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Road traffic injury prevention and control

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Road traffic injury prevention and control

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Editorial: Road traffic injury prevention and control

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Editorial on the Research Topic
Road traffic injury prevention and control

According to the World Health Organization (WHO), road traffic injuries (RTIs) cause ∼1.19 million deaths globally each year. Over 90% of the fatalities on the roads occur in low- and middle-income countries (LMICs). More than half of these deaths are of vulnerable road users including pedestrians, cyclists, and motorcyclists. In addition to fatalities, between 20 to 50 million people sustain non-fatal injuries annually, many of which result in life-lasting disabilities. Given the persistent and devastating burden of road traffic crashes, there is an urgent need for further research and concerted action to address this critical public health issue. The articles in this Research Topic of Frontiers in Public Health tackle this pressing challenge, providing a comprehensive and multidimensional exploration of road traffic injury prevention and control.

This editorial synthesizes the contributions of the 11 articles in this Research Topic, which offer valuable evidence to inform future policy, practice, and research priorities in the field of road safety.

Several contributions examine RTI morbidity or mortality trends in broader contexts. Berheto et al. present a three-decade analysis of injury data in Ethiopia, highlighting a substantial decline in incidence and mortality but revealing inter-regional disparities that warrant localized prevention efforts. Their study underscores that, despite national progress, injuries remain a public health priority, requiring sustained and context-specific interventions. Meanwhile, Du et al. employ an age-period-cohort analysis in Jiangsu Province, China, documenting declining mortality rates for certain injuries, including those from road traffic crashes, yet noting a rise in unintentional falls. This intricate evolution underscores the importance of continuous surveillance to modify strategies as injury profiles shift over time.

Methodological advances improve our capacity to understand and prevent severe outcomes. Xiao et al. compare a rare events logistic regression model with a classic logit model to predict fatal crashes. Their findings demonstrate that rare event modeling more accurately identifies risk factors of fatal crash, providing a robust analytical tool for policymakers and researchers targeting high-risk conditions. Huang et al. adopts a Bayesian random-parameter spatial logistic model to investigate the effect of emergency medical service (EMS) response time on fatality risk in freeway crashes in China. Their work links shorter EMS response time with lower fatality odds, suggesting that improving pre-hospital emergency care capacity could be an effective life-saving strategy.

Environmental and contextual factors influencing RTIs are also highlighted. Li et al. focus on the effects of ambient temperature on traffic-related fatalities in Jinan, China. They find that both extremely high and low temperatures increase RTI risks, with delayed impacts across different modes of transportation. This research suggests the need to consider climate factors when planning road safety measures, especially as climate change intensifies temperature extremes. Similarly, Kim et al. investigate perceived pedestrian safety and show that while physical features like crosswalks and traffic signages, infrastructure quality, and comfort also shape subjective safety. Pedestrian-centered improvements must therefore consider not only engineering solutions but also user perception, fostering more friendly and secure walking environments.

The role of technology as a protective and preventive measure appears in multiple articles. Useche et al. systematically review the use of in-vehicle advanced driver assistance systems (ADAS) to prevent car-cyclist collisions. While studies support ADAS benefits, they also reveal potential downsides, such as driver overreliance. The studies also highlight a critical research gap: developing driver-training and awareness strategies to ensure ADAS complements, rather than substitutes for, attentive driving. Booker et al. discuss the Safe System Approach and how technology can help reduce serious RTIs. Their review points to the importance of evidence-based policy, context-specific technology adoption, and careful evaluation to achieve equitable safety gains worldwide.

Several articles delve into the behavioral, health system, and psychosocial dimensions of RTIs. Endalew et al. survey drivers of public transportation in Ethiopia, linking RTIs to a range of factors, from alcohol use to poor vehicle maintenance. These findings suggest that interventions cannot rely solely on infrastructure upgrades; rather, improved driver training, stricter enforcement, and better working conditions may be necessary to reduce crashes. Papadakaki et al. shine a spotlight on an often-overlooked consequence of RTIs: mental health impairment. Their review of European evidence shows that psychological repercussions can persist long after the initial trauma and that survivors often receive insufficient mental health support. This reveals a pressing need for integrated trauma care protocols that address both physical and psychological rehabilitation.

Focusing on survivors, Allen Ingabire et al. assess the quality of life of road traffic orthopedic injury victims in Rwanda two years after experiencing the injury. They find persistent functional and psychosocial limitations, emphasizing the value of rehabilitation and long-term support services. Beyond immediate trauma care, enhancing survivor reintegration and autonomy requires coordinated efforts, from policy implementation to health system strengthening. Similarly, while primarily focusing on trends, Du et al. also highlight the significance of targeted interventions that consider age and cohort patterns to protect at-risk populations, such as older adults, who sustain more severe injury outcomes.

These articles underscore the multifaceted nature of RTI prevention and control. Their collective insights demonstrate that achieving safer roads involves more than improved vehicles and infrastructure. It requires integrating robust epidemiological surveillance, advanced statistical methods, climate considerations, technology evaluation, driver training, equitable policies, and comprehensive rehabilitation. The Safe System Approach discussed by Booker et al. offers a valuable framework, but its success depends on interdisciplinary collaboration, political commitment, and sustainable resource allocation.

Future research should prioritize harmonizing data collection, establishing standardized metrics, and investing in longitudinal studies. Doing so will permit reasonable comparisons of interventions across regions, promoting knowledge transfer between different sociodemographic settings. Moreover, mental health outcomes and survivor quality of life need more attention, ensuring that post-crash care extends beyond EMSs and includes long-term psychosocial support.

In conclusion, the articles in this Research Topic collectively advance our knowledge of RTI epidemiology, risk factors, interventions, and outcomes. Policymakers, researchers, and practitioners need to collaborate to translate these insights into action. Achieving the Sustainable Development Goal of halving global road traffic deaths and injuries by 2030 requires coordinated efforts across sectors. As this Research Topic demonstrates, there is a wealth of evidence to guide these efforts and pave the way toward safer roads and healthier communities.

Author contributions

QL: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. GH: Conceptualization, Investigation, Methodology, Writing – review & editing. JL: Conceptualization, Investigation, Methodology, Writing – review & editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Neglected burden of injuries in Ethiopia, from 1990 to 2019: a systematic analysis of the global burden of diseases study 2019

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Background: The 2030 agenda for sustainable development goals has given injury prevention new attention, including halving road traffic injuries. This study compiled the best available evidence on injury from the global burden of diseases study for Ethiopia from 1990 to 2019.

Methods: Injury data on incidence, prevalence, mortality, disability-adjusted life years lost, years lived with disability, and years of life lost were extracted from the 2019 global burden of diseases study for regions and chartered cities in Ethiopia from 1990 to 2019. Rates were estimated per 100,000 population.

Results: In 2019, the age-standardized rate of incidence was 7,118 (95% UI: 6,621–7,678), prevalence was 21,735 (95% UI: 19,251–26,302), death was 72 (95% UI: 61–83), disability-adjusted life years lost was 3,265 (95% UI: 2,826–3,783), years of live lost was 2,417 (95% UI: 2,043–2,860), and years lived with disability was 848 [95% UI: (620–1,153)]. Since 1990, there has been a reduction in the age-standardized rate of incidence by 76% (95% UI: 74–78), death by 70% (95% UI: 65–75), and prevalence by 13% (95% UI: 3–18), with noticeable inter-regional variations. Transport injuries, conflict and terrorism, interpersonal violence, self-harm, falls, poisoning, and exposure to mechanical forces were the leading causes of injury-related deaths and long-term disabilities. Since 1990, there has been a decline in the prevalence of transport injuries by 32% (95% UI: 31–33), exposure to mechanical forces by 12% (95% UI: 10–14), and interpersonal violence by 7.4% (95% UI: 5–10). However, there was an increment in falls by 8.4% (95% UI: 7–11) and conflict and terrorism by 1.5% (95% UI: 38–27).

Conclusion: Even though the burden of injuries has steadily decreased at national and sub-national levels in Ethiopia over the past 30years, it still remains to be an area of public health priority. Therefore, injury prevention and control strategies should consider regional disparities in the burden of injuries, promoting transportation safety, developing democratic culture and negotiation skills to solve disputes, using early security-interventions when conflict arises, ensuring workplace safety and improving psychological wellbeing of citizens.

KEYWORDS

disability-adjusted life years, global burden of diseases, injuries, interpersonal violence, self-harm, transport injuries, years lived with disability, years of life lost

Background

Injury is a major public health problem worldwide, causing substantial premature death and serious nonfatal consequences that may lead to permanent impairment (1, 2). Injury consequences extend beyond health to have a significant macroeconomic impact. In 2019, injuries, such as road traffic crashes, unintentional injuries, self-harm, and interpersonal violence caused 4.3 million deaths globally, accounting for 10% of the total deaths and over 40 million years lived with disability (YLDs) (1, 3, 4). While injury affects all ages, youths, and young adults are particularly vulnerable (1–3, 5, 6). Moreover, the injury burden is disproportionately high in low- and middle-income countries (LMICs) (3, 4). According to the 2019 Global Burden of Diseases, Injuries, and Risk Factors (GBD) study there are significant regional variations in the global incidence of injuries (6). Over 90% of injuries that occur globally take place in LMICs, where there are inadequate safety precautions and medical services available (3, 5).

Ethiopia is a resource-constrained country where the burden of injury is unknown due to a lack of injury surveillance (7–10). Additionally, the existing studies focus on specific injury types at healthcare institutions or are small-scale surveys, which fall short of guiding evidence-based intervention strategies (11–13). However, the country has experienced frequent intergroup conflicts as a result of political disputes involving efforts to change the form of government (14–16). Unintentional injuries, such as drowning, falling, poisoning, and animal contact are growing public health problems (8, 17–20). Furthermore, road traffic injuries in particular are the leading causes of premature deaths and long-term disabilities (7, 8). For instance, a study conducted in healthcare facilities in Addis Ababa showed that road traffic injuries posed a high burden on the health facilities due to high incidence (11, 20). Approximately six out of 10 (61%) injury-related admissions and half (52%) of severe injuries have resulted in death (20). A systematic review also showed a high (32%) prevalence of road traffic injuries among trauma patients in Ethiopia, with regional disparities ranging from 14 to 60% (21).

The negative consequences of injuries to development and health have been stressed in the 2030 agenda of the sustainable development goals (SDGs) (22). Moreover, there are various goals and targets for preventing violence and injury included in the SDGs, which provide a governance framework for cross-sector preventative action (23). To determine if progress is being made, this initiative requires analyses of high-quality data. However, studies that systematically investigate injuries at national and sub-national levels are scarce in Ethiopia. The lack of such evidence impairs the design of appropriate preventive measures, and the management of survivors who need medical care and psychosocial support. Therefore, this study aimed to estimate the incidence, prevalence, mortality, disability-adjusted life years (DALYs) lost, years of life lost due to premature mortality (YLLs), and YLDs due to injuries, and the associated causes in all regional states and chartered cities in Ethiopia during 1990 to 2019 by using data from the 2019 GBD study. The findings of the study will inform policies and programs aiming at improving injury prevention strategies and societal well-being in Ethiopia.

Methods

Setting

Ethiopia is Africa's second most populous country with an estimated population of 112 million in 2019 (24). The country is administratively divided into 10 regional states and two chartered cities. According to the United Nation's world population prospect, the median age of the population is 20 years with an annual population growth rate of 2.5% in 2020 (24). Over 80% of the population resides in rural areas, where healthcare accessibility is limited (25).

Data sources, processing, and analyses

This study used data from the 2019 GBD study accessible through GBD Compare (6, 26). The 2019 GBD study complies with the guidelines for accurate and transparent health estimates reporting recommendations (27). The causes of premature death, loss of health and prolonged disability are structured using a hierarchical classification, according to international classification of diseases (ICD) or alternative classification systems to the GBD cause list, and used for modeling to produce results that are mutually exclusive and collectively exhaustive (6). In the 2019 GBD study injury incidence and death are classified as ICD-9 codes E000-E999 and ICD-10 chapters V to Y with exception that deaths and cases of alcohol poisoning and drug overdoses are classified under drug and alcohol use disorders. A cause-specific mortality was estimated using cause of death ensemble model that produces several plausible combinations of covariates using a covariate selection algorithm (6). The study quantifies the comparative magnitude of health loss due to diseases, injuries, and risk factors stratified by age, sex, and geographies for specific points in time, and produces regular estimates of all-cause mortality, deaths by cause, DALYs, YLLs, and YLDs for a list of causes over the years 1990 to 2019 (6). The study produced these estimates for 204 countries and territories that were grouped into 21 regions and seven super-regions.

Input data for injuries are compiled from a range of sources, including international databases that capture several cause-specific fatal discontinuities and supplemental data in the presence of known issues with data quality, representativeness, or time lags in reporting (6). Based on addition of new data and change in methods, the GBD estimates are updated for the whole time series. Each metric of interest borrows strength between locations and over time through the spatiotemporal Gaussian process regression. The 2019 GBD results, thus, supersede those from previous rounds. The GBD injury-specific estimates for Ethiopia were derived from data obtained from police report, Addis Ababa mortality surveillance program, Ethiopian health and demographic surveillance system, and different surveys, like demographic and health surveys. The explicit list of data sources used in this study is available at: http://ghdx.healthdata.org/gbd-2019/data-input-sources.

In this analysis, we extracted estimates of injuries on incidence, prevalence, mortality, DALYs, YLLs, YLD, and the associated causes in all regional states and chartered cities in Ethiopia during 1990 to 2019. All rates were age-standardized and aggregated for different socio-demographic categories, regions, and cities. Trends of the metrics were also explored for the regions and charted cities over the years 1990 to 2019. The 95% uncertainty intervals (UI) were presented for each summary statistics. UIs were generated for every metric using the 25 and 97.5th ordered 1,000 draw values of the posterior distribution. The details of the estimation techniques were published elsewhere (6, 28).

Results

Incidence and prevalence

In 2019 there were an estimated 8.1 million (95% UI: 7.4–8.9) new cases of injury, with 4.3 million males and 3.8 million females. In the same year, there were an estimated 16.6 million (95% UI: 14.7–20.0) prevalent cases, with 8.7 million males and 7.8 million females. The age-standardized incidence rate was 7,118 cases per 100,000 population (95% UI: 6,621–7,678) and the age-standardized prevalence rate was 21,735 cases per 100,000 population (95% UI: 19,251-26,302). A higher than the national age-standardized incidence rate was observed in the Somali region [7,724 cases per 100,000 population (95% UI: 7,210–8,318)], followed by the Southern Nations and Nationalities and Peoples' region [7,588 cases per 100,000 population (95% UI: 7,090–8,165)]. Similarly, a higher than the national age-standardized prevalence rate of injury was observed in the Gambella region [25,386 cases per 100,000 population (95% UI: 21,487–31,496)], followed by the Tigray region [24,123 cases per 100,000 population (95% UI: 20,950–29,038)]. Between 1990 and 2019, the age-standardized incidence rate was decreased by 76% (95% UI: 74–78), and the age-standardized prevalence rate by 13% (95% UI: 3–18). The highest reductions were observed in Addis Ababa, Amhara, and Benishangul-Gumuz regions (Table 1).

Mortality

An estimated 43,658 (95% UI: 37,027-51,499) injury-related deaths occurred in 2019, with 30,430 deaths among males and 13,228 deaths among females. This accounted for about 7.8% (9.5% males vs. 5.4% females) of deaths from all-causes in Ethiopia. The corresponding age-standardized death rate was estimated to be 72 deaths per 100,000 population (95% UI: 61–83), with 96 deaths per 100,000 males and 47 deaths per 100,000 females. A higher than the national age-standardized death rate of injury was occurred in the Southern Nations Nationalities and Peoples' region [101 deaths per 100,000 population (95% UI: 81–119)], Afar region [95 deaths per 100,000 population (95% UI: 76–119)], Somali region [84 deaths per 100,000 population (95% UI: 66–108)], Benishangul-Gumuz region [84 deaths per 100,000 population (95% UI: 68–104)], and Gambella region [74 deaths per 100,000 population (95% UI: 61–90)]. There was a 70% (95% UI: 65–75) reduction in injury-related death rate between 1990 and 2019, with noticeable inter-regional disparities (Table 1; Figure 1).

Disability-adjusted life years lost

Injuries resulted an estimated 2.8 million (95% UI: 2.4–3.0) DALYs lost in 2019, which accounted for about 7.4% (9.0% males vs. 6.4% females) of the disability-adjusted life years (DALYs) lost from all-causes in Ethiopia. The corresponding age-standardized rate of DALYs lost was estimated to be 3,265 years per 100,000 population (95% UI: 2,826–3,783), which was more than three-times lower than the 1990 estimate of 11,386 years per 100,000 population (95% UI: 10,561–12,165). A higher than the national age-standardized rate of DALYs lost was observed in the Southern Nations Nationalities and Peoples' region [4,227 years per 100,000 population (95% UI: 3,482–5,083)], Afar region [4,041 years per 100,000 population (95% UI: 3,307-4,975)], Benishangul-Gumuz region [3,950 years per 100,000 population (95% UI: 3,299–4,716)], Somali region [3,884 years per 100,000 population (95% UI: 3,174–4,797)], and Gambella region [3,362 years per 100,000 population (95% UI: 2,751–4,070); Table 2]. The burden of DALYs lost due to injuries increased until the age of 24 years and then decreased as age increased, (Figure 2).

Years of life lost

There were an estimated 2.2 million (95% UI: 1.8–2.6) years of life lost (YLLs) in 2019, which was nearly three-times lower than the 1990 estimate of 6.1 million (95% UI: 6.1–6.5) YLLs in Ethiopia. The corresponding age-standardized rate of YLLs as a result of injuries was 2,417 years per 100,000 population (95% UI: 2,043–2,860). A higher than the national age-standardized rate of YLLs was observed in the Southern Nations Nationalities and Peoples' region [3,392 years per 100,000 population (95% UI: 2,705–4,101)], Afar region [3,234 years per 100,000 population (95% UI: 2,489–4,129)], Benishangul-Gumuz region [3,132 years per 100,000 population (95% UI: 2,507–3,896)], and Somali region [2,970 per 100,000 population (95% UI: 2,329–3,768)]. Males encountered a higher rate of YLLs in each region across the country (Table 2). The burden of YLLs due to injuries increased until the age of 24 years and then decreased as age increased (Figure 2).

Years lived with disability

In 2019 injuries contributed to 630,454 (95% UI: 460,443–865,634) YLDs in Ethiopia, with the corresponding age-standardized rate of 848 years per 100,000 population [95% UI: (620–1,153)]. A higher than the national age-standardized rate of YLDs was observed in Gambella region [1,023 years per 100,000 population (95% UI: 741–1,391)], Harari region [986 years per 100,000 population (95% UI: 715–1,325)], Tigray region [956 years per 100,000 population

TABLE 1 Age-standardized rate of injury incidence, prevalence, mortality, and annualized rate of change by sex and sub-national states in Ethiopia, from 1990 to 2019.

Region	Sex	Age-standardized incidence per 100,000 population	Annualized rate of change	Age-standardized prevalence per 100,000 population	Annualized rate of change	Age-standardized mortality per 100,000 population	Annualized rate of change
		2019	1990–2019	2019	1990–2019	2019	1990–2019
All regions combined	Male	7700.2 (7167.8–8320.4)	−79.6 (−81.2, −77.7)	23800.8 (20668.5–29606.1)	−15.3 (−21.1, −4.8)	95.8 (78.6–117.3)	−71.1 (−76.5, −63.1)
	Female	6556.5 (6058.5–7,140)	−71.5 (−74.5, −67.9)	19577.1 (17583.9–22979.4)	−10.2 (−14.9, −0.8)	46.7 (39–55)	−69.5 (−75.6, −62.8)
	Both	7117.6 (6620.9–7678.4)	−76.3 (−78.4, −73.8)	21735.2 (19250.8–26302.2)	−12.7 (−18, −2.7)	71.6 (61.1–82.7)	−70.3 (−74.9, −64.6)
Tigray	Male	7512.6 (6944.3–8,152)	−77 (−79.1, −74.3)	27,007 (23116.5–33177.4)	−17.7 (−22.7, −10.2)	86.9 (65.7–113.9)	−71.4 (−78.7, −61.8)
	Female	6544.6 (6002.4–7158.4)	−63.8 (−68.4, −58.9)	21335.7 (18795.1–25338.3)	−12.6 (−16.3, −6.8)	41.9 (32.4–53.5)	−70.7 (−78, −60.8)
	Both	7002.5 (6466.1–7584.1)	−71.8 (−74.7, −68.3)	24122.8 (20949.7–29037.7)	−15 (−19.2, −8.1)	63.8 (51.8–77.9)	−71.2 (−77.1, −64.5)
Afar	Male	7963.2 (7419.9–8594.8)	−74.4 (−76.8, −71.1)	22305.2 (19607.2–27289.7)	−15.9 (−21.7, −5.8)	109.1 (79.4–147)	−66 (−76.2, −48.7)
	Female	6549.7 (6071.5–7105.4)	−67.2 (−71.2, −63.2)	18077.1 (16039–21,412)	−16.7 (−22.1, −7.1)	78.5 (61.1–101.4)	−58.1 (−70.3, −39.4)
	Both	7291.7 (6797.4–7851.9)	−71.7 (−74.6, −68.2)	20539.9 (18136.7–24795.8)	−15.5 (−21.1, −5.6)	95.4 (76.4–119)	−63.5 (−71.9, −50.9)
Amhara	Male	7493.1 (6945.1–8080.7)	−85.3 (−86.3, −84.1)	24848.2 (21461.2–30,493)	−17.1 (−22.7, −8.7)	91.4 (67.5–124.6)	−78.1 (−83.6, −71)
	Female	6165.6 (5656.4–6708.4)	−82.7 (−84.4, −80.3)	19930.9 (17608.7–23599.6)	−15.2 (−20.4, −7.5)	37.6 (29.5–47.9)	−80.8 (−84.8, −75.9)
	Both	6,820 (6316.8–7,384)	−84.1 (−85.3, −82.6)	22387.1 (19610.9–26,965)	−16.3 (−21.6, −8.2)	64.1 (51.7–81)	−79 (−83.2, −74)
Oromia	Male	7438.4 (6906.1–8049.4)	−76.7 (−78.9, −73.8)	22403.7 (19658.8–27102.5)	−18.1 (−23.7, −9.6)	81.3 (64.1–102.3)	−70.7 (−77.6, −59.3)
	Female	6,698 (6177–7305.4)	−61.5 (−66, −56.8)	20429.3 (18638.3–23200.7)	−5.6 (−10, 1.7)	45.6 (35.8–55.9)	−63.9 (−73.4, −51.5)
	Both	7060.3 (6555.2–7640.4)	−71 (−73.9, −67.4)	21458.7 (19300–25,309)	−12.1 (−17, −4)	63.8 (53.8–74.9)	−68 (−74, −58.7)
Somali	Male	8644.8 (8050.4–9314.9)	−72.7 (−75.2, −69.3)	25158.4 (22149.3–29794.7)	−1.7 (−7.4, 5.4)	103.8 (75.5–142.6)	−51.7 (−62, −38)
	Female	6683.1 (6168.4–7280.8)	−64.1 (−68.1, −59.9)	19117.4 (17035.4–22234.6)	−10.3 (−15.9, −1.6)	54.8 (40.4–72.5)	−52.3 (−65, −36.5)
	Both	7,724 (7210.1–8317.6)	−69 (−72.1, −65.4)	22640.2 (20096.4–26691.1)	−3 (−9.2, 4.9)	84.1 (66–108.2)	−59.8 (−70.5, −45.2)
Benishangul-Gumuz	Male	7794.8 (7259–8,404)	−78.2 (−80, −75.8)	22644.4 (19778.6–27873.1)	−15.9 (−21.9, −5.5)	95.9 (71.7–129.2)	−67.5 (−74.3, −57.7)
	Female	6505.7 (6057.2–7045.3)	−69.1 (−72.9, −65.1)	18275.7 (16453.4–21254.8)	−16.3 (−21, −7.4)	70.3 (53.2–88.8)	−69.5 (−77.9, −56.2)
	Both	7148.8 (6691.6–7,702)	−74.6 (−77, −71.7)	20621.4 (18307.9–24,830)	−15.8 (−21.4, −6.2)	83.9 (67.6–103.6)	−64.6 (−74.9, −50.4)
Southern Nations, Nationalities	Male	8271.6 (7700.6–8920.7)	−74.1 (−76.5, −70.9)	23584.6 (20284.4–32674.6)	−11.2 (−18.9, 12.7)	135 (104.3–167.1)	−60 (−69.8, −46)
	Female	6949.1 (6442.6–7521.3)	−60.5 (−65.1, −55.5)	17,835 (15805.2–22725.6)	−8.1 (−14.2, 12.1)	66 (51.3–81)	−54 (−66.3, −39.1)
	Both	7588.1 (7090.1–8165.1)	−68.8 (−72, −65.1)	20726.6 (18113.4–27915.8)	−9.6 (−16.6, 13.4)	100.6 (81–119)	−58.3 (−66.7, −48.3)
Gambella	Male	7608.8 (7064.8–8220.8)	−77.4 (−79.4, −74.5)	29316.2 (24337.9–37178.9)	−3.6 (−11.6, 5)	117.2 (89.3–150.5)	−62.1 (−70, −50.5)
	Female	6068.3 (5594.3–6,609)	−62.3 (−66.5, −57.8)	22047.8 (18926.8–27039.1)	7.2 (−3.2, 23.4)	33.2 (26.3–40.5)	−64.7 (−74.7, −49.3)
	Both	6787.4 (6304.7–7330.8)	−71 (−73.9, −67.7)	25386.4 (21486.9–31495.5)	3.1 (−6, 14.5)	73.8 (60.8–89.9)	−66.6 (−76.6, −54.1)
Harari	Male	6906.1 (6380–7479.1)	−80.8 (−82.5, −78.5)	25238.6 (21631.5–31019.3)	−14.4 (−23, −3.3)	86.9 (63.5–120.9)	−71.1 (−78.3, −62.1)
	Female	6072.8 (5604.7–6600.3)	−64.9 (−69.1, −60.6)	20167.2 (17508.8–24360.7)	1.3 (−8.3, 16.6)	40.3 (30.3–53.1)	−89.1 (−92.1, −84.8)
	Both	6504.7 (6031.2–7054.6)	−72.7 (−75.6, −69.1)	22673.4 (19609.9–27456.6)	−1.3 (−10.6, 11.4)	62.6 (49.8–79.2)	−68 (−77.7, −53.9)
Dire Dawa	Male	7218.6 (6677.5–7813.5)	−76.4 (−78.7, −73.4)	23231.4 (20271.7–28388.4)	−13 (−19.6, −3)	81.1 (59.9–113.6)	−70.7 (−78.9, −56.6)
	Female	6119.8 (5641.3–6671.8)	−65.2 (−69.3, −60.8)	18455.7 (16445–21692.7)	−7 (−13.2, 3.4)	37.5 (28.3–49.5)	−67.7 (−77.5, −53.2)
	Both	6664.3 (6173.3–7212.6)	−72 (−75, −68.5)	20802.2 (18407.1–25,010)	−9.7 (−16, 0.5)	58.7 (46–74.2)	−68.8 (−75.6, −59.3)
Addis Ababa	Male	7191.4 (6646.4–7,820)	−86 (−87, −84.9)	23367.9 (20207.8–28719.1)	−19.4 (−25.9, −8.4)	76.9 (58.7–98.3)	−80.8 (−84, −76.8)
	Female	6058.7 (5524.1–6649.5)	−81.9 (−83.8, −79.6)	18234.3 (16036.1–21771.2)	−19 (−24.9, −10.1)	32 (25–43.3)	−79.2 (−84.2, −73.2)
	Both	6568.9 (6053–7152.7)	−84.4 (−85.6, −82.9)	20713.2 (18131.2–25180.7)	−19.4 (−25.5, −9)	52.8 (44.5–63.8)	−83.1 (−87, −76.8)

(95% UI: 703–1,282)], Somali region [914 years per 100,000 population (95% UI: 669–1,213)], Amhara region [873 years per 100,000 population (95% UI: 642–1,171)], and Dire Dawa city administration [850 years per 100,000 population (95% UI: 629–1,134)]. The rate of YLDs was higher among males in each region across the country (Table 2). The burden of YLDs due to injuries increased until the age of 34 years and then decreased as age increased (Figure 2).

