.2	3688.8	43.2	42.6	0.98 (0.64–1.49)
Others	7399.0	342.0	3.7	3.9	1.05 (0.29–3.73)
BCO codes[††]					
Armed forces	1077.0	74.6	0.5	0.8	1.60 (0.18–13.96)
Public officials	4675.0	123.5	2.3	1.4	0.60 (0.11–3.21)
Sciences and arts	6762.4	273.6	3.4	3.1	0.91 (0.23–3.50)
High school technician	15,655.5	442.8	7.8	5.0	0.64 (0.22–1.80)
Administrative services	7,048.5	474.0	3.5	5.3	1.51 (0.45–5.07)
Sales and trade services	42,691.6	2822.4	21.3	31.8	1.49 (0.87–2.55)
Agricultural	39,620.4	648.6	19.8	7.3	0.36 (0.16–0.82)
Industrial services 1	63,060.0	3200.0	31.5	36.0	1.14 (0.71–1.83)
Industrial services 2	5787.6	569.5	2.9	6.4	2.20 (0.64–7.52)
Repairs and maintenance	14,000.7	257.6	7.0	2.9	0.41 (0.12–1.38)
Triennium					
Continued					

Variables	YPLL		%YPLL		
	BCO-CITA	WR-BCO-CITA	BCO-CITA	WR-BCO-CITA	%YPLL ratio: WR-BCO-CITA/BCO-CITA (95% CI)
2014–2016	64,056.0	2776.0	31.9	31.2	0.97 (0.60–1.58)
2017–2019	65,152.1	2873.7	32.5	32.3	0.99 (0.61–1.60)
2020–2022	71,367.1	3247.2	35.6	36.5	1.02 (0.65–1.61)
Subgrupo V10–V19†					
V10	862.4	94.6	0.4	1.1	2.75 (0.32–3.33)
V11	1343.2	36.5	0.7	0.4	0.57 (0.06–5.35)
V12	22,525.0	819.2	11.3	9.2	0.81 (0.35–1.86)
V13	66,771.7	2912.8	33.4	32.8	0.98 (0.61–1.57)
V14	34,270.3	2709.7	17.1	30.5	1.78 (1.00–3.17)
V15	363.0	–	0.2	–	–
V16	498.0	–	0.3	–	–
V17	7353.0	226.1	3.6	2.5	0.69 (0.17–2.78)
V18	30,001.4	664.0	15.0	7.5	0.50 (0.21–1.14)
V19	36,097.6	1414.7	18.0	15.9	0.88 (0.45–1.70)

Table 5. Years of Potential Life Lost (YPLL) among cyclists aged 10–69 years injured in transport accidents (ICD-10 codes V10-V19)†, classified by BCO-CITA and WR-BCO-CITA, in Brazil, 2014–2022 (n = 6590). Data source: Mortality Information System (MIS), Department of Informatics of the Unified Health System (DATASUS), Brazilian Ministery of Health. †International Classification of Diseases, 10th revision (ICD-10), codes V10-V19 (see Fig. 1 for a complete description). ††Brazilian Classification Occupation-10 major groups[26]. BCO-CITA: deaths due to cycling injuries in transport accidents, with a valid occupational code. WR-BCO-CITA: subset of BCO-CITA classified as work-related.

this limitation, YPLL proportions were analyzed to identify subgroups bearing the highest burden. The highest YPLL values were observed among men, individuals aged 34–48, those identifying as white, individuals with low education levels and single workers, a demographic profile similar to that reported in previous studies on traffic fatalities[43]. Additionally, workers in the industrial and sales/services sectors accounted for 74.2% of total YPLL, highlighting their particular vulnerability. Despite the increasing use of bicycles for work-related activities, certain occupational groups remain disproportionately exposed to risk. While the use of absolute YPLL value has inherent limitations, this indicator remains a valuable tool, particularly given the high quality, completeness and reliability of the data source used in this study[48], providing robustness to our results.