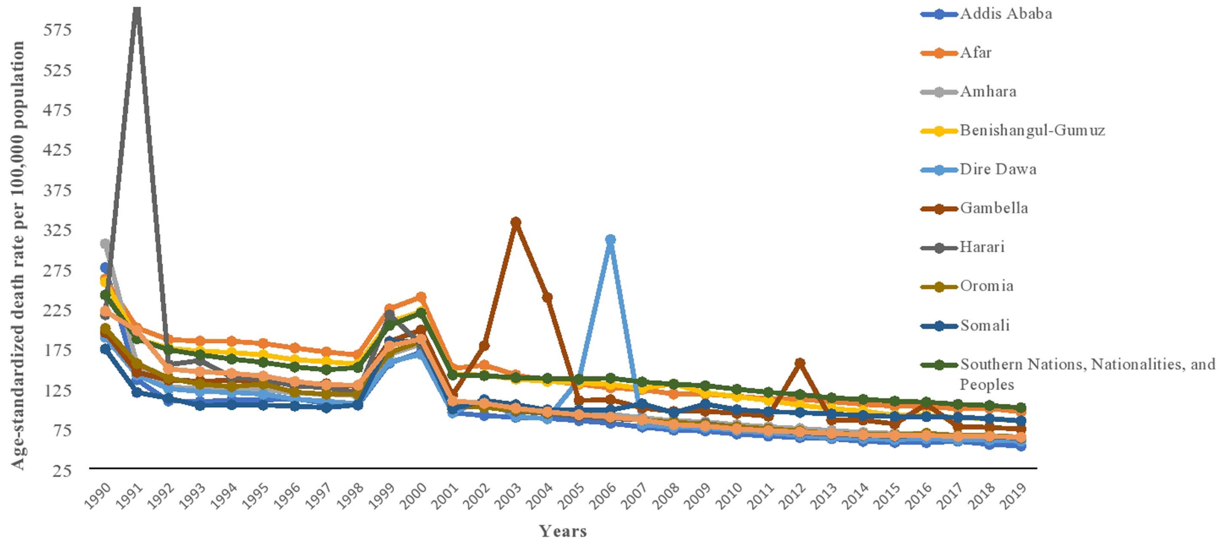

FIGURE 1
Trend of age-standardized death rate due to injury in Ethiopia, 1990–2019.

The leading causes of injuries

The top-five leading causes of incident injuries in 2019 were exposure to mechanical forces [1,381 cases per 100,000 population (95% UI: 1,098–1,674)], animal contacts [1,209 cases per 100,000 population (95% UI: 1,000–1,486)], falls [1,162 cases per 100,000 population (95% UI: 958–1,400)], foreign bodies [1,158 cases per 100,000 population (95% UI: 939–1,434)], and transport injuries [1,089 cases per 100,000 population (95% UI: 927–1,277)]. Similarly, the most common causes of prevalent injuries were conflict and terrorism [4,889 cases per 100,000 population (95% UI: 2,608–9,342)], interpersonal violence [3,640 cases per 100,000 population (95% UI: 3,208–4,175)], transport injuries [3,183 cases per 100,000 population (95% UI: 2,962–3,451)], exposure to mechanical forces [2,688 cases per 100,000 population (95% UI: 2,327–3,060)], and falls [2,440 cases per 100,000 population (95% UI: 2,116–2,823)]. Since 1990, there has been a decline in the prevalence of transport injuries by 32% (95% UI: 31–33), motorcycle injuries by 29% (95% UI: 27–31), motor vehicle injuries by 28% (95% UI: 26–30), exposure to mechanical forces by 12% (95% UI: 10–14), and interpersonal violence by 7.4% (95% UI: 5–10). However, there was an increment in the prevalence of falls by 8.4% (95% UI: 7–11) and conflict and terrorism by 1.5% (95% UI: 38–27; Table 3).

The top-five leading causes of injury-related deaths in 2019 were transport injuries [15 deaths per 100,000 population (95% UI: 13–18)], interpersonal violence [10 deaths per 100,000 population (95% UI: 8–12)], self-harm [10 deaths per 100,000 population (95% UI: 8–13)], falls [10 deaths per 100,000 population (95% UI: 8–11)], and poisoning [four deaths per 100,000 population (95% UI: 3–5)]. Since 1990, there was a noticeable reduction in the death rate due to poisoning by 61% (95% UI: 44–71), transport injuries by 55% (95% UI: 40–66), self-harm by 53% (95% UI: 33–65), interpersonal violence by 38% (95% UI: 13–57), and falls by 21% (95% UI: 13–41; Table 3).

The top-five leading causes of DALYs lost in 2019 were transport injuries [760 years per 100,000 population (95% UI: 647–891)], interpersonal violence [457 years per 100,000 population (95% UI: 381–557)], self-harm [333 years per 100,000 population (95% UI: 268–419)], falls [300 years per 100,000 population (95% UI: 252–354)], and exposure to mechanical forces [221 years per 100,000 population (95% UI: 166–285)]. Since 1990, there was a remarkable reduction in DALYs lost due to self-harm by 57% (95% UI: 39–69), transport injuries by 56% (95% UI: 44–66), interpersonal violence by 39% (95% UI: 16–56), exposure to mechanical forces by 38% (95% UI: 16–57), and falls by 23% (95% UI: 2–39). Furthermore, the major causes of YLDs were transport injuries [216 years per 100,000 population (95% UI: 159–283)], conflict and terrorism [212 years per 100,000 population (95% UI: 116–431)], and falls [123 years per 100,000 population (95% UI: 89–166)]. The leading causes of YLLs due to injuries were transport injuries [545 years per 100,000 population (95% UI: 452–661)], interpersonal violence [408 years per 100,000 population (95% UI: 333–505)], and self-harm [325 years per 100,000 population (95% UI: 259–411); Table 4].

Discussion

Our analysis incorporated the burden and trend of injuries associated with morbidity and mortality at the national and sub-national levels in Ethiopia from 1990 to 2019 using the GBD study data. While injury-related deaths have substantially decreased over the past three decades, they still account for 7.8% of deaths from all-causes. When comparing the burden of major public health priority diseases in Ethiopia, deaths due to injury are greater than the combined deaths from malaria and tuberculosis. The death rate has declined by 70% between 1990 and 2019. This may be related to indirect effects of Ethiopia's overall socioeconomic improvement over the previous two decades, including access to health, education, and social services (29). There is good evidence that improved living conditions, reduced poverty, and better access to services are determinants of injury-related morbidity and mortality (30–33). The

TABLE 2 Age-standardized rate of injury-related DALYs, YLLs, YLDs, and annualized rate of change by sex and sub-national states in Ethiopia, from 1990 to 2019.

Region	Sex	Age-standardized DALYs per 100,000 population	Annualized rate of change	Age-standardized YLLs per 100,000 population	Annualized rate of change	Age-standardized YLDs per 100,000 population	Annualized rate of change
		2019	1990–2019	2019	1990–2019	2019	1990–2019
All regions combined	Male	4320.1 (3642.3–5133.5)	−74.7 (−78.8, −69)	3359.8 (2752.8–4112.3)	−78.5 (−82.6, −72.8)	960.3 (696.3–1323.3)	−33.2 (−39.9, −20.7)
	Female	2196.6 (1859.5–2,603)	−73.6 (−77.7, −68.5)	1463.7 (1188.3–1794.5)	−80 (−84.1, −75.1)	732.9 (544.3–981.6)	−26.5 (−33.1, −15.9)
	Both	3264.9 (2825.5–3782.9)	−74.1 (−77.5, −69.7)	2416.9 (2042.8–2,860)	−78.8 (−82.2, −74.3)	848 (620.1–1153.2)	−29.9 (−36.3, −18.4)
Tigray	Male	3994.5 (3214.2–4986.8)	−73.7 (−79, −67.1)	2888.8 (2165–3791.8)	−78.3 (−83.9, −71.1)	1105.7 (807.9–1486.3)	−39.4 (−45.9, −31.4)
	Female	1984.5 (1599.3–2438.7)	−72.9 (−78.1, −66.9)	1172.1 (877.2–1,569)	−81 (−86.3, −74.3)	812.4 (599.9–1077.2)	−29.4 (−35.2, −23.1)
	Both	2965.5 (2479.1–3534.6)	−73.2 (−77.6, −67.9)	2009.4 (1587.7–2530.2)	−79.1 (−83.5, −73.7)	956.2 (702.5–1281.6)	−34.7 (−40.6, −27.4)
Afar	Male	4,851 (3681.1–6384.9)	−68.5 (−77.1, −55.3)	3945.1 (2815.8–5428.8)	−72.2 (−80.9, −58.5)	905.9 (658.6–1,237)	−26.4 (−32.6, −15.6)
	Female	3,100 (2461.5–3,901)	−66.7 (−75, −55.4)	2405.4 (1808.8–3161.8)	−71.4 (−79.6, −59.1)	694.6 (512–922.8)	−22.8 (−28.4, −14.5)
	Both	4041.1 (3307.2–4974.6)	−68 (−74.8, −59)	3233.8 (2488.6–4128.7)	−72 (−78.9, −62.8)	807.3 (588.9–1095.2)	−24.8 (−30.7, −14.7)
Amhara	Male	4202.7 (3326.2–5447.7)	−81.8 (−85.3, −77)	3203.2 (2408.9–4408.4)	−85 (−88.7, −80.1)	999.6 (730.8–1,352)	−39.7 (−46.4, −31.1)
	Female	1939.9 (1593.1–2362.8)	−83.1 (−85.9, −79.4)	1192.7 (924.8–1547.1)	−88.4 (−91, −84.8)	747.2 (554.6–989.7)	−36 (−43.6, −28.3)
	Both	3066.8 (2555.2–3751.3)	−82.1 (−84.9, −78.6)	2193.8 (1744.6–2826.7)	−86 (−88.8, −82.6)	873.1 (641.6–1170.6)	−37.9 (−44.6, −29.8)
Oromia	Male	3648.8 (3052.4–4,394)	−73.4 (−78.5, −65.6)	2747.9 (2200.3–3445.8)	−77.9 (−82.9, −69.2)	900.8 (657.2–1228.8)	−31.6 (−37.5, −22.3)
	Female	2083.4 (1722.6–2539.6)	−68.4 (−74.7, −60)	1356.9 (1040.2–1757.3)	−76.2 (−82.6, −67.8)	726.5 (542.9–953.8)	−20 (−25.7, −13)
	Both	2874.7 (2468.6–3349.1)	−71.4 (−75.8, −64.9)	2059.4 (1715.9–2,480)	−77 (−81.5, −70.2)	815.3 (598.8–1098.2)	−26.2 (−31.8, −18.1)
Somali	Male	4881.3 (3805.6–6,351)	−55.7 (−64.5, −45.1)	3842.8 (2833–5239.4)	−60.5 (−70.5, −48.8)	1038.5 (761.6–1390.9)	−19.1 (−25.3, −12.5)
	Female	2613.7 (2057–3272.5)	−61.7 (−69.7, −51.9)	1856.5 (1333.3–2486.8)	−68.5 (−77, −57.9)	757.1 (564.6–987.1)	−17.8 (−23.5, −11)
	Both	3883.9 (3174.4–4797.4)	−56.1 (−63.5, −48)	2,970 (2328.6–3767.6)	−61.7 (−69.7, −52.9)	913.9 (668.7–1212.8)	−16.7 (−22.7, −10)
Benishangul-Gumuz	Male	4662.7 (3672.1–5906.1)	−71.7 (−77.7, −62.9)	3734.8 (2816.1–4937.4)	−75.4 (−81.7, −66)	927.9 (669.2–1,273)	−29.3 (−35.8, −18.1)
	Female	3194.3 (2508.3–3915.8)	−69.2 (−76.6, −59.8)	2498.3 (1867–3,195)	−73.6 (−81.1, −64.1)	695.9 (516.7–917.4)	−23.6 (−29.2, −15.3)
	Both	3950.2 (3299.4–4716.3)	−70.5 (−75.7, −64)	3131.8 (2507.3–3895.7)	−74.5 (−80.1, −68)	818.3 (598.9–1105.1)	−26.4 (−32.3, −16.6)
Southern Nations, Nationalities	Male	5708.2 (4541.8–7053.8)	−65.2 (−72.5, −55.1)	4754.9 (3664.9–5950.2)	−68.5 (−76.1, −57.9)	953.3 (651.9–1508.2)	−26.2 (−36.2, 6.2)
	Female	2,759 (2173–3437.5)	−62.8 (−71.6, −52.2)	2043.5 (1508.8–2636.8)	−68.7 (−77.8, −57.7)	715.5 (509.8–1,061)	−20.2 (−28.7, 4)
	Both	4226.5 (3481.8–5082.8)	−64.4 (−71, −56.4)	3391.9 (2704.5–4101.4)	−68.5 (−75.2, −60.7)	834.6 (581.7–1285.4)	−23.3 (−32.5, 6.1)
Gambella	Male	5110.2 (4022.8–6468.1)	−69.6 (−77.1, −58.7)	3910.1 (2888.2–5165.5)	−74.4 (−82, −63.2)	1200.1 (866.9–1623.2)	−21.7 (−27.8, −15)
	Female	1749 (1434.1–2126.9)	−71.6 (−77.9, −63.9)	873.8 (678.1–1107.3)	−83.3 (−88.2, −77.1)	875.2 (637.4–1182.1)	−6.6 (−16.5, 6.7)
	Both	3361.7 (2751.1–4069.8)	−68.5 (−74.6, −60.5)	2338.6 (1849.7–2945.7)	−75.4 (−81.2, −67.2)	1,023 (740.7–1390.6)	−13.7 (−21.1, −4.7)
Harari	Male	4048.5 (3181.7–5210.9)	−83.6 (−87.4, −78.3)	2944.2 (2120.2–4,105)	−87.3 (−90.9, −81.9)	1104.3 (802.7–1488.9)	−28.6 (−34.7, −21.1)
	Female	2033.4 (1575.2–2607.8)	−71.2 (−78.2, −62.4)	1170.8 (832.4–1657.3)	−80.9 (−86.9, −72.1)	862.5 (628.4–1165.4)	−7 (−17.4, 7.8)
	Both	3036.4 (2471.9–3712.5)	−73.7 (−78.9, −66.7)	2050.8 (1569.1–2,677)	−80.3 (−85.2, −73.4)	985.6 (715–1325.2)	−11.1 (−20.7, 1.8)
Dire Dawa	Male	3693.5 (2885.3–4,816)	−73.8 (−79.9, −64.3)	2731.1 (2003.6–3,820)	−78.6 (−84.9, −69)	962.4 (706.2–1303.2)	−26.6 (−33.3, −17.2)
	Female	1807.4 (1423.8–2,290)	−73.5 (−79.4, −65.4)	1068.4 (761.5–1534.4)	−81.9 (−87.7, −72.9)	739 (552–974.4)	−20.5 (−27, −11.6)
	Both	2737.2 (2213.8–3358.6)	−73.5 (−78.8, −66.9)	1887.4 (1459.4–2456.3)	−79.5 (−84.5, −72.6)	849.8 (628.5–1134.2)	−23.7 (−30.1, −14.6)
Addis Ababa	Male	3491.7 (2788–4382.7)	−82.4 (−86, −78)	2590.3 (1938.5–3403.4)	−85.8 (−89.4, −81.2)	901.4 (659.2–1236.2)	−43.1 (−49.8, −33.4)
	Female	1,560 (1242.3–1981.8)	−85 (−87.9, −81)	887.8 (640.1–1246.9)	−90.4 (−93.1, −86.3)	672.2 (494.5–900.6)	−40.9 (−47.6, −33.2)
	Both	2457.5 (2033.3–2,952)	−83.5 (−86.2, −80.1)	1,673 (1321.3–2124.3)	−87.6 (−90.3, −84.3)	784.4 (574.2–1061.2)	−42.1 (−48.7, −33.3)

2019 data are higher than a similar study conducted in 2017 (8), although within the margin of error. The results demonstrate that injuries are not declining quickly enough to be in line with the SDG target by 2030.

At sub-national level, this study has revealed that the Southern Nations Nationalities and Peoples' region has the highest injury-related deaths and DALYs, followed by the Afar region. There is no comparable study in Ethiopia to compare the findings regionally.

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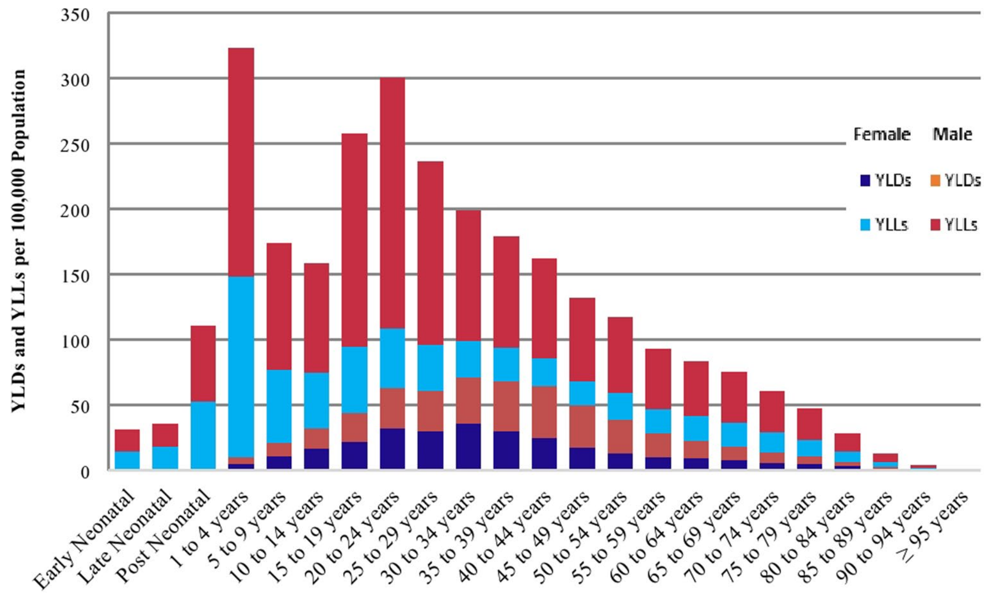

FIGURE 2
YLDs and YLLs by age and sex in Ethiopia, 2019.

However, a systematic review and meta-analysis of road injuries has shown that the Southern Nations Nationalities and Peoples' region has the highest disability associated with injury (21). There are several potential explanations for this. The region has a dense population, mobile youth, local and international trafficking, and high level of migration (34–36). Moreover, the region is comprised of more than 65% of all ethnic groups in Ethiopia, and this may be linked with a higher frequency of interpersonal violence related injuries. In terms of YLD and prevalence rate, the Gambella and Tigray regions were disproportionately affected. The Tigray region has experienced a prolonged conflict between armed groups and the government forces, the Ethio-Eritrean war, and frequent boarder conflicts with Eritrea (14, 16). However, the region has made relatively better progress in healthcare coverage, education, and infrastructure that could have decreased injury-related deaths and increased people living with long-term disability (37). The Gambella region also shares a similar history of intergroup conflicts and frequent short-term conflicts between the government forces and armed groups (14). The events in these regions may have contributed to the injury death rate being the highest in 1999 and 2000, specifically the war between Ethiopia and Eritrea (14, 16). However, all regions throughout the country have maintained a reduction of injury-related death and disability in the past 30 years. On the other hand, the absolute number of injuries did not decrease significantly and actually increased from 2010 to 2019. High developmental activities in the country in recent years and increased population size might have contributed to this trend (38), whereas an improvement in healthcare services may have improved the survival of individuals who experienced severe injuries.

Throughout the study period at the national and sub-national levels, males were disproportionately affected by injury. The literature shows that males are more likely to die and suffer long-term disability from injury than females (5, 39, 40). There are several possible reasons to explain men's vulnerability to injuries in a patriarchal society, such as Ethiopia. Males tend to engage in risky behaviors, like drive over limit, non-use of seatbelts, drive after drinking alcohol, and unsafe jobs (7, 41, 42). They also engage in armed conflicts (42, 43). Moreover, studies indicate that males use illegal substances, drugs, and alcohol more often than females, this may increase the level of aggression, involvement in criminal activities, and injury risk (41, 42). When investigating the age distribution, the risk of death and disability from injuries was observed to be higher among the lower age groups. This could be explained by the fact that people in this age group are less likely to keep workplace safety precautions, have higher risk-taking behaviors, and engage in injury prone activities (41, 44, 45).

Approximately 79% of the total injury-related deaths were caused by the five most frequent injuries: road traffic injuries, interpersonal violence, self-harm, falls, and poisoning. The road traffic injuries as the leading causes of injury-related death and disability aligns closely with the global injury ranking of road injuries, self-harm, and interpersonal violence (6). Moreover, road traffic injuries account for more than 61% of injury-associated hospitalizations and 52% of these had fatal outcomes (7, 10, 11, 20). The Ethiopian health sector transformation plan recognizes that road traffic injuries are one of the growing and predominant public health problems in the country (37).

Interpersonal violence and self-harm are among the leading causes of premature deaths in Ethiopia. This is consistent with available surveillance data, which revealed that assault and intentional self-harm accounts each for 10% of overall injury-related deaths (12). Falls are becoming a main cause of injury resulting in death and disability in Ethiopia (12, 13). The present study showed that nationally falls are the fourth leading cause of death, and the numbers of deaths and DALYs associated with falls have increased by 55 and 46%, respectively; between 1990 and 2019. This is the only injury cause for which the rates of DALYs and deaths remained unchanged over time. This might be due to the

TABLE 3 Age-standardized rate of incidence, prevalence and mortality by injury cause and annualized rate of change in Ethiopia, from 1990 to 2019.

Causes of injury	Age-standardized incidence per 100,000 population	Annualized rate of change	Age-standardized prevalence per 100,000 population	Annualized rate of change	Age-standardized mortality per 100,000 population	Annualized rate of change
	2019	1990–2019	2019	1990–2019	2019	1990–2019
Transport injuries	1,089 (926.5–1276.5)	−31.3 (−33, −29.5)	3183.2 (2962.4–3451.1)	−32 (−32.9, −31.1)	15.2 (12.8–18.2)	−54.6 (−66.2, −40.4)
Road	1044.7 (884.1–1233.5)	−31.8 (−33.6, −30)	2983.6 (2759.1–3238.2)	−32.8 (−33.7, −31.9)	14.5 (12.2–17.4)	−54.3 (−65.8, −39.8)
Pedestrian	298.3 (237.1–371.6)	−41.5 (−43.8, −39)	1072.4 (935.8–1234.6)	−42.1 (−43.3, −40.8)	6.3 (4.7–8.4)	−60.7 (−72.8, −39.4)
Cyclist	403.6 (320.2–508.6)	−26.8 (−29.4, −23.9)	921.2 (780.3–1108.3)	−24.8 (−26, −22.9)	0.7 (0.4–1.1)	−54.8 (−75.6, −30.9)
Motor vehicle	214.6 (161.7–269.8)	−30.1 (−33.1, −26.8)	573.1 (490–673.3)	−28 (−29.5, −26.4)	6.4 (4.9–7.9)	−45.8 (−61.4, −19.4)
Motorcyclist	97.1 (78.4–120.1)	−25.8 (−29.4, −21.7)	361 (315.3–410.7)	−28.8 (−30.5, −26.6)	1.1 (0.6–1.8)	−52.3 (−76.7, −17.4)
Other road injuries	31.2 (20.4–44.6)	−5.4 (−10.9, 0.1)	56 (47.5–64.7)	−4.9 (−7.3, −2.7)	0.1 (0–0.1)	−60.7 (−81.9, −29.5)
Other transport injuries	44.3 (34.4–56.8)	−17.4 (−24.2, −10.9)	199.6 (163.1–239.5)	−18.5 (−21.1, −15.3)	0.7 (0.5–1.2)	−61.1 (−75.6, −42.9)
Falls	1162.1 (958.4–1400.2)	9 (5.3, 12.9)	2440.3 (2116–2822.5)	8.4 (6.9, 10.5)	9.6 (8.1–11.3)	−21.3 (−40.5, 12.5)
Drowning	5.4 (4.3–6.7)	−28.1 (−33.7, −22.6)	20.9 (18.7–23.5)	−29.4 (−31.7, −27.4)	1.8 (1.5–2.6)	−67.5 (−75.3, −48.6)
Environmental heat and cold exposure	66.9 (49.3–89.3)	−8.3 (−14.2, −3)	234.6 (185–292.4)	−6.9 (−10.2, −4.3)	1.2 (0.7–1.7)	−54 (−67.4, −36.6)
Fire, heat, and hot substances	172.4 (128.5–219.7)	−23.2 (−29, −17.9)	1749 (1465.5–2,110)	−23.9 (−26.6, −21.1)	3.4 (2.4–4.8)	−47.9 (−63.7, −8.5)
Poisonings	26.8 (20.1–34.9)	−35.7 (−40.7, −30.1)	26.6 (22.8–31.2)	−38.6 (−41.8, −35.7)	4.1 (2.5–5.1)	−61.4 (−70.8, −43.7)
Poisoning by other means	20.3 (14.7–27)	−41.3 (−46.4, −36)	20 (16.4–24.5)	−44.8 (−47.5, −42)	2.1 (1.1–2.9)	−73.9 (−81.6, −58.6)
Poisoning by carbon monoxide	6.5 (4.3–9.7)	−8.1 (−17.8, 2.1)	6.5 (5–8.7)	−6.1 (−10.5, −2.4)	2 (1.3–2.7)	−22.9 (−54.3, 26.9)
Exposure to mechanical forces	1381.1 (1098–1674.3)	−11.7 (−15.8, −7.8)	2687.8 (2326.9–3060.1)	−11.7 (−13.7, −9.7)	4.4 (3.2–5.7)	−41.2 (−59.8, −16.3)
Adverse effects of medical treatment	110.3 (90.5–133)	−26 (−29.4, −22.4)	8.4 (6.2–10.9)	−26 (−29.3, −22.4)	3 (1.5–7.8)	−58.9 (−69.5, −44.9)
Animal contact	1208.7 (1000–1485.5)	−31.3 (−33.9, −28.5)	696.3 (595.3–811.2)	−31.4 (−32.7, −30.2)	3.6 (2.8–5.1)	−53.8 (−68, −19.8)
Non-venomous animal contact	852.6 (691.5–1072.3)	−31.2 (−33.9, −28.6)	551.9 (460.8–665.4)	−32.2 (−33.8, −30.7)	1.4 (0.9–2.7)	−54.5 (−76.1, 6.2)
Foreign body	1157.7 (939–1434.1)	1 (−0.8, 3.2)	808.4 (667.8–954.8)	−0.6 (−2.5, 1.4)	2.4 (2.1–2.8)	−41 (−52.9, −26.2)
Other exposure to mechanical forces	1340.4 (1065–1631.4)	−10.9 (−14.9, −7)	2564.8 (2202.3–2943.1)	−10.5 (−12.6, −8.5)	2.5 (1.6–3.6)	−25.9 (−53.4, 14.8)
Unintentional firearm injuries	40.7 (29.9–54.4)	−33.1 (−38.2, −26.4)	123 (106.6–144.1)	−30.4 (−33.6, −27.3)	1.8 (1.2–2.5)	−54.3 (−73.2, −31.6)
Pulmonary aspiration and foreign body in airway	19.5 (13.3–30)	−26 (−33.2, −18)	34.7 (26.2–46.5)	−25.8 (−30.4, −21.3)	1.6 (1.2–2.1)	−33.7 (−49.3, −12.1)
Venomous animal contacts	356.1 (261.2–475.2)	−31.4 (−34.5, −28)	144.3 (116.1–181.2)	−27.9 (−30, −25.8)	2.2 (1.6–2.9)	−53.4 (−68.1, −30.5)
Self-harm	26.9 (22.6–32.3)	−40.7 (−42.6, −38.5)	92.9 (79.3–105.1)	−41.8 (−43.6, −39.6)	10.1 (8.2–12.9)	−53.3 (−65.3, −32.7)
Interpersonal violence	231.1 (186.8–274.4)	−27.1 (−29.3, −24.5)	3639.8 (3208–4,175)	−7.4 (−9.8, −5)	9.7 (7.9–11.9)	−37.9 (−57, −13.3)
Conflict and terrorism	39.3 (30.9–48.2)	−99.8 (−99.8, −99.8)	4889.4 (2608.3–9341.9)	1.5 (−26.7, 37.7)	0.2 (0.1–0.2)	−99.8 (−99.9, −99.8)
Physical violence by firearm	3.8 (3–5.1)	−21 (−25.7, −15.6)	11.1 (9.6–12.6)	−26.9 (−28.8, −24.9)	2.9 (2.2–3.7)	−37.7 (−63.9, −4.9)
Executions and police conflict	10.9 (7.8–14.3)	0 (0, 0)	87.6 (52.8–138.3)	0 (0, 0)	0.1 (0.1–0.1)	934.3 (705.2, 1166.4)
Physical violence by other means	149.8 (119.3–184.2)	−29.1 (−31.5, −26.5)	250.7 (215.4–297.2)	−30.3 (−32.1, −28.8)	3.8 (2.9–4.7)	−39.7 (−61.6, −12.7)
Physical violence by sharp object	77.5 (60.3–95.5)	−23.1 (−26.1, −19.8)	169.7 (149.5–194.5)	−26.5 (−28, −25)	3 (2.3–3.8)	−35.6 (−58, 1.6)
Self-harm by firearm	2.2 (1.5–3.2)	−26.7 (−32, −20.4)	6.8 (5.8–8)	−24 (−27.1, −20.6)	0.5 (0.3–0.9)	−50.2 (−74.9, −11.8)
Self-harm by other specified means	1162.1 (958.4–1400.2)	−41.7 (−43.6, −39.6)	86.1 (72.4–98.7)	−42.8 (−44.7, −40.6)	9.6 (7.8–12.4)	−53.4 (−65.6, −33.4)

TABLE 4 Age-standardized rate of DALYs, YLDs, and YLLs by injury cause and annualized rate of change in Ethiopia, from 1990 to 2019.

Causes of injury	Age-standardized DALYs per 100,000 population	Annualized rate of change	Age-standardized YLDs per 100,000 population	Annualized rate of change	Age-standardized YLLs per 100,000 population	Annualized rate of change
	2019	1990–2019	2019	1990–2019	2019	1990–2019
Transport injuries	760.4 (646.6–891.3)	−56 (−65.9, −44.1)	215.6 (158.5–283)	−32.1 (−33.3, −31.1)	544.9 (452.2–660.8)	−61.4 (−71.8, −47.4)
Road	712.4 (604.4–836.7)	−55.9 (−65.7, −44.1)	201.7 (148–265.3)	−32.7 (−33.8, −31.6)	510.7 (422.7–615.9)	−61.2 (−71.8, −47.2)
Pedestrian	290.3 (231.9–366.2)	−63.4 (−73.3, −47.2)	72.2 (50.6–96.6)	−42.7 (−44.1, −41.1)	218 (162.6–295.4)	−67.3 (−78, −48.2)
Cyclist	81.9 (61.9–103.6)	−40.6 (−55.2, −29.1)	59.8 (42.8–79.8)	−23.6 (−25.3, −21.8)	22.2 (13.3–36.4)	−62.8 (−81.2, −39.5)
Motor vehicle	269.6 (212.8–330.8)	−49.8 (−63.4, −24.4)	42 (30.3–56.2)	−26.9 (−28.7, −25.1)	227.6 (172.3–289.9)	−52.5 (−66.9, −24)
Motorcyclist	64.8 (43.3–90.2)	−52.2 (−71.4, −26.7)	24.5 (17.7–32.8)	−29.1 (−30.9, −27.1)	40.2 (22–66.7)	−60.1 (−81.6, −25.5)
Other road injuries	5.8 (4.5–7.3)	−47.3 (−69.3, −16.8)	3.1 (2.2–4.2)	−3 (−5.4, −0.8)	2.7 (1.8–3.8)	−65.4 (−85.2, −29.7)
Other transport injuries	48.1 (35.4–69.5)	−57.5 (−70.5, −42.5)	13.8 (9.9–18.2)	−22.7 (−25, −20.2)	34.2 (22.8–55)	−64.1 (−77.5, −47.2)
Falls	299.5 (251.9–354.4)	−23.1 (−38.6, 2.4)	122.5 (88.6–165.7)	7.1 (5.3, 8.9)	177 (147.3–213)	−35.7 (−53.7, −0.1)
Drowning	93.6 (72.6–145)	−73.5 (−80.9, −54.9)	1.4 (1–1.8)	−32.2 (−35.1, −29.4)	92.2 (71.3–143.6)	−73.8 (−81.1, −55)
Environmental heat and cold exposure	48.6 (32.2–67.9)	−52.7 (−68, −34.9)	10.8 (7.6–14.6)	−10.7 (−13.9, −8.1)	37.7 (22.7–56.6)	−58.3 (−73.8, −38.7)
Fire, heat, and hot substances	186.7 (142.8–245.3)	−50.7 (−64.3, −19)	72.9 (52.8–97.4)	−29.7 (−33.3, −26.1)	113.8 (76.6–167.3)	−58.7 (−73.9, −12.9)
Poisonings	151.1 (93.1–194.6)	−68.3 (−76.6, −48.5)	3 (2–4.2)	−39.4 (−43.9, −34.7)	148.1 (90–191.2)	−68.6 (−76.9, −48.7)
Poisoning by other means	91.7 (51.3–128.6)	−76.8 (−83.9, −59.5)	2.3 (1.4–3.2)	−45.9 (−49.8, −41.5)	89.4 (48.8–126.2)	−77.1 (−84.3, −59.6)
Poisoning by carbon monoxide	59.5 (37.8–86)	−27.6 (−60.1, 28)	0.8 (0.5–1.1)	−5.9 (−12.9, 0.8)	58.7 (36.9–85.3)	−27.8 (−60.4, 28.5)
Exposure to mechanical forces	221 (165.8–285.4)	−37.8 (−57, −15.5)	64.8 (45–91.1)	−14.8 (−16.9, −12.7)	156.2 (103.4–216.8)	−44 (−66.4, −15.9)
Adverse effects of medical treatment	94.9 (52.3–218.2)	−68.1 (−79.8, −50.5)	1.1 (0.7–1.7)	−26 (−29.3, −22.4)	93.8 (51–217.3)	−68.3 (−80, −50.6)
Animal contact	132.2 (100.6–188.4)	−56.4 (−70, −23.4)	14.8 (10–21.1)	−33.5 (−35.6, −31.7)	117.5 (86.7–173.6)	−58.2 (−72.1, −22.3)
Non-venomous animal contact	61.4 (42.9–101)	−59.2 (−76.1, −12)	9.4 (6.2–13.9)	−36.7 (−39.6, −34.5)	52 (34.6–93.3)	−61.7 (−79.4, −8.1)
Foreign body	116.3 (99.2–133.5)	−41.1 (−52.2, −27.6)	32.3 (22.9–44.2)	−3.7 (−5.9, −1.6)	83.9 (70.5–99.6)	−48.8 (−60.6, −33.5)
Other exposure to mechanical forces	154.9 (107.8–207.4)	−24.9 (−48.7, 7.1)	57.5 (39.7–81.4)	−12.5 (−14.6, −10.5)	97.4 (57.3–148.9)	−30.7 (−60, 17.3)
Unintentional firearm injuries	66 (42.9–89.7)	−55.6 (−74, −32.7)	7.3 (5.2–9.6)	−29.6 (−32.4, −26.1)	58.8 (36.3–81.7)	−57.5 (−76.7, −33.1)
Pulmonary aspiration and foreign body in airway	56.4 (41.3–73.1)	−41.6 (−57.2, −19.1)	2.1 (1.5–2.9)	−29 (−33.2, −24.8)	54.2 (39.1–70.9)	−42 (−58, −18.8)
Venomous animal contacts	70.9 (53–97.2)	−53.7 (−67.8, −28.9)	5.4 (3.6–7.4)	−26.9 (−30.1, −23.8)	65.5 (47.6–91.4)	−55 (−69.8, −28.9)
Self-harm	333.1 (268–419)	−57.4 (−69, −39)	8.4 (6.1–11.1)	−45.6 (−48, −43)	324.7 (259.3–411)	−57.6 (−69.5, −38.9)
Interpersonal violence	457.5 (380.6–556.7)	−38.5 (−56.4, −15.8)	49.4 (37.9–63.7)	−17.1 (−20.2, −13.6)	408.1 (332.5–504.8)	−40.4 (−59.1, −15.7)
Conflict and terrorism	221.1 (124.5–440.2)	−96.4 (−98, −93.1)	212.3 (115.8–430.6)	−46.9 (−64.9, −12.7)	8.8 (8–9.7)	−99.8 (−99.9, −99.8)
Physical violence by firearm	132.8 (99.7–169.4)	−38.4 (−63.6, −6)	0.8 (0.6–1.1)	−23.4 (−25.7, −20.8)	132 (98.9–168.6)	−38.5 (−63.8, −5.8)
Executions and police conflict	8.8 (7.6–10.6)	1542.4 (1,115, 2046.8)	3.4 (2.3–5)	0 (0, 0)	5.4 (5–6)	912.5 (681.3, 1152.5)
Physical violence by other means	178.2 (138–217.9)	−41.5 (−61.9, −16.2)	13.7 (9.8–18.3)	−30 (−32.1, −28)	164.5 (124.5–205.3)	−42.3 (−63.9, −15.2)
Physical violence by sharp object	119.2 (91–151.8)	−38.9 (−60.6, −2.9)	7.5 (5.4–10)	−26.1 (−28.2, −24.3)	111.6 (84.5–145.4)	−39.6 (−62.1, −1)
Self-harms by firearm	19.9 (13.1–33.4)	−52.1 (−75.3, −9.1)	0.5 (0.3–0.6)	−21.3 (−24.2, −18.6)	19.5 (12.6–32.9)	−52.6 (−75.7, −8.8)
Self-harm by other specified means	313.1 (252.9–390.9)	−57.7 (−69.6, −39.8)	8 (5.7–10.5)	−46.6 (−48.9, −44)	305.2 (243.4–381.5)	−57.9 (−69.9, −39.7)

increase of aging populations as a result of improved life expectancy in Ethiopia (38). Studies indicate that people older than 65 years may experience frequent falls that cause moderate to severe adverse health consequences (13).

The GBD methodologies' limitations and strengths are discussed elsewhere in the literature, and need to be taken into account when interpreting the results (5, 6). Yet, this study has a number of strengths, including comprehensive and representativeness at sub-national level using all Ethiopian data sources that are readily available, which enhance the validity of estimates that cannot be seen in individual household surveys with varied data quality. However, the absence of a reliable injury surveillance and vital registration system in the country may lead to wider uncertainty in determining the causes of injury mortality.

Injury prevention initiatives in Ethiopia

Preoccupied with communicable disease control, Ethiopia has long ignored injury, despite the fact that it imposes a significant economic and health burden on the country. However, recent years have seen a rise in focus on injury prevention (37, 46). Different government bodies, including the Ministry of Health, Ministry of Transport, and Ministry of Women and Child Affairs are working on at least one type of injury prevention, which may be strengthened as a result of the current study's findings. For instance, the Ethiopian essential health services package includes emergency surgeries (46), which are crucial for addressing the effects of injuries, while the Ministry of Women and Children Affairs is working on preventing gender-based violence and providing victims with treatment. In addition, individual activists, opinion leaders, and well-known writers and musicians in Ethiopia continuously engage in safety advocacy, education, and injury prevention to dispel the widespread misconception of there is nothing that can be done to prevent injuries. Additionally, a local NGO by the name of Save The Nation focuses on capacity building, road safety awareness creation initiatives, media campaigns, and resource mobilization. In order to avert post-injury adverse outcomes, insurance agencies are deemed to cover the emergency healthcare costs. Therefore, this study enables the stakeholders working on injury prevention through evidence-based priority settings, resource mobilization, and advocacy efforts.

Conclusion

In Ethiopia the number of deaths, age-standardized rates of incidence, prevalence, DALYs, YLLs, and YLDs due to injuries have decreased steadily during the past 30 years. Yet, the burden remains unacceptably high. Moreover, there is a substantial regional disparity in the burden of injury. The majority of deaths and disabilities are caused by traffic injuries, falls, self-harm, and interpersonal violence. Children under the age of 5 years, adolescents, and young adults are disproportionately affected by injuries. The majority of injuries are preventable using simple public health measures, road safety, and security interventions. Coordinated efforts are, therefore, required by researchers, public health authorities, and policymakers to reduce the burden of injury in Ethiopia.

Data availability statement

The datasets presented in this article are not readily available because one can access them from the IHME repository directly. Requests to access the datasets should be directed to http://ghdx.647healthdata.org/gbd-results-tool.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

TB conceived, designed, and conducted the study. ST, AM, and MS consulted the overall process of the study. ST, TB, AM, MS, FG, GT, SW, SMe, SMo, AW, and MN involved in the analysis and interpretation of the findings. All authors contributed to the article and approved the submitted version.

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The GBD study is a systematic, scientific, and global effort to quantify and compare the magnitude of health loss from disease, injury, and risk factors by age, sex, and population over time. We are grateful for this global initiative.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Fatal crashes and rare events logistic regression: an exploratory empirical study

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Objective: Fatal road accidents are statistically rare, posing challenges for accurate estimation through the classic logit model (LM). This study seeks to validate the efficacy of a rare events logistic model (RELM) in enhancing the precision of fatal crash estimations.

Methods: Both LM and RELM were employed to examine the relationship between pertinent risk factors and the incidence of fatal crashes. Crash-injury datasets sourced from Hillsborough County, Florida served as the empirical basis for evaluating the performance metrics of both LM and RELM.

Results: The analysis revealed that RELM yielded more accurate predictions of fatal crashes compared to LM. Receiver operating characteristic (ROC) curves were constructed, and the area under the curve (AUC) for each model was computed to offer a comparative performance assessment. The empirical evidence notably favored RELM over LM as substantiated by superior AUC values.

Conclusion: The study offers empirical validation that RELM is demonstrably more proficient in predicting fatal crashes than the LM, thereby recommending its application for nuanced traffic safety analytics.

KEYWORDS

traffic safety, fatal crashes, rare events, logit model, binary classification

1 Introduction

The persistently high mortality rates from traffic crashes have intensified their classification as a significant global public health issue (1, 2). According to the World Health Organization (3), fatalities attributed to traffic crashes witnessed a 25% increase, rising from 1.08 million in 1990 to 1.35 million in 2016. This uptick not only represents a societal tragedy but also imposes considerable economic strain on communities and families.

Numerous studies have been undertaken to explore the relationships between various risk factors—such as sex, age, educational attainment, weather conditions, and alcohol consumption—and the outcomes of traffic crashes (4–10). Given that crash severity is generally categorized by levels, discrete outcome models have been instrumental in investigating the correlations between fatal crashes and contributory factors (11–16).

Among the models utilized, the binary logit model (LM) is predominant. However, this approach has limitations when dealing with rare events, such as fatal crashes. For instance, the Hong Kong Transport Department's statistics from 2015 reveal that, of 16,170 injury-related crashes, only 117 were fatal, representing a meager 0.72% of the total dataset (17). Extant literature corroborates that LM tends to significantly underestimate the occurrence of such rare events (18).

Against this empirical backdrop, the present study deploys a rare events logistic model (RELM) to enhance the precision of fatal crash estimations. The RELM has been successfully applied in other domains such as geomorphology, social science, and epidemiology (19–21). To the authors' best knowledge, this study involves the inaugural application of RELM in the specific field of fatal crash estimation.

2 Methodology

2.1 Logit model

Logistic regression is the most used method in crash injury severity analyses. To model the relationship between fatal crashes and the risk factors, the outcome variable y_i in the *ith* crash was set to be one of the two values: $y_i = 1$ representing fatal crashes and $y_i = 0$ representing non-fatal crashes. The probability of $y_i = 1$ is denoted by $\Pr(y_i = 1)$, which is calculated using the following equation:

Logistic regression is the predominant method employed in the analyses of crash injury severities. To elucidate the relationship between fatal crashes and associated risk factors, we define the outcome variable y_i for the *i*th crash as binary: $y_i = 1$ signifies a fatal crash, while $y_i = 0$ indicates a non-fatal crash. The probability that $y_i = 1$, denoted as $\Pr(y_i = 1)$, is calculated using the logistic function:

$$\Pr\left(y_i = 1\right) = \frac{1}{1 + e^{-\beta x_i'}} \tag{1}$$

In Equation (1), $e^{-\beta x_i'}$ encapsulates the linear combination of predictor variables, known as the utility function, which is expressed as:

$$\beta x_i' = \beta_0 + \beta_1 x_{1i} + \cdots + \beta_k x_{ki} \tag{2}$$

Here, x_{ki} represents the value of the *k*th variable for the *i*th observation and β_k is the corresponding coefficient.

There is another way to formulate the aforementioned question. Let us assume an unobserved continuous variable y_i^*, which represents the propensity of where a fatal crash occurred. y_i^* follows a logistic distribution, which is close to normal (mathematically, the difference exists but is trivial). If we want to know the effects of x_i, the standard approach is to run a regression with x_i as the dependent variable. To determine whether the crash is fatal or not, we observed whether this propensity is greater than a specific threshold. As documented by King and Zeng (19), this mechanism turns out to be the chief troublemaker in bias induced by rare events. The coefficients of β are estimated using the maximum-likelihood method with the following equation over a dataset of n observations:

$$\Pr\left(y_i = 1\right) = \frac{1}{1 + e^{-\beta x_i'}} \tag{3}$$

In Equation (3), $e^{-\beta x_i'}$ is the multiple linear combinations of explanatory variables, which are also known as the utility function, and can be represented as:

$$\beta x_i' = \beta_0 + \beta_1 x_{1i} + \cdots + \beta_k x_{ki} \tag{4}$$

where x_{ki} denotes the value of variable k for sample i and β_k is the coefficient of variable k.