MIS, the data source used here, is Brazil's primary mortality registry and one of the country's key MIS, recording approximately 1 million deaths annually[49–51]. The dataset analyzed here showed an 83% completion rate for the occupation field of the DC, which is considered to be of moderate quality[49]. Although significant improvements in MIS data quality have occurred over time, the system still presents gaps in critical variables such as education, race/color and access to medical assistance, limiting the scope of more comprehensive analyses. A particularly critical issue is the incomplete reporting of occupation field. Even when the "Usual Occupation" field is filled out, many DCs either omit or leave blank the WRA field. Here, 57% of BCO-CITA cases lacked information regarding work-relatedness (missingWR-BCO-CITA) making it difficult to assess the full impact of work-related factors. Another important consideration is the regional disparity in data completeness. Studies have shown that Brazil's North and Northeast regions experience higher levels of underreporting and incomplete records[52,53], which may contribute to an underestimation of WRCFs in these regions. Therefore, when interpreting MIS data, it is important to consider the issues of data completeness and potential underreporting in DC fields to minimize biases.

The original database comprised 12,713,910 deaths registered between 2014 and 2022, from which 2,904,005 BCO records were excluded from the analysis (Fig. 1). This methodological decision was guided by the DC manual, which instructs that the "Usual occupation" field should be filled with the deceased's main economic activity during their lifetime[24]. The most recent BCOs (2024)[26] does not include specific codes for categories such as students, housewives, retirees/pensioners, unemployed individuals and prisoners, as these may not correspond to formal occupations. Excluding these cases likely did not introduce selection bias, as the excluded BCO codes were predominantly associated with individuals below 10 years and above 69 years of age, categories excluded from our analyses.

In Brazil, occupational studies typically set the minimum age at 16 years, in accordance with the Federal Constitution[53] and Statute of Children and Adolescents[54] or 18 years, which marks the age of majority[55]. However, this study included individuals aged 10 years or older in the identification of BCO-CITA cases, recognizing that cycling does not require governmental authorization and may be used by younger individuals for economic activities. Among the five BCO-CITA fatalities in the 10–14 age group, none were classified as WR-BCO-CITA, although two cases lacked information in the corresponding field. In the 15–18 age group, 7 WR-BCO-CITA cases were recorded, while 62 deaths were missingWR-BCO-CITA. Notably, the lack of records in the WRA field may obscure the presence of child labor—an economic activity common in many low- and middle-income countries (LMICs). This not only exposes children and adolescents to unsafe working conditions but also threatens their physical, mental, social and moral development, often interfering with their education[56,57].

To define the study period, a 9-year timeframe (2014–2022) was adopted and segmented into three-year intervals to assess trends during the COVID-19 pandemic (2020–2022) in comparison to the two preceding periods (2014–2016 and 2017–2019). The years 2023 and 2024 were excluded, as the MIS database accessed in early 2025 still classified these records as "preliminary". Data prior to 2014 were also excluded due to lower information quality[58]. The study identified an increasing trend in proportional mortality across the three-year periods for both BCO-CITA and WR-BCO-CITA. The COVID-19 pandemic had a significant impact on urban mobility worldwide. In countries with well-developed road infrastructure, such as the United States, increased use of off-road spaces by cyclists led to a 28% decrease in collisions with motor vehicles[59]. Cities with bike sharing apps, like New York, experienced a non-significant reduction in cycling compared to other modes of transport, like the subway[60]. In contrast, Brazil's deficient public transportation system presented additional challenges for workers, particularly in 2020 and 2021. With reduced capacity limits on public buses, trains and subways to limit crowding, many workers turned to alternative modes of transport, including cycling. A significant portion of these new cyclists had little to no prior experience, potentially contributing to the rise in BCO-CITA fatalities. Also, the economic downturn and widespread loss of formal employment during the pandemic may have contributed to workers' migration to informal activities, including app-based delivery services, which saw increased demand during lockdowns. This shift in labor dynamics may have further contributed to the rise in proportional fatality among WR-BCO-CITA cases.