Alternatively, one may conceptualize the problem using a latent variable y_i^*, which signifies the propensity for a crash to be fatal. This latent variable follows a logistic distribution, which, despite its mathematical distinctiveness, is practically akin to a normal distribution. The impact of the predictors x_i is typically assessed by regressing them against this unobserved variable. The determination of the crash outcome—fatal or otherwise—is contingent upon whether the propensity surpasses a specified threshold. As highlighted by King and Zeng (19), this threshold mechanism introduces a primary source of bias in the presence of rare events. The logistic regression coefficients β are estimated by employing the maximum-likelihood estimation method applied across a dataset comprising n observations:

$$L\left(\beta\right) = \prod_{i=1}^{n}\left[\left(\frac{1}{1 + e^{-\beta x_i'}}\right)^{y_i}\left(1 - \frac{1}{1 + e^{-\beta x_i'}}\right)^{1-y_i}\right] \tag{5}$$

It is imperative to acknowledge that, in the analysis of rare events data, additional occurrences of the event of interest (coded as "1") provide greater informational value than non-occurrences (coded as "0"). During the estimation phase, the standard error of the estimated coefficient β is derived from the variance:

$$V\left(\hat{\beta}\right) = \frac{1}{\sum_{i=1}^{n} \pi_i(1 - \pi_i)x_i^2} \tag{6}$$

In Equation (6), the summation $\sum_{i=1}^{n} \pi_i(1 - \pi_i)$ is notably influenced by the rarity of the event under study. The term $\pi_i(1 - \pi_i)$ attains its maximum when $\pi_i = 0.5$ and approaches zero as π_i converges to either extremity of the probability spectrum. Given that rare events data typically yield minuscule estimates of π_i for all observations, it is crucial to consider that these estimates will be substantially smaller than 0.5. Nonetheless, if the logit model possesses explanatory significance, the estimated probabilities π_i corresponding to the occurrences of "1" will be markedly higher than those associated with "0". These estimates will also lie nearer to the apex of informational value at 0.5. Consequently, this results in the additional occurrences of "1" being more informative for the model than the additional occurrences of "0".

2.2 Rare events logistic model

To ameliorate the bias in estimation attributed to the use of LM in rare events data, King and Zeng (18) introduced the RELM. RELM not only mitigates underestimation bias but also enhances the efficiency of data collection and reduces the requirements for data storage space during the sample selection phase.

2.2.1 Sample selection

As highlighted in the preceding discussion, the LM exhibits suboptimal performance when instances of $y_i = 1$ are infrequent within the dataset. To address this limitation, a strategic alteration in data collection is proposed. By archiving all observations where a fatal crash occurred ($y_i = 1$) and a random subset of non-fatal crash observations ($y_i = 0$), we can refine the accuracy of the standard logit model's estimations.

2.2.2 Adjustment of estimates for selection bias

To correct for selection bias inherent in choice-based sampling, two primary methods are employed: the prior correction and the weighting correction. The subsequent sections will elucidate these approaches in detail.

Research by King and Zeng (18) demonstrates that the logit model coefficients remain statistically consistent between population estimates and those derived from selected data. The objective of the prior correction method is to adjust the intercept $\hat{\beta}_0$ in the logit model using the following formula:

$$\beta_0 = \hat{\beta}_0 - ln\left[(\frac{1-\tau}{\tau})(\frac{y}{1-y})\right] \tag{7}$$

where τ represents the proportion of $y_i = 1$ within the population, while y signifies the proportion of $y_i = 1$ within the sampled dataset. The calculation of the probability of rare events occurrence is contingent upon accurate estimations of both β_0 and β_k, as indicated in Equation (1).

It is essential to note that the prior correction method necessitates the knowledge of τ, the population proportion of $y_i = 1$. In the context of this study, τ can be directly ascertained from the initial dataset of crash data. A principal benefit of the prior correction method lies in its user-friendliness; it can be readily implemented with any statistical software capable of fitting standard logistic models. For instance, the study by Ren et al. (22) leveraged this method to adjust estimates concerning the influence of various factors on red-light running behavior. Next, we will delineate an alternative approach that can augment the efficacy of the logistic model (LM) when used in conjunction with prior correction.

The weighting correction involves assigning weights to the data to balance the discrepancies in the proportions of $y_i = 1$ between the sample and the population, which arise from choice-based sampling. This method entails optimizing a weighted log-likelihood function rather than the conventional log-likelihood function:

$$\ln L_w\left(\beta|y\right) = \omega_1 \sum_{\{y_i=1\}} \ln \pi_i + \omega_0 \sum_{\{y_i=0\}} \ln\left(1-\pi\right) = -\sum_{i=1}^{n} \omega_i \ln\left(1+e^{(1-2y_i)x_i\beta}\right) \tag{8}$$

In this context, the weights ω_1 and ω_0 are defined as $\omega_1 = \tau/y$ and $\omega_1 = \tau/y$, respectively, where $\omega_i = \omega_1 y_i + \omega_0(1-y_i)$. The parameters τ and y retain their definitions from the "prior correction" section.

Although this method may appear more complex than the prior correction technique, Equation 6 is formulated to enable researchers to apply it using any standard logit software package.

Xie and Manski (23) posited that weighting correction could surpass prior correction in effectiveness when the available sample is substantial, and there is a mis-specification of the functional form. Conversely, Amemiya and Vuong (24) indicated that, while weighting correction may be marginally less efficient than prior correction, the difference in efficiency is typically negligible.

2.2.3 Computing probability estimates

Subsequent to implementing the prior correction and weighting methods, we adapt modifications suitable for both cohort and choice-based sampling designs in rare events logistic models. The bias in the estimated coefficients $\hat{\beta}$ is appraised using the weighted least-squares method, formulated as:

$$bias\left(\hat{\beta}\right) = \left(X^{'}WX\right)^{-1} X^{'}W\xi \tag{9}$$

where $\xi_i = 0.5Q_{ii}\left((1+\omega_1)\hat{\pi}_i - \omega_1\right)$ symbolizes an adjustment factor, where Q_{ii} are the diagonal constituents of the matrix $Q = X\left(X'WX\right)^{-1}X'$ and $W = diag\left\{\hat{\pi}_i(1-\hat{\pi}_i)\omega_i\right\}$ is a diagonal matrix with elements $\hat{\pi}_i(1-\hat{\pi}_i)\omega_i$. Consequently, the adjusted coefficients $\tilde{\beta}$ are calculated as follows:

$$\hat{\beta} - bias\left(\hat{\beta}\right) = \tilde{\beta} \tag{10}$$

The final corrected probability P_i can be approximated by the following expression:

$$P_i = \tilde{\pi}_i + C_i \tag{11}$$

where the correction term C_i is delineated as follows:

$$C_i = (0.5-\tilde{\pi}_i)\,\tilde{\pi}_i\,(1-\tilde{\pi}_i)\,X_i V\left(\tilde{\beta}\right)X_i^{'} \tag{12}$$

Within this equation, $V\left(\tilde{\beta}\right)$ denotes the estimated variance-covariance matrix of the adjusted coefficients $\tilde{\beta}$. $X_i = (1, x_i)$ represents the vector of predictors, including the intercept for the ith observation, and X_i' is its transpose. Collectively, these amendments constitute the methodology of the RELM. To the authors' knowledge, this is the first instance of applying RELM within the domain of fatal crash estimation.

3 Data description

Data on crash-related injuries that occurred in the year 2006 in Florida were procured from the Florida Department of Highway Safety and Motor Vehicles (DHSMV). The dataset encompasses 107,464 driver-vehicle units implicated in 53,732 traffic incidents. A meager 0.34% of these incidents resulted in fatalities, highlighting their infrequency. The variables under scrutiny encompass critical attributes, such as those associated with the driver, the vehicle, the roadway, and the environmental context, as delineated in prior research (25–28). Table 1 delineates the variables and their corresponding characteristics as encapsulated within the Florida dataset.

Notably, the "speed ratio"—defined as the quotient of the estimated speed prior to the collision and the statutory speed limit post-collision—is posited to correlate positively with injury severity (25). Furthermore, the analysis includes "points of impact" (POIs) on the vehicle, enumerated in the Florida crash reports and illustrated in Figure 1. These POIs are categorized in alignment with the schema proposed by Huang et al. (29), where Level 1 encompasses nine POIs (nos. 1–2, 5–7, 9–10, 14, and 21) located peripherally relative to the driver's seat, such as the front and rear passenger sides. Level 2 consists of five POIs (nos. 3, 8, 11, 15, and 17) situated in closer proximity to the driver than those in Level 1. Level 3 includes POIs (nos. 4, 12–13, 18, and 20), which are nearest to the driver, comprising the windshield and the front passenger and driver sides. The final category, Level 4, is assigned to two POIs (nos. 16 and 19).

4 Model evaluation

In the evaluation of our models, namely, RELM and the LM, we quantify the predictive performance using the area under the receiver operating characteristic curve (AUC-ROC). The AUC is a widely accepted metric for model performance evaluation, particularly in binary classification problems. It provides an aggregate measure of performance across all possible classification thresholds. The calculation of the AUC involves plotting the true positive rate (sensitivity) against the false positive rate (1-specificity) at various threshold settings (30). The AUC value ranges from 0 to 1, where an AUC of 1 indicates perfect predictive accuracy and an AUC of 0.5 suggests performance no better than random chance.

To estimate the AUC accurately, we employ the trapezoidal rule for numerical integration as this method is well-suited for the discrete data points that characterize an empirical ROC curve (31). Furthermore, we validate the robustness of our AUC estimates through K-fold cross-validation, which mitigates the potential for overfitting by ensuring that each observation is used for both training and validation. This process involves partitioning the data into K equal-sized segments, training the model on $K-1$ segments,

TABLE 1 Variables contained in the dataset.

Factor	Attributes	Count	Proportion
Injury severity	Fatality	363	0.34%
	Non-fatal or no injury	107,101	99.66%
Driver age	Under 25 years	27,685	25.76%
	25–65 years	69,677	64.84%
	Above 65 years	10,102	9.40%
Driver sex	Male	60,567	56.36%
	Female	46,897	43.64%
Alcohol/drug use	No drink or drugs	103,218	96.05%
	Drink or drugs	4,247	3.95%
Seat belt	Not using a seat belt	5,531	5.15%
	Using a seat belt	101,933	94.85%
Driver fault	At fault	44,690	41.59%
	Not at fault	62,774	58.41%
Vehicle year	1996–2006	81,704	76.03%
	<1996	25,760	23.97%
Vehicle type	Passenger car	73,492	68.39%
	Van	8,550	7.96%
	Light truck/pick-up	21,832	20.32%
	Medium/heavy truck	3,590	3.34%
Speed ratio	<0.5	36,676	34.13%
	0.5–1.0	65,641	61.08%
	>1	5,147	4.79%
POI	Level 1	74,949	69.74%
	Level 2	18,381	17.10%
	Level 3	13,816	12.86%
	Level 4	318	0.30%
Day of week	Weekday	81,930	76.24%
	Weekend	25,534	23.76%
Location	Rural	50,384	46.88%
	Urban	57,080	53.12%
Light condition	Daylight	81,980	76.20%
	Dark	25,484	23.80%
Weather	Clear	79,720	74.18%
	Not clear	27,744	25.82%
Surface	Dry	94,726	88.15%
	Not dry	12,738	11.85%
Vision	Not obscured	99,718	92.79%
	Obscured	7,746	7.21%
Highway	Divided highway	60,014	55.85%
	Undivided highway	47,450	44.15%

Number of observations = 107,464.

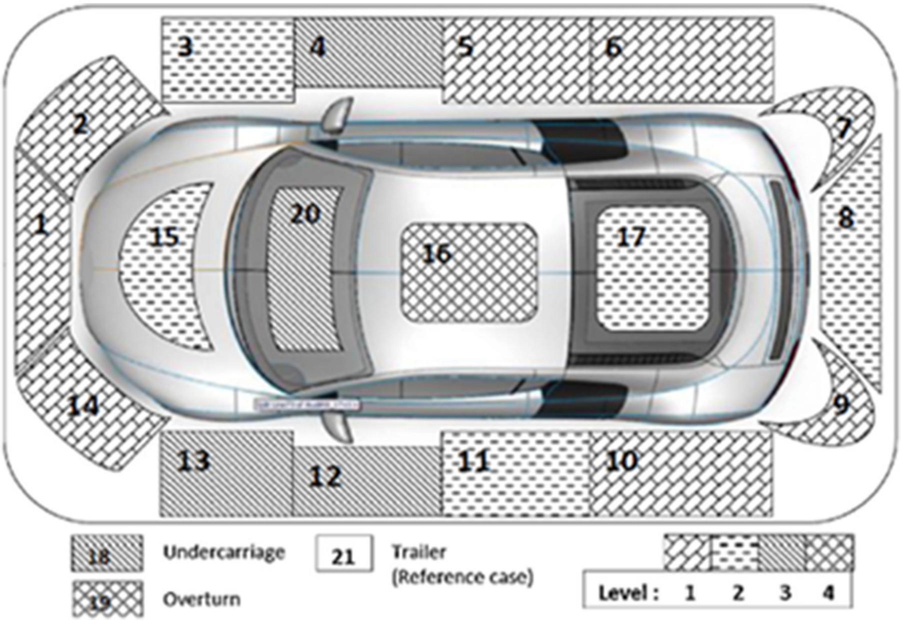

FIGURE 1
An illustration of the points of impact.

and validating it on the remaining segment. This is repeated K times, with each segment used exactly once for validation. The average AUC across all K iterations provides a reliable estimate of the predictive performance of the models. In this study, K was set to 5.

5 Results

5.1 Data sampling

As previously mentioned, the initial step involves the partial extraction of the complete dataset for regression analysis. This entails retaining all instances of fatal crashes while selectively including a subset of non-fatal crashes. To ascertain the optimal proportion of "1" events in the newly constituted dataset, this study computes the coefficients employing both the prior correction and weighting correction methods, incrementally adjusting by 1% within a range from 0.05 to 0.95. The variation in classification accuracy is further assessed using two metrics: the accurate classification rate (ACR), defined as the quotient of correctly identified fatal accidents to the total number of actual fatal accidents; and the false classification rate (FCR), computed as the quotient of erroneously classified incidents to the total number of events.

Figure 2 delineates the interplay between the three aforementioned variables: ACR, FCR, and the ascending fraction of "1" events in the sampled data. The depiction includes red dots representing outcomes via the prior correction method and blue stars indicating results from the weighting method. A 3D subgraph within Figure 2A visualizes the pairwise interactions among these factors, with the remaining panels (Figures 2B–D) presenting projections along different axes.

Analysis of Figure 2 reveals a close alignment between the trajectories of ACR and FCR across both correction methodologies. A trend emerges where an elevated ACR correlates with a heightened FCR. Notably, the ACR ascends more precipitously than the FCR within the "1" event ratio spectrum from 0.05 to 0.5, while this growth rate inverts for ratios between 0.5 and 0.95.

Figure 3 presents the AUC for both methods across varying proportions of fatal to non-fatal crashes. The diagram indicates that the AUC for the prior correction method remains unaffected by the percentage of "1" event post-selection. In contrast, the weighting method demonstrates superior predictive performance at most "1" event ratios. Green stars mark the coordinates with the maximum AUC values, which inform the selection of rates for the weighting method in the rare events logistic model—specifically, 43% in the corrected dataset. For the implementation of the rare events logistic model, the Stata statistical software package was employed.

5.2 The parameters of models

The parameter estimates for the RELM and the LM are consolidated in Tables 2, 3, respectively. These tables encapsulate the significant parameters deduced from the empirical analysis, illustrating that the magnitude and direction of the coefficients for both models are largely consistent. The significance and impact of the variables, with the salient exception of the POI, are in concordance with the injury severities reported in antecedent research, notably by Zeng and Huang (26).

Our analysis of driver demographics indicates a heightened risk of fatality for older drivers following a collision, corroborating the findings from existing literature that underscores age as a critical determinant in traffic injury severity. In relation to vehicular and environmental factors, the data suggest that more recent vehicle

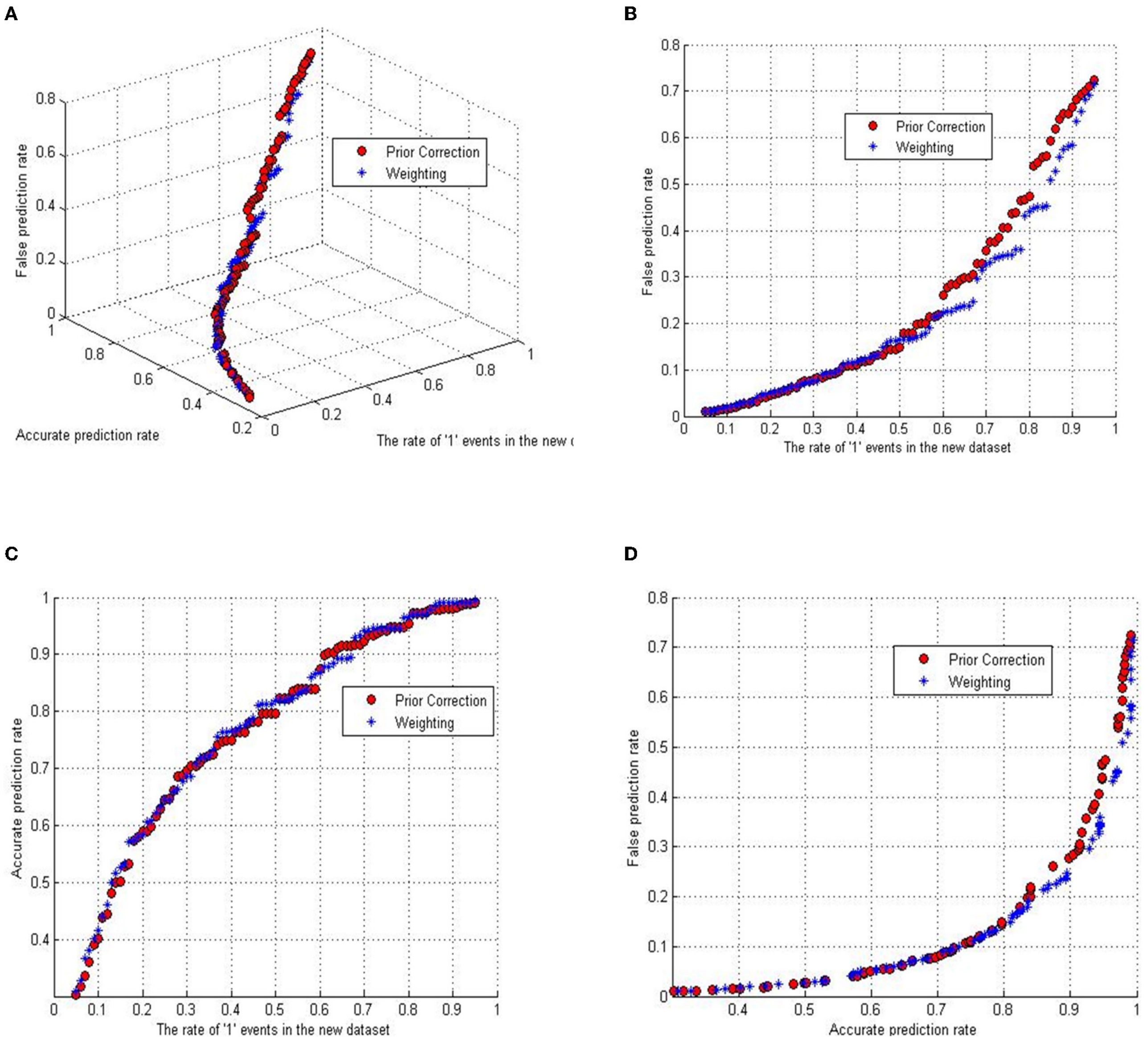

FIGURE 2
The relationship between measurements and the ratio of rare events. **(A)** The relationship between accurate classified rate, false classified rate, and the fatal event ratio. **(B)** The relationship between false classified rate and the fatal event ratio. **(C)** The relationship of accurate classified rate versus the fatal event ratio. **(D)** The relationship between accurate classified rate and false classified rate.

models correlate with a reduction in injury severity, supporting the premise that advancements in vehicular safety technologies have ameliorated crash outcomes. In clear contrast, while operators of medium/heavy trucks exhibit a lower fatality likelihood, drivers of passenger cars show an increased fatal outcome propensity. This disparity may be attributable to inherent variations in vehicle safety features, structural mass, and design specifications.

5.3 Comparative analysis of classification efficacy

Table 4 delineates the predicted outcomes derived from both the RELM and the LM, incorporating statistically significant variables at the 0.05 level into the classification procedure. The predictive classifications of the models are juxtaposed against the actual incident outcomes, with Table 4 providing a comprehensive summary of these predictions. The data articulated in Table 4 highlights the superior performance of RELM in comparison with LM. A notable deficiency of LM is its significant underestimation of fatal accident risk, failing to identify any incident as fatal. In contrast, RELM achieves an accurate classification rate of 77.7%. Despite an increase in the false alarm rate by 12.8%, RELM is deemed tolerable when juxtaposed against the grave implications of underestimating fatal accidents; for instance, Aguero-Valverde (32) equates the impact of 1 fatal crash to that of 20 property-damage-only (PDO) crashes.

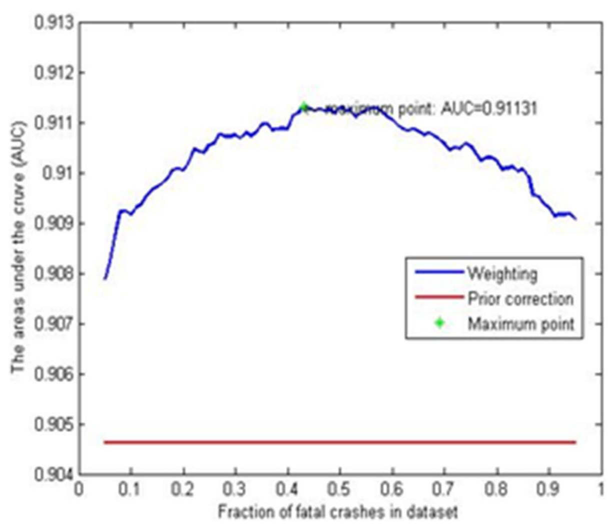

FIGURE 3
AUC values for the weighting method and the prior correction method.

TABLE 2 Model parameters of RELM.

Variable	Coefficient	95% confidence interval	
Age level 3 (above 65 years)	2.553	2.192	2.914
Drug use	1.854	1.495	2.213
Using seat belt	2.279	1.940	2.619
Veh_year (<2006)	−0.415	−0.720	−0.110
Medium/heavy truck	0.492	0.160	0.824
Speed ratio (<0.5)	−1.703	−2.226	−1.180
Speed ratio (0.5–1.0)	−1.308	−1.791	−0.825
POI	1.536	1.217	1.855
Not at fault	−2.609	−3.118	−2.100
Rural	1.017	0.709	1.325
Daylight	−0.843	−1.160	−0.526
Constant	0.036	−0.615	0.687

An extended evaluation of the performance of the two models was conducted through the ROC curves, as exhibited in Figure 4. The predictive accuracy for fatal and non-fatal cases is contingent upon a predetermined probability threshold. An observation is designated as a fatal accident if its predicted probability transcends this threshold; otherwise, it is categorized as non-fatal. The ROC curves graphically represent the tradeoff between the true positive rate and the false positive rate as the threshold varies from 0 to 1. The AUC for each model is computed, revealing that the ROC curve for the RELM generally resides above that of the LM for thresholds below 0.8, indicative of enhanced predictive accuracy of RELM. Moreover, a juxtaposition of the AUC values in Figure 4 confirms the integrated predictive superiority of the RELM model over the LM.

TABLE 3 Model parameters of LM.

Variable	Coefficient	95% confidence interval	
Age level 3 (above 65)	1.970	1.722	2.219
Drug use	2.016	1.711	2.322
Using seat belt	2.122	1.873	2.371
Veh_year (<2006)	−0.281	−0.512	−0.050
Medium/heavy truck	0.411	0.158	0.663
Speed ratio (<0.5)	−0.926	−1.294	−0.557
Speed ratio (0.5–1.0)	−0.984	−1.315	−0.653
POI level 3	1.489	1.260	1.717
Not at fault	−2.957	−3.397	−2.516
Rural	1.003	0.773	1.233
Daylight	−0.396	−0.639	−0.154
Constant	−5.934	−6.418	−5.451

TABLE 4 The prediction results of LM and RELM.

	LM	RELM
Number of crashes	107,464	
Number of fatal crashes	363	
Number of predicted fatal crashes	0	14,013
Number of true positives	0	282
Accuracy	/	77.7%

6 Discussion

This study employs the rare events logistic model to scrutinize the relationship between various risk factors and the incidence of fatal road accidents in Florida. The analysis identifies six variables—older adult casualties, substance abuse, non-usage of safety equipment, passenger car, POI at level 3, and rural accidents—as positively correlated with driver fatalities. Conversely, five variables—vehicle age, speed ratios 1 and 2, driver at fault, and daylight incidents—exhibited a negative correlation with accident risk.

The findings unequivocally show that RELM supersedes LM in estimating fatal crash risks. As hypothesized, LM systematically underestimates these risks, a shortfall that RELM substantially rectifies, achieving an accuracy rate of ∼80%. While a slight increase in false classification is noted, this tradeoff is deemed acceptable given the enormity of losses associated with each fatal accident. The AUC values further corroborate the superior performance of RELM over LM in this context.

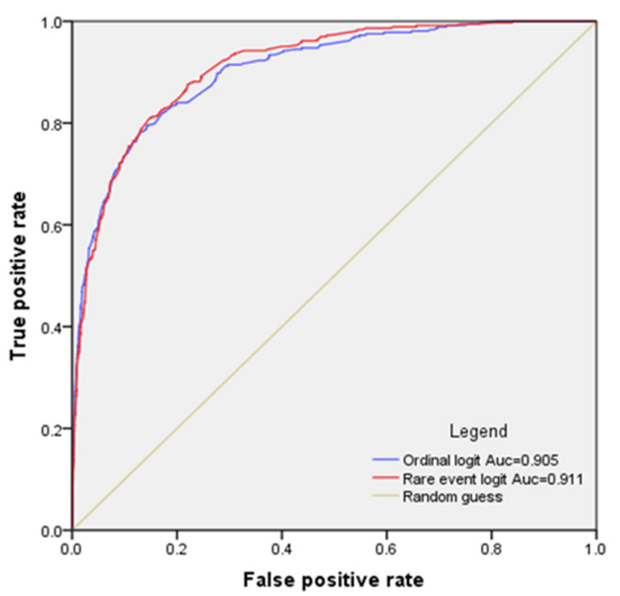

FIGURE 4
ROC curves for RELM and LM methods.

The findings of this study have several implications for stakeholders involved in road safety. It is recognized that annual inspections cannot alter the fundamental crashworthiness of older vehicles; however, ensuring that aging vehicles are maintained can help mitigate risks where possible. Nevertheless, the intrinsic limitations in safety offered by older vehicle designs compared to their modern counterparts must be acknowledged. Thus, stakeholders should focus on enhancing public awareness regarding the potentially increased risks associated with older vehicles and should advocate for policies that encourage the use of vehicles with advanced safety features. For demographic groups such as older adult drivers and men who are statistically at a greater risk, targeted safety campaigns and driving aids could be beneficial. This could involve educational initiatives that promote defensive driving techniques and raise awareness about the increased risk factors these demographics face. Furthermore, urban planners and transportation authorities should take into account the findings regarding speed limits. While not the sole factor, the data suggest that higher speed limits can contribute to the severity of crashes. Therefore, a holistic approach to road design that incorporates traffic calming measures and considers the impact of speed on traffic incident severity is warranted. These measures could help in reducing the likelihood of fatal outcomes in crashes.

This study is subject to certain constraints that warrant acknowledgment. The classification of POIs into predefined levels, a method predicated on established literature, may not capture the entirety of POIs that may significantly influence crash severity. The dataset utilized provided a finite array of POIs, thereby omitting potentially crucial impact points not recorded within it. This omission could lead to a partial portrayal of crash dynamics. Moreover, spatial correlation, a factor that could yield valuable insights into the patterns and causes of fatal crashes, was not incorporated into the RELM used in this analysis. Other influential variables, such as law enforcement strategies and traffic volume data, were also not included in our dataset. The absence of these variables limits the breadth of our analysis, potentially affecting the robustness of our findings. Acknowledging these limitations, future investigative efforts in this field should endeavor to integrate a more detailed classification of POIs, alongside variables capturing spatial correlation, law enforcement efforts, and traffic metrics. Such enhancements in data collection and model sophistication would provide a more holistic understanding of the factors contributing to fatal crash outcomes.

Data availability statement

The data is not available to the public due to data privacy policy. Requests to access these datasets should be directed to ZX, xuzhzh26@mail.sysu.edu.cn.

Author contributions

YX: Writing—original draft. LL: Writing—original draft. HZ: Writing—original draft. QT: Writing—review & editing. JW: Writing—original draft. YY: Writing—original draft. ZX: Writing—original draft, Conceptualization, Formal analysis.

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Conflict of interest

YX and QT were employed by Changsha Planning and Design Institute Co., LTD.

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Enhancing pedestrian perceived safety through walking environment modification considering traffic and walking infrastructure

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Urban policies have recently been formulated, following the increasing interest in pedestrian-friendly cities, people-centered safety, and accessibility. Despite the research efforts on physical walking safety, safety evaluations centered on pedestrian perception have been under-reported. Investigating the factors affecting pedestrian subjective safety perception is critical to promoting walking intention because pedestrians forgo walking if they feel unsafe. This study explored the relationship between various walking environmental factors and pedestrians' psychological perception of safety by surveying 99 pedestrians' perceptions at nine study sites and conducting a field investigation. Because of the multifaceted nature of pedestrian perception, mediation effect analyses were also conducted to understand the relationship between walking environment factors and perceived safety in depth, considering the role of the perception of traffic characteristics and walking infrastructure. This study found that walking environmental factors closely related to physical safety (e.g., traffic safety facilities and crosswalks) may not greatly contribute to perceived safety and demonstrated that maintaining infrastructure quality is essential for enhancing perceived safety, considering the mediating effect of the perception of infrastructure on perceived safety. The results imply that to improve the walking environment, it is necessary to consider both the physical safety and the perceived safety of pedestrians. This requires comprehensive planning for enhancing traffic safety facilities as well as ensuring user comfort and pleasure through quality infrastructure. This study can provide a basis for enhancing pedestrian-centered safety and promoting residents' walking intention for public health while increasing their perceptions of safety.

KEYWORDS
pedestrian safety, safety perception, walking environment, traffic, infrastructure, mediation analysis

1 Introduction

Walking is the most environmentally friendly and equitable means of transportation. Walkability is the foundation of sustainable and equitable cities, and planning for the walking environment should be performed to ensure people enjoy safe, efficient, and pleasant walking (1). The transport and urban policy paradigm has, thus, recently emphasized human-centric safety and accessibility rather than vehicle-centric mobility. Enhancing pedestrian safety is essential, as pedestrians are the most vulnerable road users to potential dangers. Pedestrians' subjective perception of safety is also critical to encouraging walking because pedestrians forgo walking for pleasure unless they feel safe (2). Therefore, research on environmental improvement measures aimed at increasing pedestrian perceived safety is needed to create a walkable environment devoid of fear and anxiety. Accordingly, factors on pedestrians' perceived safety should first be investigated.

That walking environment factors, such as obstacles, traffic facilities, and pathway characteristics, affect pedestrian physical safety has been widely reported (3). However, while most research has focused on physical safety, research on the relationship between pedestrians' perception of safety and walking environmental factors is lacking. By identifying the impacts of walking environmental factors on perceived safety, walking environments can be improved by considering both pedestrians' physical and perceived safety. Therefore, this study aims to identify the relationship between various walking environmental factors and pedestrians' perceived safety. In particular, pedestrian safety perception comprises various aspects, such as perceptions of dynamic traffic characteristics (e.g., moving vehicles) and static infrastructure for walking (e.g., traffic facilities and pathway conditions); therefore, the impact of walking environmental factors is analyzed by considering both the role of human perception on traffic and walking infrastructure on perceived safety.

In this study, "perception of traffic," "perception of walking infrastructure," and "overall perceived safety" are measured, and linear regression analysis is conducted to investigate the relationship between them. The regression analysis also explores the relationship between walking environmental factors and perceived safety. Finally, the mediation effect of the perception of traffic and walking infrastructure between walking environmental factors and pedestrians' perceived safety is analyzed to elucidate this relationship.

The scope of perceived safety in this study is confined to pedestrian traffic-related safety, and the research sites are busy streets on and around university campuses located in Seoul's city center, where pedestrian safety has been a persistent concern. According to the Korea Consumer Agency (4), 23% of pedestrians were at risk from accidents at such locations, which is higher than elsewhere in Korea. The choice of research sites in this study was informed by the high demand for environmental improvements to enhance pedestrian safety.

2 Literature review

The physical factors that affect pedestrian safety have been amply researched. Mukherjee and Mitra (5) statistically proved the following to be the leading causes of pedestrian deaths from traffic accidents: the approaching speed of vehicles, vehicular traffic and pedestrian volume at intersections and their interaction, disorderly movement of traffic, presence of a specific land-use type, inefficient planning and design, a wide carriageway, footpath encroachment, and restricted visibility. Yin and Zhang (6) also identified a relationship between pedestrian safety and built environment variables, such as intersection density. Sheykhfard et al. (7, 8) performed pedestrian risk assessment considering the influence of road environment factors, such as transit position, number of lanes, and limited visibility. In addition, many studies on walking environmental factors for vulnerable pedestrians, such as older adults and children, have been conducted. Park and Byeon (3) analyzed the correlation between land usage patterns and pedestrians' risk from traffic accidents and proposed the management of obstacles, street lighting, traffic signs, and road ratios to lower the risk of traffic accidents around elementary schools. Kim (9) performed regression analysis and found that various facilities, such as raised medians, three-way intersections, street trees, parks, and recreational land use, increased the safety of aged pedestrians. Sheykhfard et al. (10) identified factors affecting the safety of student pedestrians, focusing on crossing behavior at a crosswalk near a university campus. Lv et al. (11) conducted Poisson regression and analyzed the relationship between aged pedestrians and built environments; roads' green spaces, sidewalks, and intersections significantly affected the safety of these pedestrians, and green spaces only exerted their influence in an uncongested environment. Fonseca et al. (12) also found that numerous built environment attributes affected overall walkability indices, such as residential density and pedestrian facilities. Incheon Metropolitan City (13) studied on-site walking conditions by considering environmental factors, such as sidewalk separation status, total road width, amount of walking, crosswalks, bollards, speed control facilities, traffic signs, speed limit, sidewalk width, sidewalk condition, and obstacles, as walkability improvement indicators.

Although numerous studies on physical environmental factors affect pedestrian safety, research on pedestrians' perceived safety is somewhat limited despite recent interest in human-centric, pedestrian-friendly, safe, and walkable cities. For instance, Rišová and Madajová (14) measured perceived safety and walkability according to sex and time by dividing spaces and proposed a method of minimizing walking barriers. Park and Garcia (15) explored the relationship between road conditions and pedestrians' perceived safety in Auburn, Alabama, in the US, and proposed measures to improve public safety perception. Jansson (16) presented social control and urban structure as factors affecting pedestrian safety perception and found that people feel safer in the streets where police or safety personnel are present for social control; the greater the number of people on the streets, the safer they feel. Lee et al. (17) investigated pedestrian perceptions of safety-related information in the walking environment, focusing on individual situation awareness. Ariffin and Zahari (18) concluded that proximity to the destination and good weather conditions promoted walking and increased perceived walkability. Most of these walkability and pedestrian safety studies focused on social and environmental factors. However, few studies have analyzed the impact of various physical environmental factors on pedestrians' perceived safety. Zumelzu et al. (19) analyzed the impact of the built environment on the perception of walkability but did not specify perceived safety. Villaveces et al.'s (20) study was limited to analyzing the relationship within an entire physical environment, such as an urban structure; the study did not identify each environmental factor. Basu et al. (21) also investigated the influence of built environment factors on pedestrians' perceptions of attractiveness and safety, but these factors were limited to meso- or macroscale factors, such as land use and landscaping elements, including green areas. Similarly, Amiour et al. (22) systematically reviewed articles on objective and perceived traffic safety, highlighting that only a few papers went into detail on safety perception related to the objective built environment.

The literature review reveals that pedestrian safety perception has been under-researched; because a well-constructed physical environment may not necessarily make pedestrians feel safe, the relationship between walking environmental factors and perceived safety should be further studied to improve both pedestrians' physical and perceived safety. In this regard, a previous study showed that perceived safety has a significant effect on the choice of walking (23). Because research on safety perception has focused on social and macro- and mesoscale environmental factors that are difficult to manage, micro-scale physical environmental factors that are relatively easy to control need to be further studied. In addition, because people and vehicles coexist on a variety of walking infrastructures, the underlying perceptions of traffic characteristics and infrastructure must be comprehensively considered by analyzing the impact of microscale physical environmental factors and perceived safety. Therefore, the creation and improvement of pedestrian environments and transportation facilities will not only promote the physical safety of pedestrians but also lower pedestrians' perceptions of danger, making walking the preferred transport mode.

3 Materials and methods

3.1 Research hypothesis and process

Figure 1 shows the research model. This study is based on the hypothesis that the effects of physical walking environment factors on pedestrian safety perception are complex. This complexity may be attributed to pedestrians' perception having several aspects, such as perception of physical infrastructure as well as traffic or crime hazards (24). As this study focuses on pedestrian traffic-related safety, factors such as crime safety are excluded from the analysis. To elucidate perceived safety, this study was thus based on a model that posits that the two subelements of pedestrians' perception—perception of traffic and perception of walking infrastructure—analogously mediate pedestrians' overall perceived safety. Many microscale physical walking environmental factors may impact safety perception. Among many factors, this study chose those that were used as the indicators of walking environment improvement from Incheon Metropolitan City (13) because the indicators provide quantitative evaluation criteria for various walking environment elements and have been used in multiple real-world environments. They include sidewalk separation; amount of walking; number of crosswalks; traffic safety facilities such as speed control facilities and traffic signs and road marks; sidewalk width, and sidewalk conditions considering the obstacles, which are relatively easy to improve or monitor. Some factors are more related to physical safety (e.g., traffic safety facilities), whereas others are more related to mobility or comfort (e.g., sidewalk width and condition). In this study, we hypothesize that each factor will affect sub-dimensions of pedestrian perceptions differently and thus have different effects on overall perceived safety.

To test the hypotheses of the research model in Figure 1, the authors selected study sites with different walking environmental factors and measured the value of walking environmental factors through field investigation. The authors then measured the perception of traffic, perception of walking infrastructure, and overall perceived safety level of each site by surveying participants familiar with the sites. The analysis has three phases. First, linear regression analysis was conducted to determine the impact of perception of traffic and perception of walking infrastructure on overall perceived safety. Multiple regression analysis was then performed to explore the impact of physical walking environmental factors on the research sites. Finally, to elucidate safety perceptions, mediation analysis was conducted to identify whether different pedestrian perceptions—perception of traffic and perception of walking infrastructure—mediate between walking environmental factors and overall perceived safety.

3.2 Study sites

A preliminary site survey was conducted to identify research sites with pedestrian safety problems or high pedestrian traffic. The study

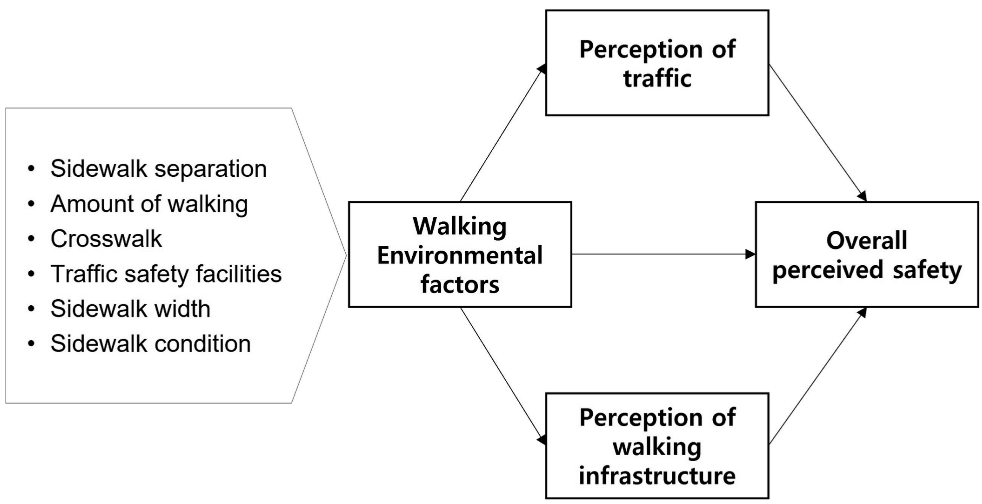

FIGURE 1
Research model.

sites comprise nine pedestrian roads with various walking environment features. Sites 1 and 2 feature clear sidewalk separations at both sides, good sidewalk conditions, and high vehicular and pedestrian traffic. Site 1 is the entrance of a university with a high traffic volume and the widest sidewalk. Site 3 has clear sidewalk separations at one side and wide roads. Site 4 is an intersection with vehicles moving in multiple directions and has high pedestrian traffic. Site 5 has clear sidewalk separations on one side; however, the width is very narrow, making it difficult for many people to use the sidewalk. Site 6 is a secondary entrance to the aforementioned university with a high traffic volume, unclear sidewalk demarcations, and poor sidewalk conditions. Site 7 has considerable traffic without traffic lights and poor sidewalk conditions. Site 8 is an intersection without clear sidewalk separation. Site 9 has high traffic volumes but is well-equipped with crosswalks and sidewalks. Figure 2 shows sample photographs of each research site.

To further analyze the pedestrians' perceived safety in each site, physical walking environments and traffic characteristics of each site were examined through an in-depth field study. Table 1 lists the features of each environmental factor for each site. The factors identified by the Incheon Metropolitan City (2022) were used to evaluate the walking environment. They were graded A if the sidewalks on both sides were well separated, B if somewhat separated but the sidewalk was interrupted or installed on only one side, and C if not well separated. The grading was converted to a three-point scale for quantitative analysis in regression analysis. Traffic safety facilities were measured as the combined number of speed control facilities, traffic signs, and road marks. The sidewalk width represented the width of the sidewalk that pedestrians can actually use. The sidewalk condition was evaluated using the sidewalk pavement condition according to Rule 237 of the Guidelines for Sidewalk Installation and Management set forth by the Ministry of Land, Infrastructure, and Transport in Korea. These factors were rated in alphabetical order from A (good) to E (poor) and converted to a 5-point scale for quantitative analysis during regression analysis. The factors were closely related to pedestrian physical safety as well as accessibility, mobility, and comfort.

3.3 Survey for measuring perceived safety

It is essential to measure the feeling of safety, which reflects the pedestrians' psychological condition. The Neighborhood Environment Walking Scale (NEWS-A) was consulted to quantitatively measure safety perceptions and identify subscales for deeper analysis (25, 26). NEWS-A is a global survey tool designed to measure how residents perceive their environment. It is widely used in assessing walking environments and walkability and focuses on users' perceptions, which is closely related to this study. Subquestions for measuring pedestrian perception in the NEWS-A comprised eight categories:

FIGURE 2
Sample photographs of research sites.

TABLE 1 Walking environmental factors by sites.

Factors	Unit	Sites								
		1	2	3	4	5	6	7	8	9
Sidewalk separation	A (Good)–C (Bad)	A	A	B	A	C	C	A	C	A
Amount of walking	Person/h	400	400	200	200	30	30	100	50	150
Crosswalk	Number	1	1	4	3	0	0	1	1	3
Traffic safety facilities	Number	7	4	4	4	5	0	0	0	3
Sidewalk width	Meter	9.2	2.83	2.2	3.81	1.02	1.36	5.88	1.78	5.77
Sidewalk condition	A (Good)–E (Bad)	A	A	A	B	B	D	C	B	A

residential density, land use mix-diversity, land use mix-access, street connectivity, walking/cycling infrastructure, esthetics, automobile traffic, and crime safety (24), among which perception on walking infrastructure and traffic fall within the scope of this research (i.e., the relationship between microscale physical walking environmental factors and perceived safety). The survey items for this study were also structured accordingly by utilizing the questionnaire provided by NEWS-A. Notably, NEWS-A has been used extensively in walkability studies, making it a highly reliable survey instrument (27).

The survey comprised six questions in total: two on the perception of traffic, two on the perception of walking infrastructure, and two on overall perceived safety (Table 2). The survey was conducted in each study site; it comprised 54 questions in total, 6 for each of the nine sites. Due to the multiplicity of study sites, the three aspects of the safety construct were reduced to two questions to minimize respondents' fatigue. A five-point Likert scale was used to evaluate the survey responses regarding satisfaction as follows: very satisfied (22), satisfied (27), neutral (2), dissatisfied (4), and very dissatisfied (13). Local community members who were familiar with all the study sites were selected as survey respondents. A link to the online survey was distributed to a local online community with a wide range of ages. The survey was then completed by volunteers who were interested in pedestrian safety in their neighborhood. A total of 99 eligible responses out of 125 were analyzed after excluding 26 unreliable ones. As the research site largely has young and middle-aged people, the respondents were mainly healthy, aged 10–40. An *a priori* power analysis was conducted using G*Power version 3.1.9.7 (28) to determine the minimum sample size required to test the study hypothesis. The results indicated that the sample size required to achieve an 80% power for detecting a medium effect, at a significance criterion of $\alpha = 0.05$, was $N = 98$ for the F-test for multiple linear regression with six predictors. Thus, the obtained sample size of $N = 99$ in this study was adequate to test the study hypothesis. To verify the reliability of the results, Cronbach's alpha was used to indicate the consistency of answers between similar questions. Cronbach's alpha was at least 0.6 per question, indicating that they were reliable.

TABLE 2 Survey questionnaire.

Constructs	Questions
Perception of traffic	The speed of motor vehicles/motorbikes in this area is appropriate.
	The speed and amount of traffic do not create a sense of danger for pedestrians.
Perception of walking infrastructure	Walkways are well separated from vehicles and motorbikes, and motorcycles.
	Walking facilities such as sidewalks and crosswalks are well arranged.
Overall perceived safety	This area does not feel dangerous for walking.
	I generally feel safe in this area.

TABLE 3 Survey results for pedestrian perceptions by sites.

	Perception of traffic (1 (bad)-5 (good)) [Mean(SD)]	Perception of walking infrastructure (1 (bad)-5 (good)) [Mean(SD)]	Overall perceived safety (1 (bad)-5 (good)) [Mean(SD)]
Site 1	3.21 (1.18)	3.03 (1.10)	2.79 (1.09)
Site 2	3.88 (0.69)	3.75 (0.83)	3.72 (0.74)
Site 3	3.65 (0.79)	3.45 (0.95)	3.55 (0.89)
Site 4	2.87 (0.97)	2.75 (0.80)	2.66 (0.85)
Site 5	3.27 (0.81)	2.99 (0.89)	3.07 (0.88)
Site 6	2.62 (0.92)	2.44 (0.90)	2.53 (0.84)
Site 7	2.85 (1.06)	2.92 (0.92)	2.70 (0.89)
Site 8	3.00 (0.71)	2.86 (0.75)	2.89 (0.64)
Site 9	3.52 (0.62)	3.44 (0.54)	3.38 (0.62)
Total	3.20 (0.75)	3.07 (0.83)	3.03 (0.89)

4 Results

4.1 Descriptive analysis of perceived safety by sites

Table 3 presents the survey results for perceived safety in each site. Each site had a minimum score of 1 (bad) and a maximum score of 5 (good) for perceptions of traffic and walking infrastructure, and overall perceived safety. The results revealed that the average score of all sites for the perception of traffic, perception of walking infrastructure, and overall perceived safety were 3.20, 3.07, and 3.03, respectively. The results per site indicated that Site 2, which has clear sidewalk separations and good sidewalk conditions, was perceived as satisfactory in terms of traffic and infrastructure and, thus, safest. In addition, Site 3 had clear sidewalk separations and good sidewalk conditions, which translated to a relatively good safety perception. Site 6, which has frequent traffic, unclear sidewalk separation, and poor sidewalk conditions, was perceived as the least safe, with dissatisfaction in terms of traffic characteristics and infrastructure.

A linear regression analysis was conducted to determine whether perceptions of traffic or walking infrastructure affect the overall perceived safety of each site (Table 4). In the analysis by factor of all sites, the significance probability was less than or equal to 0.001, implying that the perceived safety was significant. Both perceptions of traffic and walking infrastructure significantly impacted perceived safety in all sites. A linear regression analysis was performed to determine the impact of perception of traffic and perception of walking infrastructure on safety perception in all nine sites (Table 5). The regression model was statistically significant ($F = 1110.998$, $p < 0.001$), and its power of explanation was approximately 71.4%. The Durbin–Watson (D-W) statistic also had a value of 1735, indicating no independence assumption issues; all VIF values were less than 10, suggesting that multicollinearity issues were absent. The Breusch–Pagan test is used to determine whether or not heteroscedasticity is present in the multiple regression model (29). The results revealed that the null hypothesis for homoscedasticity (i.e., the residuals are distributed with equal variance) cannot be rejected (BP = 2.838, $p = 0.242$), implying that heteroscedasticity was absent in the model. The results demonstrated that both perceptions of traffic and infrastructure had a significant linear relationship with overall perceived safety. Although the perception of infrastructure was slightly more influential, the results imply that pedestrian perception of safety is affected by pedestrian perceptions of dynamic traffic characteristics of pathways, such as the amount and speed of vehicles and physical infrastructure characteristics.