Established in 1997, the BTC defines the rights and responsibilities of cyclists[1]. Article 96 officially recognizes bicycles as a mode of transportation, permitting their circulation in both urban and rural areas, even in the absence of dedicated cycling infrastructure such as cycle paths or shoulders. Recently, efforts to promote cycling have expanded, including the creation of the Brazil bicycle program (*Programa Bicicleta Brasil*)[61], which aims to encourage the use of bicycle as a sustainable urban mobility solution. Also, Law No. 14729/2023[62] mandates that urban transportation planning must incorporate provisions for non-motorized vehicles. Despite these advances, a critical gap remains in protections for cyclists engaged in app-based delivery services, as no federal regulation specifically addresses their working conditions. While the legal frameworks seek to support cyclists, dedicated cycling infrastructure remains limited in Brazil. According to the Brazilian Bicycle Sector Association[63], the combined length of cycle path networks across the 26 state capitals and Brasília totaled 4365 km in 2023, an insignificant fraction compared to the country's vast road network, which spans approximately 1.7 million kilometers[64].

The DC does not include specific fields to record whether PPE was used in fatalities resulting in WRAs. It is therefore plausible that, among the 272 WR-BCO-CITA cases analyzed, a significant proportion of victims were not wearing helmets at the time of the accident. This assumption is supported by the fact that the BTC does not mandate helmet for non-motorized vehicles. For instance, a case–control study conducted in South Korea, involving 1394 injured cyclists (282 fatalities and 1112 survivors), reported a helmet usage rate of 11%. Helmet use was significantly more common among survivors (12.9%) than fatality (3.9%), with an OR of 2.99 (95% CI 1.50–5.98)[14]. The protective effect of helmets has been extensively documented in both children[65] and adults[66]. While helmet use remains optional in Brazil, many countries have implemented mandatory helmet laws. A 2018 meta-analysis found that such regulations led to a 20% reduction in overall head injuries (95% CI − 27% to − 13%) and a 55% decrease in severe head injuries (95% CI − 78% to − 8%). Notably, among children, legislation covering all cyclists was more effective in reducing injuries than those restricted to only minors[67].

The reduction in bicycle-related traffic accidents may be associated with the development of dedicated cycling infrastructure, including cycle routes, cycle lanes and cycle paths, particularly in urban areas with heavy motor vehicle traffic. A descriptive study conducted in São Paulo, using data from MIS and the Traffic Engineering Company (CET-SP) from 2000 to 2017, found an inverse correlation between the expansion of municipal cycling infrastructure and cyclist fatality rate (Pearson correlation coefficient = − 0.88; p = 0.0007)[21]. Similar trends have been observed in international studies. In Seville, Spain[68] and Toronto, Canada[69], the implementation of cycle paths led to a measurable decrease in collisions between cyclists and motor vehicles. Among the various types of infrastructure, cycle paths-segregated from motorized traffic, offers the safest option for cyclists. However, in densely populated urban environments where physical segregation may not be feasible, alternative measures such as cycle lanes (marked with paint, signage and road studs) and cycle routes (shared roads without physical separation) provides safer alternatives compared to the absence of infrastructure[35,36]. The demonstrated benefits of dedicated cycling infrastructure underscore the need for policymakers to prioritize its implementation, expansion and maintenance especially in urban settings.

The rapid evolution of app-based delivery services has greatly expanded use of bicycles for economic activities on digital platforms[12]. Registering for these services is typically easy, requiring the individual to be at least 18 years old and possess a valid form of identification, a smartphone and a bank account. However, the precarious nature of this arrangement becomes apparent when examining whether the companies provide essential PPE for their cyclists. An evaluation of policies at Brazil's two largest food delivery platform, both of which permit bicycle registration revealed critical oversights, neither platform offers essential PPE to its delivery workers. Rather, they merely recommend the use of protective gear or, in some cases, provide discounts or partnerships with third-party suppliers. This lack of direct support leaves cyclists vulnerable to accidents and injuries, underscoring a fundamental gap in workers protection. While app-based delivery services have undoubtedly reshaped bicycle-based work by increasing accessibility, they have also introduced new form of precarity. By allowing workers to register without ensuring compliance with safety requirements outlined in articles 105 of the BTC and 166 of the Consolidation of Labor Laws. These platforms raise serious concerns regarding corporate social responsibility and the broader welfare of their workers.