4.2 Regression analysis between environmental factors and perceived safety

As a preliminary analysis, sites with different walking environmental factors, based on the results from Table 1, were compared with the scores of perception of traffic, perception of walking infrastructure, and overall perceived safety (Figure 3). Figure 3 on safety perception revealed differences between well-equipped and poorly equipped walking environmental factors, such as the degree of sidewalk separation, the number of crosswalks, the number of traffic safety facilities, and the level of sidewalk conditions. The descriptive figure implies that safety perception is generally higher in well-managed locations, with more traffic safety facilities and crosswalks and better sidewalk conditions, in keeping with walking environment improvement plans. On the other hand, when the sidewalk width was greater, the value for the perception of traffic was slightly weaker and likely to be affected by high vehicle and pedestrian flow rates in the busy street. In summary, most environmental factors unsurprisingly exhibited a consistently positive and negative relationship with the perception of traffic, perception of walking infrastructure, and overall perceived safety. However, the sidewalk width exhibited an opposite or insignificant relationship with these measures.

Before further identifying perceived safety-related factors, Pearson correlation was measured to analyze the relationships between the variables (Table 6). It revealed that most variables had positive

TABLE 4 Regression analysis on the effects of the perception of traffic and walking environment on perceived safety by sites.

	B	SE	*β*	*t*	*p*
Site 1					
Traffic	0.751	0.070	0.735	10.690	<0.001
Walking infrastructure	0.792	0.068	0.763	11.625	<0.001
Site 2					
Traffic	0.675	0.100	0.566	6.762	<0.001
Walking infrastructure	0.780	0.069	0.753	11.257	<0.001
Site 3					
Traffic	0.998	0.058	0.869	17.328	<0.001
Walking infrastructure	0.889	0.053	0.864	16.927	<0.001
Site 4					
Traffic	0.833	0.075	0.749	11.122	<0.001
Walking infrastructure	0.955	0.063	0.838	15.125	<0.001
Site 5					
Traffic	0.918	0.077	0.772	11.971	<0.001
Walking infrastructure	0.847	0.061	0.814	13.811	<0.001
Site 6					
Traffic	0.979	0.063	0.845	15.589	<0.001
Walking infrastructure	0.881	0.037	0.924	23.836	<0.001
Site 7					
Traffic	0.720	0.080	0.675	9.003	<0.001
Walking infrastructure	0.925	0.044	0.906	21.097	<0.001
Site 8					
Traffic	0.683	0.073	0.687	9.324	<0.001
Walking infrastructure	0.722	0.063	0.758	11.456	<0.001
Site 9					
Traffic	0.696	0.090	0.616	7.706	<0.001
Walking infrastructure	0.822	0.078	0.730	10.531	<0.001

TABLE 5 Regression analysis on the effects of the perception of traffic and walking environment on the perceived safety of all sites.

	B	SE	*β*	*t*	*p*	VIF
Traffic	0.067	0.017	0.072	3.887	<0.001	1.059
Walking infrastructure	0.853	0.019	0.826	44.745	<0.001	1.059

$F = 1110.998$ ($p < 0.001$), $R^2 = 0.714$, adj $R^2 = 0.714$, D-W = 1.735.

relationships. In particular, sidewalk separation, speed facilities, and sidewalk condition had a correlation coefficient greater than 0.7, indicating high linear correlations with each other. However, sidewalk width was not significantly related to any pedestrian perceptions. Nevertheless, as shown in Figure 3, too narrow a sidewalk width negatively impacts pedestrian perceptions, and an adequate sidewalk width positively impacts perceptions.

Multiple regression analysis was performed to determine the effects of walking environmental factors on overall perceived safety, and the results are listed in Table 7. The regression model was statistically significant ($F = 26.023$, $p < 0.001$) with 15.0% of the power of explanation. There were no independence assumption issues with

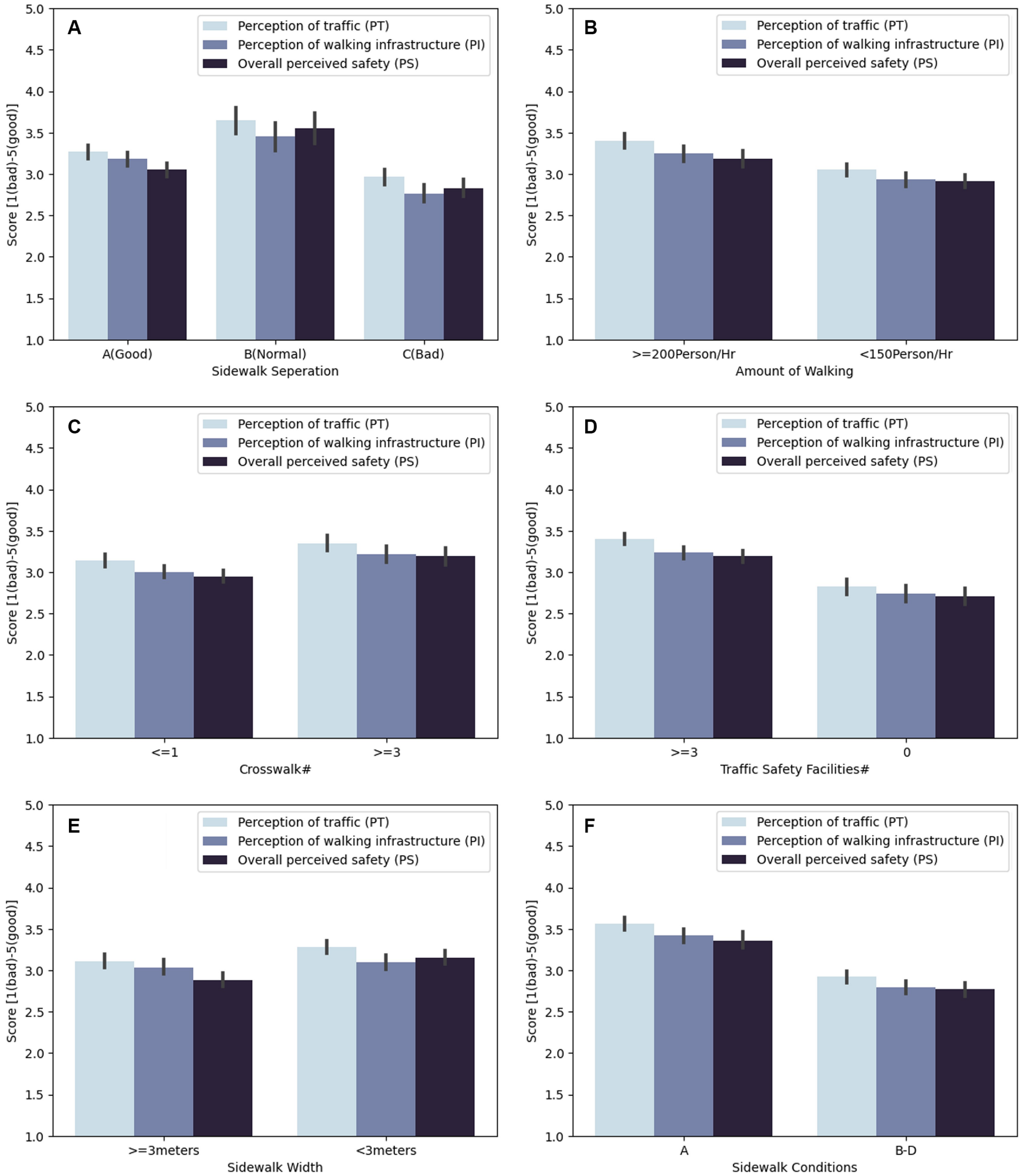

FIGURE 3
Pedestrian perception according to walking environmental factors: **(A)** The impact of sidewalk separation; **(B)** the impact of the amount of walking; **(C)** the impact of the number of crosswalks; **(D)** the impact of the number of traffic safety facilities; **(E)** the impact of sidewalk with; and **(F)** the impact of sidewalk conditions.

1.491 of D-W statistic and no multicollinearity issues with all VIF values less than 10. The Breusch–Pagan test result ($BP = 7.784$, $p = 0.2544$) also demonstrated that heteroscedasticity is absent in the multiple regression model.

A test for the significance of regression coefficients demonstrated that sidewalk separation ($\beta = 0.165$; $p = 0.017$) and sidewalk condition ($\beta = 0.451$; $p = 0.001$) had a significant positive impact on perceived safety. Furthermore, traffic safety facilities ($\beta = -0.048$, $p < 0.001$) and sidewalk width ($\beta = -0.296$, $p < 0.001$) negatively impacted perceived safety.

Mediation analysis was conducted to verify if the perception of traffic and the perception of walking infrastructure mediate the relationship between walking environmental factors and overall perceived safety (Table 8). To determine direct and indirect effects, the mediation analysis was performed using PROCESS (30), based on the percentile bootstrap method. Specifically, 5,000 samples were obtained via random sampling. Similar to Preacher and Hayes (31), the present study considered the mediation effect to be statistically significant if the lower and upper values of the confidence intervals of the mediation effect coefficients did not contain zero. The mediation analysis

TABLE 6 Pearson correlations between variables.

Correlations(N = 594)									
	Sidewalk separation	Amount of walking	Cross-walk	Traffic safety facilities	Sidewalk width	Sidewalk condition	PT	PI	PS
Sidewalk separation	1								
Amount of walking	0.708**	1							
Crosswalk	0.442**	0.227**	1						
Traffic safety facilities	0.360**	0.666**	0.211**	1					
Sidewalk width	0.751**	0.564*	0.148**	0.381	1				
Sidewalk condition	0.461**	0.671**	0.537**	0.712**	0.335**	1			
PT	0.232**	0.312**	0.255**	0.200	0.365	0.365**	1		
PI	0.194**	0.247**	0.177**	0.175**	0.344	0.344**	0.235**	1	
PS	0.090**	0.178**	0.175**	0.146	−0.065	0.317**	0.266**	0.842**	1

**$p < 0.01$, *$p < 0.05$. PT, perception of traffic; PI, perception of walking infrastructure; PS, overall perceived safety.

TABLE 7 Multiple regression analysis of the effect of walking environmental factors on overall pedestrian perceived safety.

	Unstandardized		Standardized	t	p	VIF
	B	SE	β			
Sidewalk separation	0.170	0.071	0.165	2.401	0.017*	4.938
Amount of walking	0.000	0.000	0.023	0.361	0.718	4.240
Crosswalk	−0.053	0.032	−0.076	−1.656	0.098	2.205
Traffic safety facilities	−0.048	0.020	−0.121	−2.421	0.016*	2.613
Sidewalk width	−0.109	0.019	−0.296	−5.791	<0.001*	2.709
Sidewalk condition	0.427	0.056	0.451	7.635	0.001*	3.633

$F = 26.023$ ($p < 0.001$), $R^2 = 0.150$, adj $R^2 = 0.144$, D-W = 1.491.

demonstrated that the perception of traffic and perception of walking infrastructure mediated the relationship of overall perceived safety with sidewalk separation, amount of walking, crosswalks, speed facilities, and sidewalk condition and did not mediate sidewalk width. In general, the results demonstrate that the mediating effect of the perception of walking infrastructure is significantly larger than that of the perception of traffic or direct effects. Specifically, the indirect impact of the perception of walking infrastructure was relatively higher for sidewalk separation (indirect effect = 0.1669, $p < 0.05$) and sidewalk condition (indirect effect = 0.2678, $p < 0.05$). These findings suggest that creating quality infrastructure from a pedestrian perspective is crucial to perceived safety.

5 Discussion

This study found that pedestrians' overall perceived safety was significantly affected by their perceptions of both traffic characteristics and walking infrastructure, and that perception of walking infrastructure quality particularly seemed to have a deeper relationship with overall perceived safety. Mediation analysis also proved that perception of traffic and perception of walking infrastructure mediated the impacts of all walking environmental factors on overall perceived safety to a different degree, except for the sidewalk width. That is, perceptions of both dynamic traffic characteristics and static infrastructure complexly affect overall perceived safety. Moreover, high indirect impacts of the perception of walking infrastructure, which mediate the relationship of sidewalk separation, crosswalks, traffic safety facilities, and sidewalk conditions with perceived safety, demonstrated that the quality of infrastructure may greatly contribute to enhancing the safety perception. Thus, to create a pedestrian-friendly street where people are actually safe and feel safe, comprehensive management is required, including control over traffic speed and volume and efforts to maintain good infrastructure quality.

Analyzing the effects of the walking environmental factors on perceived safety in detail revealed that the most positive factors were sidewalk separation and sidewalk condition. These factors can enhance the perception of walking infrastructure quality and increase overall perceived safety. As such, the major finding of this study is that factors related to overall pathway quality, such as cleanliness, comfort, and better mobility, can also help increase the pedestrian perception of safety. Keeping sidewalks clean and in good condition is essential to create a walkable city with a feeling of safety. Considering that sidewalk separation, related to both comfort and safety, also turned out to be a significant factor, it is important to separate sidewalks from roads through elevation or fixed bollards to improve perceived safety and encourage walking.

This research finding is in line with the findings of previous studies. Basu et al. (21) claimed that perceptions of attractiveness (or satisfaction) and safety in the built environment need to be considered

TABLE 8 Mediation analysis results for pedestrian perceived safety.

	Total effect	Direct effects	Indirect effects	Boot SE	Bootstrap CI	
					LLCI	ULCI
Sidewalk separation	0.0928	−0.0956				
Perception of traffic			0.0215*	0.0054	0.0119	0.0329
Perception of walking infrastructure			0.1669*	0.0289	0.1089	0.2229
Amount of walking	0.0012	−0.0004				
Perception of traffic			0.0002*	0	0.0001	0.0003
Perception of walking infrastructure			0.0014*	0.0002	0.001	0.0018
Crosswalk	0.1225	0.0082				
Perception of traffic			0.0123*	0.0037	0.0054	0.0201
Perception of walking infrastructure			0.1020*	0.0192	0.0654	0.1404
Traffic safety facilities	0.0583	−0.0053				
Perception of traffic			0.0059*	0.0018	0.0026	0.0098
Perception of walking infrastructure			0.0577*	0.0112	0.352	0.08
Sidewalk width	−0.0239	−0.0407				
Perception of traffic			0.0004	0.0009	−0.0013	0.0024
Perception of walking infrastructure			0.164	0.0102	−0.0035	0.0364
Sidewalk condition	0.2999	0.0083				
Perception of traffic			0.0238*	0.0071	0.0109	0.383
Perception of walking infrastructure			0.2678*	0.0262	0.2179	0.3198

*$p < 0.05$.

together even though the study focused on crime security. One of the study's findings is that pedestrians feel that the walking environment is not only more attractive but also safer when trees are present on the walking path, which highlights the importance of infrastructure quality in enhancing perceived safety. Herrmann-Lunecke et al. (32) also demonstrated that micro-scale elements in the built environment, such as the presence of sidewalks and their cleanliness and quality, could improve pedestrian comfort and safety, which agrees with the results of the current study.

However, the walking environment factors for physical safety do not necessarily have a positive relationship with feelings of safety. Multiple regression analyses revealed that crosswalks and traffic safety facilities had weak negative relationships with perceived safety, which is also supported by the fact that perception of traffic mediated these walking environmental factors and overall perceived safety. These facilities are essential to physical safety. However, these facilities are located in areas with high vehicle traffic, and numerous vehicles lead to a negative perception of traffic and, consequently, less safety perception, as demonstrated in the research result. While it is necessary to place crosswalks and traffic safety facilities on these roads to enhance safety, their management is essential to keep the quality of the roads high and maintain appropriate levels of pedestrians' feeling of safety. Sidewalk width also negatively impacted the overall perceived safety, which may be because sidewalks are wider in areas with high traffic main roads. While sidewalks being too wide does not have a positive impact on perceived safety, too narrow a sidewalk width has a significant negative impact on pedestrian perception of infrastructure and perceived safety, as shown in Figure 3. Therefore, ensuring adequate sidewalk width is essential. In sum, walking environmental factors closely related to physical safety may not contribute as much to perceived safety in some cases (e.g., traffic safety facilities and crosswalks), and in other cases, factors related to comfort or satisfaction may contribute greatly to perceived safety (e.g., sidewalk conditions). The result suggests that perceived safety is a composite function of physical safety and comfort due to infrastructure quality.

Sites 2 and 3 had the highest perceived safety, whereas Sites 4 and 6 had the lowest. Sites 2 and 3 both had well-managed sidewalk conditions, consistent with the aforementioned results. Site 4 was located at the intersection of four roads with interrupted sidewalks; despite its high traffic and safety blind spots, as the crosswalks were placed in a poorly separated area, they were underused by pedestrians. Moreover, the sidewalk condition in Site 4 was relatively poor (B grade), which led to a low overall perceived safety despite the bollards and crosswalks. This site will require regular sidewalk maintenance and clear sidewalk separation to improve people's awareness and comfort and separate vehicles and pedestrians. Site 6, with a very low level of perceived safety, had poor sidewalk conditions (D grade) and no clear sidewalk separation. Therefore, the use of sidewalks was limited as they did not function well, as determined by the authors' field investigation. Site 6 exhibited poor sidewalk conditions, which highlights the need for regular pavement on the sidewalks. Furthermore, ensuring sidewalk separation by raising the sidewalks at Site 6 will help secure physical and perceived safety as well as pedestrian comfort.

In summary, the study confirmed that both perceptions of traffic characteristics and infrastructure affected pedestrians' perceived safety. Because environmental factors for advanced physical walking safety do not always guarantee pedestrian perceived safety, traffic safety features, such as crosswalks, traffic safety facilities, and sidewalk width, should be considered together with infrastructure quality factors, such as sidewalk maintenance and clear physical and psychological separation from vehicles. The novelty of this study lies in its consideration of the impact of various environmental factors on perceived safety in traffic-related contexts, revealing that these factors affect physical safety and feelings of safety differently. In contrast, many previous studies only address perceived safety in terms of crime safety or security. The main contribution of this study to traffic-related safety is the finding that perceived safety is determined by comprehensively considering physical safety, comfort, and satisfaction on the road. Accordingly, practical ways to improve the pedestrians' walking environment to promote both physical safety and the perceived safety of pedestrians are suggested. In other words, because comfort and satisfaction greatly affect the feeling of safety, a comprehensive improvement plan is necessary to enhance perceived safety by maintaining the quality of infrastructure through continuous pathway maintenance and removing unpleasant elements while installing traffic safety facilities for physical safety. In this regard, in Crime Prevention through Environmental Design practice, one of the important principles for better-perceived safety is promoting a positive and pleasant environmental image and routine maintenance of the built environment (33), consistent with the research findings.

6 Conclusion

As urban safety and livability in walkable communities become increasingly important, city and transportation policies are being formulated to emphasize human-centric safety and accessibility. This trend requires more in-depth research into pedestrians' safety perception because residents' feeling of safety is a critical factor for enhancing their walking intention. This study analyzed the relationship between walking environments and pedestrians' perceived safety. This pedestrian-oriented study considered various aspects of pedestrians' perceptions of traffic and infrastructure to elucidate their perceived safety; it demonstrated that walking environmental factors for improving physical safety may not have the same effect on improving perceived safety and demonstrated that maintaining infrastructure quality is essential for enhancing perceived safety when considering the role perception of infrastructure has in mediating the relationship between environmental factors and perceived safety. The results suggest that both the physical safety and perceived safety of pedestrians should be considered to improve the walking environment through comprehensive planning for enhancing physical safety through traffic safety facilities. Moreover, user comfort and satisfaction should be ensured through infrastructure quality assurance. Doing so can improve the city's walkability and residents' walking intention for public health while increasing perceptions of safety, pleasure, and comfort.

This study has significance in that it reinforces the knowledge base of the impacts of walking environmental factors on perceived safety to help enhance both physical and perceived safety. However, the research sites were limited to nine areas. Furthermore, it included only some of the walking environmental factors due to a multicollinearity issue resulting from a strong correlation of many variables of walking environmental factors (e.g., bollards and traffic signs). The study was limited to locations that are not often used by older adults. Therefore, future studies may expand research areas and walking environmental factors to validate the usability and transferability of the developed model.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The requirement of ethical approval was waived by Ewha Womans University Institutional Review Board for the studies involving humans because the study was conducted based on an anonymous online survey of unspecified participants. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board also waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because the study was conducted based on an anonymous online survey of unspecified participants.

Author contributions

YK: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft. BC: Formal analysis, Methodology, Software, Validation, Writing – review & editing. MC: Conceptualization, Formal analysis, Writing – review & editing. SA: Investigation, Writing – original draft. SH: Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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"Cyclist at 12 o'clock!": a systematic review of in-vehicle advanced driver assistance systems (ADAS) for preventing car-rider crashes

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Introduction: While Advanced Driver Assistance Systems (ADAS) have become a prominent topic in road safety research, there has been relatively little discussion about their effectiveness in preventing car collisions involving specific vulnerable road users, such as cyclists. Therefore, the primary objective of this systematic literature review is to analyze the available evidence regarding the effectiveness of in-vehicle ADAS in preventing vehicle collisions with cyclists.

Methods: To achieve this goal, this systematic review analyzed a selection of original research papers that examined the effectiveness of ADAS systems in preventing car-cyclist collisions. The review followed the PRISMA protocol, which led to the extraction of 21 eligible studies from an initial pool of 289 sources indexed in the primary scientific literature databases. Additionally, word community-based content analyses were used to examine the research topics and their links within the current scientific literature on the matter.

Results: Although the current number of studies available is still scarce (most sources focus on car-motorcyclist or car-pedestrian crashes), the overall quality of the available studies has been reasonably good, as determined by the selected evaluation methods. In terms of studies' outcomes, the literature supports the value of in-vehicle ADAS for preventing car-cyclist crashes. However, threatful side effects such as unrealistic expectations of these systems and users' overconfidence or desensitization are also highlighted, as well as the need to increase driver training and road user awareness.

Conclusion: The results of this study suggest that Advanced Driver Assistance Systems have significant potential to contribute to the prevention of driving crashes involving cyclists. However, the literature emphasizes the importance of concurrently enhancing user-related skills in both ADAS use and road-user interaction through educational and training initiatives. Future research should also address emerging issues, such as ADAS-related behavioral ergonomics, and conduct long-term effectiveness assessments of ADAS in preventing car-cycling crashes and their subsequent injuries.

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KEYWORDS

ADAS, inter-user crashes, vehicles, bicycles, injury, riding safety

1 Introduction

Despite the several ongoing efforts to reduce traffic crashes and injuries involving cyclists, the latest increases in their number -transcending borders and affecting all regions- have put in evidence the need to strengthen their prevention (1). Globally, an estimated 69,000 people are killed each year while cycling and another 11 million cyclists are injured in this type of crash (2, 3). Thus, pedestrians and cyclists account for 26% of all road traffic fatalities, figures that increase to 44% in Africa and up to 36% in the Eastern Mediterranean (4). Specifically, in countries such as the United States, fatality rates per kilometer increased in recent years by 33% for cyclists, although they remained stable in other regions such as Germany, the United Kingdom or Denmark (5).

Among many latent risks for cyclists, road conflicts with motorized users and other threatening common situations put in manifest their several shortcomings in terms of riders' passive safety (i.e., related to actual post-crash consequences), thus explaining a considerable proneness to suffer severe injuries as a consequence of rising crashes among them (6). This is usually reflected in fatality data in several regions. As a figure, in countries such as Spain, about four out of every 10 cyclists (namely 42%) dead in traffic incidents were killed on conventional single-carriageway roads, where motor vehicles and bicycles necessarily share space (7).

Also, and speaking in task-related terms, cyclists represent a particularly vulnerable group on the roads due to a number of intrinsic and extrinsic factors. In this regard, in addition to the special risk in overtaking situations, their direct exposure to the environment and the lack of protective bodywork makes them more vulnerable targets in case of collisions (8, 9). The lack of turn signals and brakes on bicycles, compared to motor vehicles, can make it difficult for drivers to anticipate their movements (10). In addition, road conditions, lack of safe infrastructure for cyclists (11, 12), and lack of respect by some drivers toward this road group can significantly increase their risk of being involved in traffic crashes (13, 14).

As for road user types, in other road contexts or situations, conventional cars represent the means of transport mostly involved in collisions with cyclists. For instance, official figures indicate that, in European countries such as France, 66% of deaths in this road group occur in passenger car accidents (15). In Germany, meanwhile, 75% of on-road cyclist fatalities are linked to problematic interaction with cars (16). In this regard, mixed traffic involving motor vehicles and vulnerable road users poses a high risk as cyclists and pedestrians can be commonly (and seriously) injured or killed at speeds of 40 km/h or higher, speeds that are reached in many countries in urban areas (17, 18). Nevertheless, during the last few years ADAS designed specifically to prevent impacts with cyclists have been introduced into new vehicles, the effect of which is anticipated to provide both crash prevention and injury mitigation benefits to bicycle riders.

1.1 Are ADAS relevant contributors for current and future road safety?

Two of the currently 'hottest' topics in crash prevention are both the 'if' and 'how' of how Advanced Driver Assistance Systems (ADAS) may contribute to reducing road fatalities among vulnerable road users. And the gaps are evident when comparing their impact between car driving and cycling: although ADAS are now relatively common among four-wheeled vehicles, the number of bicycles incorporating them remains scarce in the market, even in high-income economies (19). Similarly, the more common ADAS-related safety studies are those conducted among car drivers. Still, their influence on road safety figures remains relevant as, all in all, the existing literature highlights how vehicle technology holds great potential to improve road safety globally, and the core reason explaining it could be that they contribute to preventing and counteracting human failures, possibly implicated in up to 90% of crashes (20).

Furthermore, safety-related literature highlights that, although crash-prevention technology is still limited, it might help strengthen road users' training, prevent road conflicts among different groups of them, and increase the effectiveness of road safety measures to protect vulnerable road users, including cyclists and pedestrians (19, 21). In this regard, the implementation of Advanced Driver Assistance Systems (ADAS) devices, designed to alert drivers to the presence of cyclists in their surroundings, emerges as a potentially effective and universal solution to address this global challenge (21). These devices can leverage various technologies, including cameras, radar, and proximity sensors, to detect the presence of cyclists and provide the driver with an early warning. Upon receiving a notification about the presence of a cyclist, the driver has the opportunity to take preventive measures, such as slowing down, providing more space to the rider, or waiting until it is safe to overtake (22).

Research conducted in various regions highlights the impact of ADAS systems on reducing fatalities involving vulnerable users. For instance, it is assumed that ADAS-related vehicle improvements have been responsible for a 23% reduction in car-pedestrian collisions in Sweden (23). In the United States, vehicles equipped with automatic braking systems were found to have a 43% lower likelihood of being involved in a rear-end collision toward cyclists and other drivers, and cars equipped with lane-keeping assistants had a 9% lower chance of leaving the road (24). In this same line, Cicchino concludes that, if properly used, lane departure warning systems can reduce the fatal crash rates by 86% (25). In addition, Sander and Lubbe estimate that driver warning systems can reduce intersection accidents by up to 50% (26). Also, Seacrist et al. (27) claim that automatic braking is particularly relevant for reducing collisions, with a potential to minimize incidents by 48%, followed by vehicle-to-vehicle communication (38%) and driver monitoring systems (24%). In this line with these figures, during the last few years, ADAS designed specifically to prevent impacts with cyclists have been growingly introduced into new vehicles, the effect of which is anticipated to provide both crash prevention and injury mitigation benefits to bicycle riders (28).

1.2 ADAS systems for the prevention of collisions with bicyclists

According to their function and specific features, Advanced Driver Assistance Systems can play a crucial role in preventing collisions between cars and cyclists. These systems incorporate sophisticated technologies that can detect the presence of cyclists and take action to reduce the risk of collisions (29). Several types of ADAS that can potentially be effective in preventing collisions between cars and cyclists. The most common are described below:

- Forward Collision Warning (FCW): this system uses sensors, such as cameras and radar, to detect objects in the vehicle's path, including cyclists (30). If the system identifies an imminent risk of collision with a cyclist, it issues a visual and audible warning to the driver to take evasive action or reduce speed. The key to FCW's effectiveness lies in its ability to perform real-time analysis of the collected information. Advanced algorithms constantly process data on the position, speed, and direction of surrounding objects, ensuring accurate and timely detection of any collusion threat (31). The issuance of visual and audible warnings to the driver in the event of an imminent risk enables rapid decision making, providing the opportunity to take evasive action or reduce speed to avoid collision.
- Emergency braking with pedestrian and cyclist detection: this system is an extension of FCW and, instead of simply warning the driver, can automatically activate the brakes if an imminent collision with a cyclist is foreseen (32). Pedestrian and cyclist detection is provided by advanced sensors that constantly monitor the environment. The importance of this system lies in its ability to autonomously anticipate and respond to potential threats. By extending the functionality of FCW, not only are alerts issued to the driver, but in high-risk scenarios with vulnerable road users involved, the system can take direct action to avoid collision. Advanced sensors play a key role in this capability, continuously analyzing the presence and movement of users in the vehicle's surrounding environment. In this way, it provides an active and rapid response in critical situations (33).
- Blind Spot Detection (BSD): this system use sensors to detect the presence of vehicles, including bicycles, in the car's blind spots (34). If the driver indicates a turn or lane change while a cyclist is in the blind spot, the system issues a visual or audible alert to prevent a collision. BSD technology relies on advanced sensors that continuously scan the vehicle's surroundings, identifying the presence of other road users in areas that might escape the driver's direct field of vision (35). The integration of this technology not only improves the driver's situational awareness, but also significantly reduces the risk of collisions in situations where visibility is limited.
- Lane Keeping Assist (LKA): this system helps the driver keep the car in its lane, which can be especially important when overtaking cyclists. If the vehicle comes dangerously close to a cyclist or deviates from its lane, the system can intervene in the steering to correct the trajectory (36). LKA technology uses advanced sensors to monitor the vehicle's position within the lane. When it detects that the car is getting dangerously close to a cyclist or experiencing an unintended lane drift, the system takes corrective action (37). Steering intervention is subtle but effective, helping to keep the vehicle on track and ensuring safe space around cyclists.
- Adaptive Cruise Control (ACC): this system adjusts vehicle speed to maintain a safe distance from vehicles ahead, which also applies to cyclists (38). If a cyclist is in front of the ACC-equipped vehicle, the system will slow down and maintain a safe distance. The importance of this functionality is especially highlighted in situations where the vehicle speed could be inappropriate or potentially dangerous when approaching cyclists. By considering the presence of users around the vehicle, ACC acts proactively, adjusting the speed automatically to avoid risky situations (39).
- Moving object detection systems: These systems use cameras and radar to detect the speed and trajectory of moving objects, such as cyclists. In critical situations, if the system identifies a risk, it can activate instant safety measures, such as automatic braking or issuing alerts to the driver (40). This proactive approach not only improves safety by preventing potential collisions, but also highlights the technology's ability to dynamically adapt to changing environments, thus providing an additional layer of protection for cyclists and other moving roadway elements.
- Adaptive lighting systems: This system vehicle headlights to better illuminate the presence of cyclists on the road, especially in poor visibility conditions (41). This improves the cyclist's visibility and allows the driver to react more effectively.

The combination of these ADAS systems helps prevent collisions between cars and cyclists by providing alerts and taking safety measures in risky situations. However, research on the effectiveness of these driver assistance systems, specifically on the cycling population, is limited.

1.3 Objective of the systematic review

The core aim of this systematic review of the scientific literature was to comprehensively analyze the evidence on in-vehicle Advanced Driver Assistance Systems (ADAS) for preventing road collisions with cyclists.

As a potential contribution (or set of them), this review may contribute to serve as a reference to synthesize the scientific evidence and provide an overview of the effectiveness and current topics in the implementation of these systems, as well as to identify possible areas for improvement in the protection of cyclists in the traffic environment. Also, it is noteworthy that no previous study has specifically reviewed the literature on this issue.

2 Methods

The systematic review developed in this manuscript followed the recommendations of the Cochrane Review Group (42) and the PRISMA 2020 quality standards and protocols (43). The authors of this article conducted the selection, evaluation, and data extraction of the articles individually. Joint discussions were then held to identify articles for inclusion, with final inclusion/exclusion decisions made by consensus.

2.1 Protocol and registration

In order to meet the standards protocol for this systematic review, it was registered in PROSPERO (January 24, 2024, ID: 505492). PROSPERO is an international database that registers systematic reviews in (principally, although not exclusively) health and social care. Apart from enhancing transparency, this help to reduce the risk of duplication of the review and strengthens visibility of the current review among other researchers and/or relevant stakeholders in the field.

2.1.1 Definition and scope

The standard purpose of a literature review procedure is to target publications and scientific evidence that provide a comprehensive overview of a certain pre-defined topic, i.e., advanced driving assistance systems (ADAS) used by motor vehicles to prevent collisions with cyclists. In this sense, research on any type of ADAS system may be included as long as its main function is the protection of bicycle users, such as cyclist detection devices, emergency braking systems, blind spot alerts or steering assistance systems, among others.

2.2 Eligibility

The research under consideration for this systematic review pertained to the effectiveness of Advanced Driver Assistance Systems (ADAS) in terms of preventing accidents (i.e., traffic crashes), injuries, and fatalities, as well as their influence on modifying driver behavior. Studies that do not explicitly analyze the effectiveness of ADAS systems concerning the safety of cyclists on the road will be excluded. Similarly, research that generally assesses the impact of these systems on vulnerable groups will not be included unless specific results pertaining to bicycle users are provided. Additionally, articles focusing on technological devices installed on bicycles themselves will not be considered. Therefore, this systematic review specifically concentrates on ADAS systems found solely in motor vehicles, such as cars, motorcycles, and trucks, among others.

In terms of geographical coverage, we adopted an 'open criteria.' This approach not only avoids limiting research results based on their origin but emphasizes the importance of source quality. This strategy adds value by helping identify countries and/or regions where more research on the topic is being conducted. This also allows to compile and document key findings from the scientific literature, identify potential limitations inherent to this type of study, and conduct a comprehensive discussion of the results.

2.2.1 Information sources

The review process adhered to the recommendations and requirements outlined in the PRISMA 2020 reports for systematic reviews (44). Initially, a scoping review of the literature was conducted, serving as a crucial phase preceding the comprehensive systematic review. This mapping phase aims to understand the extent and variability of the literature in a specific area, facilitating an assessment of the potential and scope of the research objectives. Additionally, it plays a key role in identifying essential terms for subsequent search strategies. During this phase, studies were identified and defined as 'goldset' studies, assisting in the identification of relevant search terms.

Electronic searches of databases, including PubMed, Scopus, and Web of Science, were conducted between September 20, 2023, and January 25, 2024. No exclusion criteria based on the year of publication were applied, encompassing all literature published from database creation to the search date. The choice of these databases was guided by their broad support and recognition as reliable indicators of quality within the scientific community. Other sources such as Medline were excluded due to scope-related issues (as this systematic review was framed within the field of technological aids to safe mobility). Google Scholar was also excluded due to its overrepresentation of gray (non-peer-reviewed) literature (45) and concerns about its scientific precision, as noted in preceding literature (46).

Furthermore, we examined other reference lists of previous similar or field-related scoping and systematic reviews of primary research that might have been relevant. However, no eligible results were not detected by our search algorithms.

2.3 Search terms and Boolean operators

Search terms (both indexed [e.g., Medical Subject Headings] and keywords) associated with all concepts were independently derived by each author in consultation with a subject matter expert librarian. The collaborative effort ensured a comprehensive approach to the identification of relevant literature covered by the scope of this systematic review.

The review criteria encompassed studies available in both English and Spanish. Consequently, key terms and Boolean search operators were tailored to accommodate these two languages (see Table 1).

The search results were exported to Endnote X8 software and subsequently imported into Covidence, a Cochrane technology platform. To curate data sources, duplicates were removed using a standard function applied to the total number of identified records.

For each title/abstract, the three reviewers independently screened for eligibility, adhering to *a priori* inclusion and exclusion criteria. Following title/abstract screening, the same three reviewers independently applied the inclusion and exclusion criteria to the remaining full-text records. Articles not directly related to the research focus were excluded during this phase. To manage potential discrepancies in the selection process, all authors individually evaluated a specific set of titles and abstracts before engaging in discussions to reach a scientific agreement.

Gray literature, including doctoral dissertations, conference papers, editorials, case reports, protocols, or case series, was not excluded, provided it was related to the research objectives. Another eligibility criterion was that articles were available in their entirety for reading, either as open access or through requests made via the institutional library system utilized by the searching authors (UV Trobes).

TABLE 1 Search strategy for eligible articles.

Search strategy item	Search strategy
Databases	PubMed, Scopus, and Web of Science
Language filter	English and Spanish (indexing languages)
Boolean search operator and Keywords	The identical Boolean search operator was used across all databases. 1 (ADAS AND systems or sistemas) 2 AND (coche-bicicleta OR car-bicycle) 3 AND (motocicleta-bicicleta OR motorcycle-bicycle) 4 AND (camion-bicicleta OR truck-bicycle) 5 AND (proteccion OR prevención OR protection OR prevention) 6 AND (accidentes OR crashes OR accidents)

2.4 Data collection

For this study, we employed the descriptive-analytic method proposed by Arksey and O'Malley (46) to critically appraise articles meeting the inclusion criteria. The three reviewers conducted a full-text review of included studies, extracting key data items, including author(s), year of publication, country of study, objectives, methods and sample, results (main findings), and key limitations. The extracted data were systematically recorded in tables and thoroughly documented.

A comprehensive description of the essential conclusions is provided, emphasizing the main findings of the selected articles. To ensure the reliability of our results and mitigate potential bias, studies underwent a quality assessment using the Critical Appraisal Skills Program (CASP). CASP provides a structured framework for critically evaluating the validity of research, aiding in the determination of the overall reliability of the studies included in the review.

3 Results

3.1 Search results

After deleting duplicate articles from the search process, a total of 289 potential articles were collected for inclusion in the study. Of these, 203 were excluded after reviewing their titles and abstracts because they were not related to the objectives of the review. Subsequently, a more thorough manual screening was performed, resulting in the identification of 21 articles fully meeting the pre-defined eligibility criteria for the study. Figure 1 illustrates the process of searching and selecting data sources.

3.2 Characteristics of eligible research articles

3.2.1 Geographical coverage

The articles chosen span a publication period extending from 2015 to 2023, with the majority of them ($n = 16$; 76.2%) published in the last 3 years (i.e., 2020–2023), in accordance to an increased development of the market of ADAS during the last few years. Remarkably, all (100%) of the studies meeting the inclusion criteria (and consequently selected for analysis) were written in English.

In addition (in accordance with the aforementioned in section 2.3), the studies were conducted in different countries, as shown in Figure 2. After a basic frequency analysis, data sources represent a total of 10 countries located in three different continents, with the majority being from European countries (a total of 17 articles, equivalent to 80.9% of the total). Specifically, the distribution of countries is as follows: Sweden ($n = 4$), China ($n = 3$), Germany ($n = 3$), Belgium ($n = 3$), Italy ($n = 2$), France ($n = 2$), Spain ($n = 1$), Canada ($n = 1$), Poland ($n = 1$), and the Netherlands ($n = 1$).

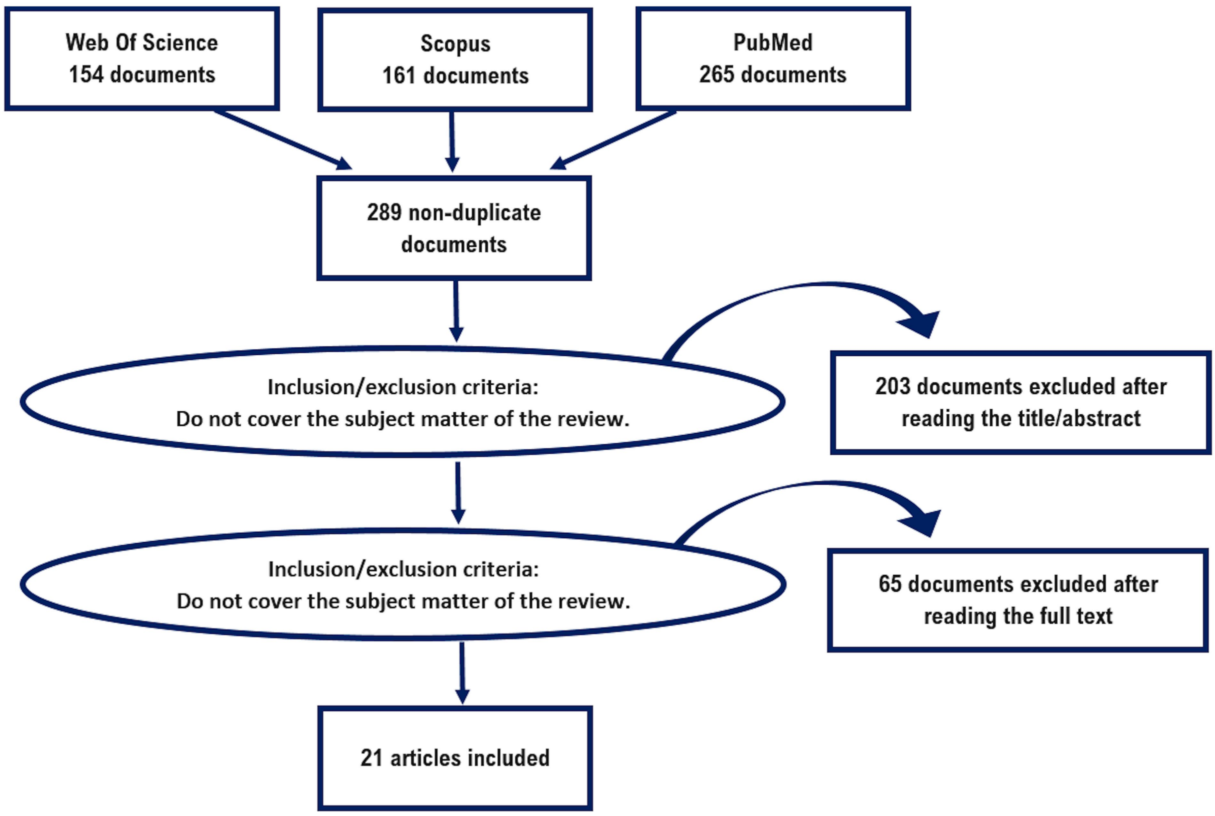

FIGURE 1
PRISMA diagram for this systematic review.

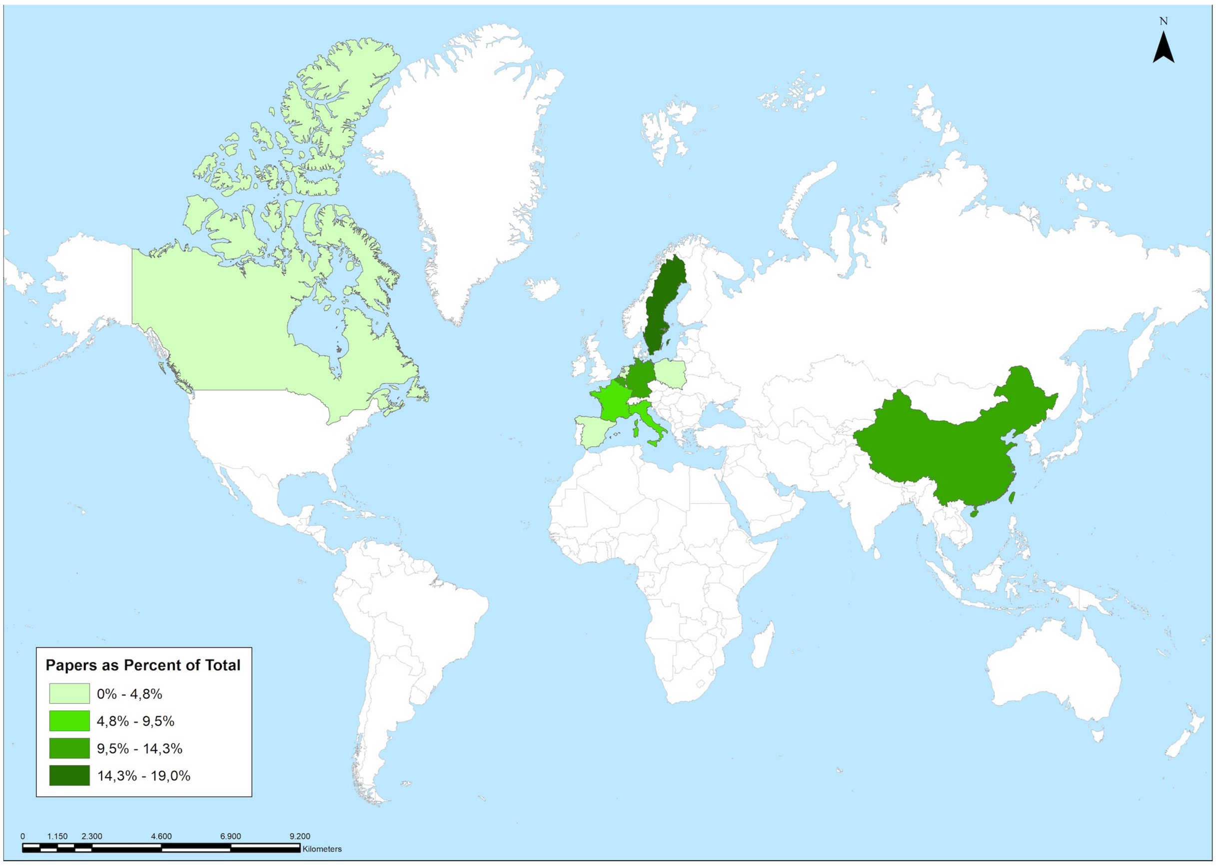

FIGURE 2
Geographical distribution (country of origin) of the selected studies.

3.2.2 Subject matters

In relation to the content and subject matter of the analyzed research outcomes, seven different groups were identified. Overall, most articles focus on evaluating specific ADAS devices performing analyses to determine their effectiveness or potential improvements after modification of certain parameters, even though with some specificities. The first ($n = 4$) delves into driver assistance technologies for overtaking cyclists, constituting 19% of the total. Similarly, a second set of studies ($n = 4$), making up 19% of the total, concentrates on vehicle emergency braking assistance devices. The third group ($n = 6$) focuses on evaluating the effectiveness of ADAS systems for detecting cyclists on the road, emerging as the most addressed topic among the appended ones, covering 28.6%. The fourth group ($n = 2$) centers on papers examining frontal collision warning devices in interactions with bicycle users (9.5%). The fifth group ($n = 1$) features a single paper evaluating a system designed to assist in turns without incidents involving cyclists, comprising 4.8%. The sixth group ($n = 3$) comprises articles that do not specifically evaluate ADAS systems but rather analyze a range of them in different scenarios to identify their effectiveness and potential enhancements in the active safety of motor vehicles. This group represents 14.3% of the papers. Lastly, the seventh group ($n = 1$) consists of a single article evaluating the false positives of Advanced Driver Assistance Systems, a critical factor influencing drivers' behavior and perception of such systems (4.8%). Figure 3 visually illustrates the distribution of these paper groups as for their coverage among the analyzed results.

3.2.3 Methodological setting

From a method-based approach (i.e., the study design used), most of the analyzed studies follow an experimental research design (71.42%, $n = 15$). Typically, an experimental methodology involves the creation of a control group, which represents the conditions without the intervention of ADAS devices, and an experimental condition, which operates with the assistance of these devices. Moreover, in some cases, it is possible to perform combinatory studies where the same group is subjected to two different phases: one without the devices and one with them, allowing direct comparison of their impact on the same set of subjects over time. In any case, within this type of methodology, three core groups or types of experiments can be identified:

On the one hand, those that are carried out in a controlled path by the researchers. This approach, which represents 38.09% ($n = 8$) of the total number of articles, is characterized by the fact that the research is carried out in a real road environment, but under controlled and safe conditions. Vehicles equipped with ADAS devices are used, real driving data are recorded, and relevant data are collected, such as speed, following distance, braking capacity or other parameters of interest.

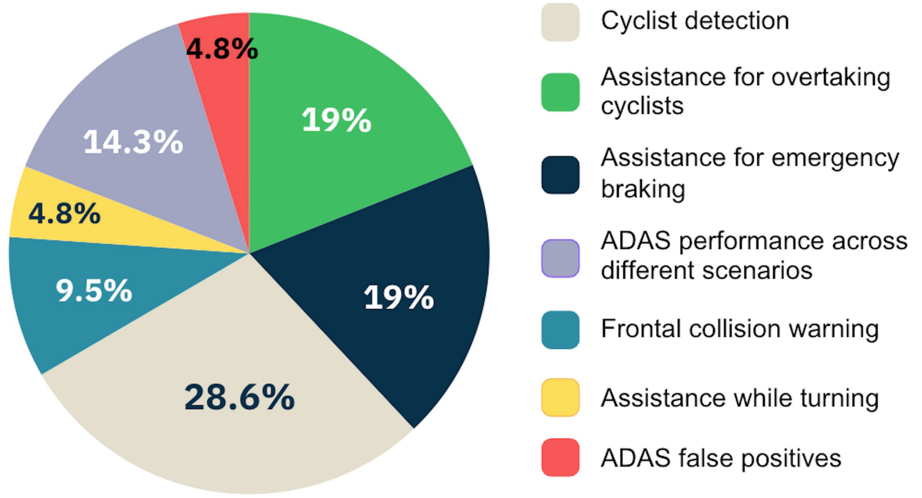

FIGURE 3
Groups of studies addressing different topics related to ADAS for preventing car-cyclist collisions, categorized by their subject matter (N = 21). The topics are listed in descending order of frequency, from the most common (cyclist detection) to less frequent themes (turning assistance and false positives).

On the other hand, 28.57% of the total research (n = 6) is conducted through driving simulators. In this approach, research is conducted in a virtual environment that simulates real traffic scenarios. Participants interact with a driving simulator that incorporates ADAS devices and are presented with a variety of traffic situations and driving scenarios, recording data similar to those obtained in a real context. Finally, one article uses a combined methodology, having performed measurements in a controlled route and simulated scenarios (4.76%, n = 1).