Given that this is a descriptive epidemiological study, establishing causal relationship regarding WRCFs is not within its scope and as such deemed unnecessary. Nevertheless, our findings highlight both the occurrence of worker fatalities in this context and the incomplete reporting of WRA on the DCs. This highlights the need to improve DC documentation by systematically including work-related classifications, which could help inform targeted interventions. Such measures may enhance the understanding of morbidity and mortality risks associated with bicycle use for occupational purposes across the country. In the study, the assessment of occupational characteristics was limited to identifying major occupational groups based on the BCO and determining whether each death was classified as work-related. Future studies utilizing primary data, including details on employment relationships, the specific purpose of bicycle use (e.g., commuting vs. work) and usage patterns, could offer a more robust occupational characterization of individuals who rely on bicycles for economic activities. Additionally, the use of data from the MIS presents certain limitations, including incomplete records and potential national representativeness. Despite these challenges, the quality of sociodemographic and occupational fields in the dataset has improved over time, enabling various studies capable of supporting occupational health surveillance and policy development[49].

It is also important to acknowledge that our analytical sample, limited to individuals aged 10–69 with deaths classified under specific BCO codes, represent only a subset of all recorded deaths during the study period. Consequently, the findings should be interpreted within the context of the study position. Although sensitivity analyses were conducted, the potential for residual bias cannot be entirely ruled out. Finally, the absence of official national data on the total number of workers using bicycles for commuting or app-based delivery work limits our ability to calculate reliable mortality rates. This lack of standardized denominators hinders group comparisons and impedes accurate assessment of the true burden of WRCFs among workers. These findings further reinforce the need for improved and standardized DC reporting to support future studies and guide effective policy interventions.

This study analyzed approximately 3 million death records containing valid BCO information over a nine-year period, including during the COVID-19 pandemic. Methodologically, the examination of a broad range of variables and the application of multiple health indicators, including proportional mortality, mean and median age at death, YPLL, %YPLL and %YPLL ratio, provided valuable insights into the profile of workers who experienced WRAs while using bicycles. The findings highlight the heightened vulnerability of cyclists and emphasize the critical need for accurate documentation of WRAs on DCs. These results should support the formulation or enhancement of public policies aimed at improving road safety for cyclists, irrespective of their reasons for bicycle use. Utimately, this study contributes to advancing strategies for sustainable and safer mobility.

Conclusions

Between 2014 and 2022, Brazil's MIS recorded 6590 BCO-CITA deaths, of which 272 (4.1%—excluding results from the sensitivity analysis) were classified as WR-BCO-CITA. Notably, information on work-related fatality status was missing in 57% of the records, indicating limitations in data completeness and suggesting a potential underestimation of WRCFs. As such, these findings, especially those related to occupational activity, should be interpreted with caution. Among the WR-BCO-CITA records with complete information, fatalities predominantly involved male cyclists aged 29–58 years, who were white, had less than 12 years of education and were single. Most deaths occurred among workers in the industrial, service and commerce sectors, with the South and Southeast regions accounting for 71% of the cases. Markedly, 61.3% of the deaths resulted from collisions between bicycles and motor vehicles, like cars, trucks, and buses (ICD-10 codes V13 and V14). The median age at death was 45 years, and the 272 WR-BCO-CITA deaths accounted for 8896.4 YPLL.

These findings highlight the need to train healthcare professionals on the importance of accurately and comprehensively completing DCs, particularly in fields related to WRAs. Such improvements can strengthen occupational health surveillance and inform public policies aimed at improving road safety, especially for workers who rely on bicycles for commuting or professional activities. Finally, the results emphasize the importance of collective education on the role and rights of cyclists in shared public spaces, which is essential for promoting sustainable and safe urban mobility.

Data availability

The complete code for data construction and processing is available at: https://doi.org/10.5281/zenodo.14927296.

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Author contributions

Jailma dos Santos Silva: Conceptualization, Methodology, Formal analysis, Writing – original draft and critical review. Mariela Sousa dos Santos: Methodology, Formal analysis, Writing – original draft. Joelma Marques: Methodology, Formal analysis, Writing – original draft. Adedayo Michael Awoniyi: Methodology, Writing – critical review and editing. Cleber Cremonese: Conceptualization, Methodology, Formal analysis, Writing – original draft and critical review. All authors read and approved the final version of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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