A small part of the investigations employs epidemiological methods (14.26%, n = 3). These are retrospective studies that use databases of road accidents from official entities or institutions and official figures on the presence, or lack thereof, of ADAS devices to evaluate the relationship between the two variables. Finally, some studies employ observational methods based on the visualization, recording and analysis of information in the real environment without the active intervention of the researchers. Thus, this type of research represents 14.26% (n = 3) of the total number of articles, and mostly corresponds to the observation and collection of data on a group of drivers using vehicles equipped with ADAS devices in everyday driving situations.

Table 2 shows the general characteristics of the analyzed original research articles.

3.3 Content analysis: word communities

Regarding the discursive outlines of the analyzed studies, the content analysis software VOSviewer (67) has been used to detect the most relevant groupings or sets of words within the textual content of the articles we have chosen. This tool, designed principally for bibliometric analysis practices, serves as an efficient method to summarize and offer comprehensive syntheses of literature outputs, thus making it easy go know the state-of-affairs on a certain topic on the basis of the published literature. Consequently, and added to the positive fact of enhancing objectivity in the analysis of literature (68) it has gained popularity and widespread adoption in recent years due to its ubiquity and utility in simplifying the retrieval and evaluation of extensive volumes of scientific data (69).

Once the data was collected, the bibliometric information and the text corpus of all the selected documents was extracted in RIS format and applied in the VOSviewer software, which establishes common patterns, links, and builds word communities (AKA *word clusters*) on the basis of the full text contents. At a practical level, identifying these word clusters favors a succinct and easy recognition of central or main themes within a given set of documents. At a research one, this significantly aids in the efficient classification and organization of the selected collection of articles. Figure 4 graphically presents the groupings and connections between words in the texts, about which it is worth mentioning that all these selected terms appear in the individual text corpus of each source a minimum of five times.

After conducting the content analysis of the original scientific papers retained in this systematic review, several topics or 'categories' can be distinguished within the discourse they address. These specific topics have been grouped into seven core word communities, each with its own particular focus and meaning. Each word community is presented with a color code that facilitates its identification and understanding.

The word community in red relates to methodological aspects in the context of research on advanced driver assistance systems (ADAS) related to the interaction between cyclists and motor vehicles. It, therefore, refers to a specific study approach that focuses on the methods and techniques used to conduct research in this field. This grouping of words includes terms such as "assistance system," "image," "dataset," and "object," all of which are related to data collection, image analysis, dataset creation, and the evaluation of specific objects.

The community represented in blue focuses on factors related to crashes involving bicyclists and motor vehicles. Key terms in this category include "crash," "interaction," "effect," "error," and "contributing factor." These terms reflect a discourse focused on road

TABLE 2 Record of the general characteristics of the selected studies.

Author (s), year of publication, country	Objectives	Methods and sample	Results (main outcomes)	Key limitations
Brijs et al., 2022 (Belgium) (47)	Design and evaluation of a driver assistance system for overtaking cyclists.	A sample of 48 drivers performed the established route with the system activated and deactivated.	The system had an impact on the duration of the overtaking phase, the lateral clearance in the overtaking phase and the hazard time in the process of the overtaking maneuver.	Repeated use of the system may reduce its effectiveness or cause learning effects that influence the results.
Siebke et al., 2023 (Germany) (48)	Emergency braking system (AEB) for cyclist detection in urban intersection scenarios is evaluated.	Driving simulations are used to evaluate 240,000 road situations with various sensor opening angles.	The presented approach allows examining the entire scenario space randomly, which minimizes the potential loss of information in risky situations.	No limitations are apparent
Rasch and Dozza, 2020 (Sweden) (49)	Design of a control model based on logistic regression to avoid false-positive ADAS activations.	Data from an experiment on a test track are recorded to establish the model.	It manifests limited ability to predict the probability and confidence of drivers braking and turning while approaching a cyclist during an overtaking, thus improving ADAS.	Small sample size
Kovaceva et al., 2022 (Sweden) (50)	The potential impact of forward collision warning systems on cyclist protection in overtaking situations is evaluated.	Drivers' reactions to the warning were analyzed, combining the data with accident frequency and an injury risk model.	With the driver response model applied to the warning system, cyclist fatalities were reduced by 53 to 96% and serious injuries by 43 to 94%.	Simulations did not include responses other than braking (e.g., turning).
Schindler and Piccinini, 2021 (Sweden) (51)	The response of drivers in two conflict scenarios with vulnerable road users is analyzed.	A group of 13 people took a tour driving a truck equipped for data recording.	Drivers adapted their kinematic and visual behavior in situations where vulnerable road users were crossing the intersection, compared to the baseline route.	Small sample size
Char and Serre, 2020 (France) (52)	Analyzed accidents between cars and cyclists to determine potential improvements for vehicle active safety systems.	Analysis of 2,261 accidents involving cars and cyclists. Safety systems are applied in the most likely incident scenarios.	A field of view of 60° and a range of 35 m would allow detection of most cyclists in accident scenarios. With a 60° field of view, 51% of cyclists could be detected up to 4 s before the crash and 72% up to 1 s before.	The sample is not representative of the national proportion of accidents.
Limani et al., 2022 (Belgium) (53)	PowerCam, a system that enables compatibility between 802.11p and conventional Wi-Fi networks, is presented to connect cars with the cell phones of vulnerable users.	A standard wifi AP is included in the roadside unit's broadcast radio and another just outside it to verify that messages are broadcast.	This methodology enables low bit-rate communication between devices without requiring formal association or authentication. The results demonstrate the system's ability to deliver messages in a timely manner to users.	May have a latency of 2 s, not being effective in specific scenarios.
Cara et al., 2015 (Netherlands) (54)	A scenario classification algorithm using machine learning is proposed to evaluate ADAS systems for cyclist protection.	A data set consisting of 99 realistic cycling scenarios recorded by a vehicle equipped with instrumentation is obtained.	An accuracy of 87.9% is achieved in the classification of the data obtained, and the execution time of 45.8 microseconds supports the suitability of the algorithm for fine online applications.	No limitations are apparent

(Continued)

TABLE 2 (Continued)

Author (s), year of publication, country	Objectives	Methods and sample	Results (main outcomes)	Key limitations
Puller et al., 2023 (Germany) (55)	A V2X-based turning aid designed to mitigate collisions with vulnerable participants in traffic is presented.	Generate information for advanced driver assistance systems to use, even when the sensors do not detect the object in the foreground, and increase awareness of crossings.	The application faces challenges in terms of user acceptance, so a key challenge for ADAS functions is to maintain a low false positive rate so that users do not lose confidence in its accuracy.	No limitations are apparent
Brijs et al., 2021 (Belgium) (56)	The impact of an advanced driver assistance system for cyclist overtaking is analyzed.	A driving simulator is used for the experiment in which there are three phases of warning priority: normal accident, hazard, and avoidable	A positive effect on lateral clearance was observed with ADAS presence, familiarity with the system, driving experience, and experience as a cyclist. A negative effect of cyclist maneuvering from the edge of the lane to the center of the lane, cyclists riding parallel, driver age, and self-reported aggressive driving.	No apparent limitations
Kovaceva et al., 2019 (Sweden) (57)	The combination of factors affecting the limits of drivers' comfort zone when overtaking cyclists in a naturalistic environment is analyzed.	Naturalistic driving data from UDRIVE, a European naturalistic driving study, is analyzed.	The higher the speed of the car, the higher the driver's comfort zone limits when approaching and passing, but the presence of an approaching vehicle decreases it when overtaking.	Limited generalization of the data set
Kovaceva et al., 2020 (Germany) (58)	The safety benefit of autonomous steering and emergency braking systems for the protection of cyclists and pedestrians is evaluated	Data from a simulation based on data from the German In-Depth Accident Study (GIDAS-PCM) were combined with real-world test results.	A systematic way of combining results from different sources is indicated, showing the positive effects of the evaluated system.	Other scenarios may require the application of an extension of the current model.
Anaya et al., 2015 (Spain) (59)	The effectiveness of V2X systems in detecting vulnerable road users is evaluated.	Two tests are performed to test the correct detection by the vehicle of both motorists and cyclists.	In both tests the vehicle correctly detects the vulnerable user even in blind spots when the distance between the two vehicles is less than 30 meters.	No limitations are evident
Guerrieri and Parla, 2021 (Italy) (60)	The aim is to obtain a program capable of detecting vulnerable road users by calculating their distance and speed, in order to be able to act from the streetcar.	Images obtained along the route of a streetcar are analyzed and processed by neural networks to obtain different parameters.	The system is able to correctly estimate the approach speed of pedestrians, cyclists and other vehicles.	No limitations are evident
Azadani and Boukerche, 2021 (Canada) (61)	The aim is to obtain the position of cyclists in motion in order to improve the detection capability of the ADAS.	Two different real scenarios are simulated in which the cyclist is in a position not visible from the vehicle, calculating his position.	In both scenarios, the ultrasonic sensors installed in different cars were able to locate the cyclist's position and share the information among several vehicles to keep the cyclist located.	No limitations shown
Chen et al., 2018 (China) (62)	The improvement of pedestrian and cyclist identification by unifying 3 different detection methodologies is evaluated.	Evaluations of the proposed detection methodology are carried out by comparing it with other detection methods.	The proposed method shows a higher efficiency in recognizing pedestrians and cyclists than other methods used.	No apparent limitations

(Continued)

TABLE 2 (Continued)

Author (s), year of publication, country	Objectives	Methods and sample	Results (main outcomes)	Key limitations
Ucińska and Pełka, 2021 (Poland) (63)	To analyze the effectiveness of the automatic braking system (AEB) in different situations in front of VRU.	44 trials of 4 tests are performed in which different scenarios are presented analyzing the AEB activity.	The different tests show the difficulty of the AEB system both in braking in time and in recognizing properly the VRUs present on the road.	Low sample size
Xu et al., 2020 (China) (64)	A neural network is trained to improve the differentiation between cyclists and motorists, as well as co-detection.	Comparison of the results obtained between the proposed method and the previously existing ones on several databases on the Internet consisting of more than one million images (4,300 of cyclists and motorists).	The results show a higher accuracy in differentiating between cyclists and motorists by up to 30%.	No apparent limitations
Duan et al., 2017 (China) (65)	Analyzing the braking behavior of drivers to improve the performance of ADAS braking systems on bicycles.	3 types of scenarios were simulated from the accident data collected and 25 drivers were tested.	The application of the data obtained can help to improve bicycle AEB systems and thus reduce the number of accidents.	Small sample size
Char et al., 2022 (France) (66)	Potential effects of earlier brake activation by drivers with a collision warning system are quantified in simulated car-to-cyclist accident scenarios.	A parametric analysis is performed by varying the field of view of the detection sensor, the activation time of the forward collision warning system and the reaction delay time of the driver to the forward collision warning system.	A 70° field of view, a system activation time of 2.6 s before impact and a driver reaction of 0.6 s to the warning system has a positive outcome in 82% of accident cases, with 78% avoiding and 4% mitigating the crash.	No apparent limitations

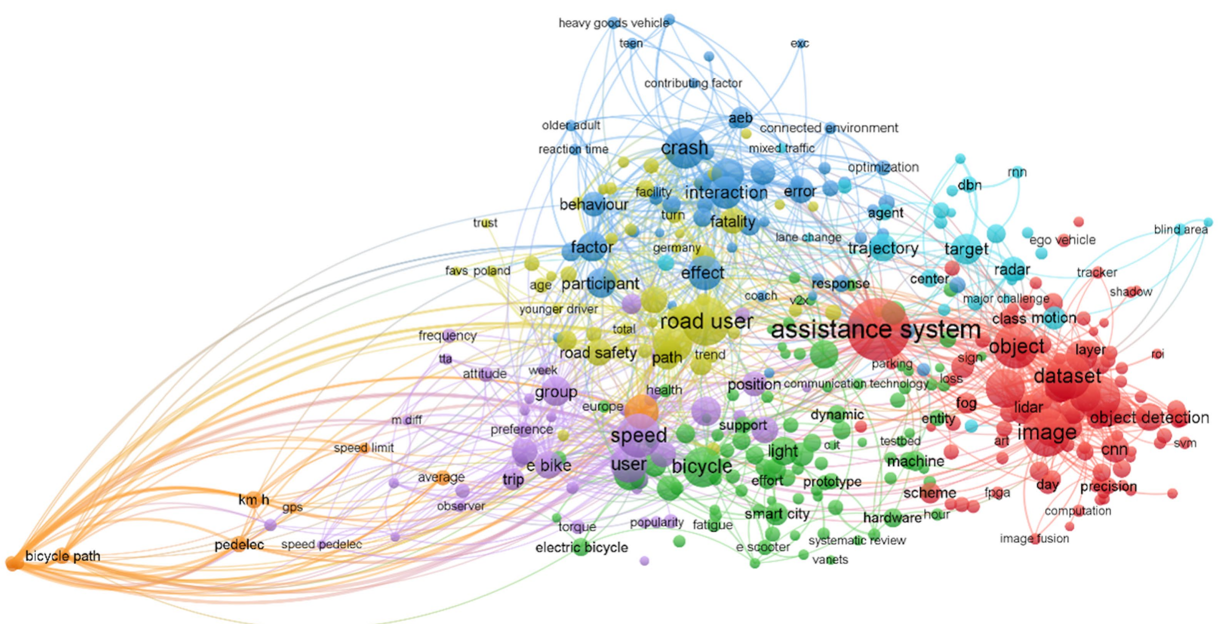

FIGURE 4
Representation of the clustered 'word communities' in the current empirical studies on the topic. Note: Each community is labeled with a different color, based on the number of commonalities and links identified in the analyzed literature sources.

safety and, specifically, interactions between bicyclists and drivers, as well as the factors contributing to crashes and their consequences.

The green word community focuses on the devices and vehicles being studied in the research. Terms such as "bicycle," "lights," "electric bike," "machine," and "prototype" relate to the features and design of ADAS devices to investigate their impact on the safety of this vulnerable group.

The yellow word community is dedicated to exploring users and their characteristics. Terms such as "road user," "road safety," "younger driver," and "age" indicate an interest in understanding the particularities of drivers who interact riskily with bicyclists, as well as those who use ADAS systems. Characteristics of bicycle users who experience incidents with motor vehicles are also apparent.

The purple community focuses on the perceptions, beliefs, and behaviors of users during their commute. Terms such as "speed," "attitude," "preference," "trip," "frequency," and "group" highlight the importance of understanding how user attitudes and behaviors can affect the implementation and effectiveness of ADAS systems. This area of study focuses on decisional aspects of users interacting with these systems and how they influence the prevalence of their use and acceptance.

The community in orange differs from the rest, as it focuses on a specific element, the "bicycle path." This separation is justified because most studies focused on interurban environments with no bicycle lanes, and cyclists share the road with motor vehicles. In this sense, this difference in discourse, as well as the small number of articles that address this topic, explain why graphically fewer relationships are identified between this word community and the rest of the groupings.

Taken together, these word communities represent the different areas of focus in research on ADAS systems and cyclist-motor vehicle interaction, providing a deeper understanding of the key issues and questions that researchers address in this field.

3.4 Evaluation of the quality of the selected studies

The quality assessment methodology provided by the Critical Appraisal Skills Program (CASP) was used to ensure that no included study had the capacity to influence or distort the results of this systematic review. Through a set of 10 specific questions, this tool allows the evaluators to assess the level of rigor, reliability and relevance of each study (70). The CASP focuses on the development of practical skills for critical evaluation, being an instrument easily adaptable to different types of studies and simple to apply, being valid for evaluating qualitative, quantitative and mixed studies. The results of the evaluation of the selected publications are shown in Figure 5. It is important to mention that all studies were included in the review because of their low risk of bias, and no articles previously selected in the screening phase were excluded in this process.

4 Discussion

In the current context of road safety, the interaction between motor vehicles and cyclists has become an issue of significant concern. Advanced driver assistance systems (ADAS) have the potential to be effective tools for reducing collisions between drivers and cyclists. For these reasons, the aim of the present systematic review has been to target and analyze the existing research analyzing the effectiveness of this type of devices, specifically for the prevention of crashes involving cyclists, and to synthesize their main results.

In terms of quantity (i.e., current volume of scientific production), it should be noted that there is still a small number of studies that analyze this specific topic, even though their overall quality has been found reasonably well after applying the selected evaluation methods. Also, it is worth mentioning that, although there is a relatively large number of articles evaluating ADAS devices on vulnerable groups, these are more focused on pedestrians or motorcyclists (71, 72). One of the inclusion criteria of the present review is that the selected research should specifically include results on cyclists, which reduces the number of potentially selectable articles, but helps to match the findings to the characteristics of this road group.

4.1 Effectiveness of ADAS systems in preventing collisions with cyclists

As evidenced, ADAS systems encompass a wide taxonomical variety of technologies, typically ranging from forward collision alerts and automatic emergency braking systems to blind spot detection systems and lane departure prevention assistance. The majority of selected researches point out that the integration of these functions in motor vehicles allows preventing collisions with cyclists in a broad number of situations (49, 52, 56, 58). The results of the different studies manifest that the models and devices evaluated, allow increases in terms of drivers' risk recognition, detection of cyclists, and visual field. On the other hand, these ADAS have been shown to imply a reduction in mean reaction times, thus contributing to reducing both fatalities and serious injuries derived from collisions involving bicycle riders (59, 62, 66).

However, conflicting factors have been also underscored through different pieces of literature, making it relevant to mention that there are variables that may influence the effectiveness of ADAS systems related to driver characteristics and the road situation or environment. For instance, Brijs et al. (47) note that driver age and self-reported aggressive driving were variables that negatively influenced overtaking performance, despite having an in-vehicle collision warning system. A possible explanation lies in the tendency of drivers with these characteristics to ignore or minimize the alerts and warnings provided by the system (73). Also, drivers who self-identify as aggressive have been found to tend to be more prone to take risks and underestimate the importance of warning signals (74). This may lead them to underestimate the proximity of cyclists and make risky decisions enhanced by psychosocial factors such as fatigue and stress, performing less safer overtaking maneuvers and thus increasing the risk of collision (75, 76).

In contrast, the variables of experience as a car driver and experience as a bicycle user had a positive impact on driver behavior during overtaking. Specifically, when these parameters were high, in the presence of the ADAS system, the lateral separation distance between the vehicle and the cyclist maintained by the driver significantly increased (47). In this regard, especially experience as a

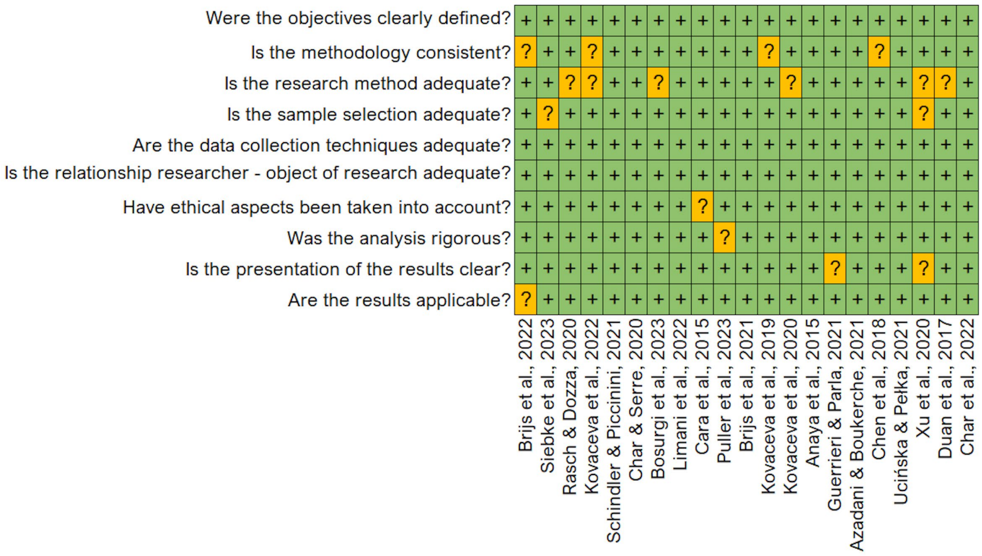

FIGURE 5
Evaluation of the quality of the selected articles using the "Critical Appraisal Skills Programme" tool.

cyclist provides a unique perspective in understanding the vulnerabilities of those who commute by bicycle (77). Drivers with experience as cyclists are often more cautious when overtaking such users, as they understand firsthand safety concerns, such as sufficient space to maneuver or the possibility of being affected by wind gusts created by vehicles passing at high speed (78).

A positive effect of familiarity with the ADAS system on driver behavior has also been evidenced. This variable contributes to a more intuitive interaction with the system, and, consequently, decreases the probability of making errors or infractions in vehicle operation (79). This finding is congruent with previous literature. The predisposition to the use of technological devices while driving has been related to the perception of technology in general at both the individual and collective levels (80). Thus, if a given region or cultural context presents a high familiarity and experience with ICTs, they are more likely to rely on these devices in a traffic context (81, 82). On the contrary, in emerging countries where there is a lower presence of technological tools, there is a greater rejection of the use of ADAS or ITS systems while driving, which may be due to elements such as the perceived lack of privacy of personal data or the lack of knowledge about their functionalities (83).

In relation to the road environment, some of the articles included in this review also point out that the complexity of the scenario plays a fundamental role in the degree of usefulness and effectiveness of ADAS systems. Bosurgi et al. (79) point out that it is difficult to determine quantitatively and in general terms the effectiveness of these driving aids. In this sense, they point out that in many road situations, the information transmitted to the driver by an onboard ADAS system enhances the maintenance of adequate behavior and an improvement in driving performance. However, in complex scenarios such as when there are special traffic components or difficult weather conditions, drivers pay less attention to the information and alerts from such systems, which is estimated to occur because the user reaches the limit of his or her capacity to process additional information (55, 65).

4.2 Impact of ADAS 'false alarms' and other relevant issues related to driver behavior

One *side-effect* commonly addressed in the literature on ADAS systems is how drivers may become over-reliant on technology and develop the expectation that they will always detect and avoid hazards (84, 85). This could lead to distraction and negligence, as drivers may take their attention away from the road and become more easily distracted by electronic devices, conversations, or other non-driving activities, assuming that the technology will take care of everything (86–88). This factor can be dangerous and contradicts the fundamental purpose of ADAS, which is to assist drivers, not replace their responsibility for safe driving (89).

Other studies focused on relevant safety-related matters such as drivers' aptitudes have also underscored the potential (and negative) effect of technology misuse and misunderstanding, especially among drivers with poor aptitudes or engaging in problematic driving behavior besides the safety potential of Advanced Driving Assistance Systems (90). Moreover, other previous studies have explored the association between drivers' cognitive abilities and decision-making skills in visually impaired drivers, finding that not all of them have the same usefulness and acceptance level (91). Additionally, prospective evidence show the need to include ADAS in drivers' training curricula, and not fully depending of technology as a 'driver behavioral management' tool, as problematic driving behaviors, such as aggressive driving or distracted driving, can create additional challenges for ADAS in predicting and mitigating potential road risks (92, 93).

In this sense, ADAS systems have been demonstrated to be, besides relatively reliable, never infallible. Their accuracy and reliability may vary depending on factors such as weather conditions and sensor quality (94). A crucial aspect of the effectiveness of these devices lies in the sensitivity and accuracy of their alerts. Thus, false alarms generated by advanced driver assistance systems pose significant challenges in the context of cyclist crash prevention (95).

When these systems issue incorrect hazard alarms, inappropriate driver responses can be triggered. These responses may include abrupt maneuvers, sudden braking, or unnecessary avoidance, which in turn may increase the risk of collisions, particularly rear-end collisions, or hazardous situations with other vehicles on the road (96).

On the other hand, another potential consequence of false alarms in ADAS systems, noted in several selected articles in the present review, is driver desensitization (50, 51). When these devices have these errors on a regular basis, drivers may become less responsive to alerts. They become habituated to the situation and may begin to ignore them or fail to respond effectively, even when a legitimate alarm is triggered. This reduces the usefulness of system alerts and can increase the risk of not reacting appropriately in real danger situations. In addition, the false accuracy of warnings directly influences the perception of users, their acceptance of these tools and, their predisposition to want to implement ADAS systems in their vehicles (52). Therefore, these devices must be able to reliably distinguish between a real cyclist and other objects or situations on the road in order to avoid unnecessary alarms that may desensitize drivers (97).

4.3 Complementary measures to reduce vehicle-cyclist incidents

In addition to ADAS systems that can be implemented in motor vehicles, it is essential to consider other both technological and non-technological measures that can have a significant impact on road safety and accident reduction between cars and cyclists. To the best of our knowledge, there is no research on the effectiveness of cyclist assistance systems. It is less common to find ADAS systems specifically designed for bicycles, as bicycles are often not equipped with the same technology as motor vehicles. Instead of ADAS systems, cyclists often use other devices and applications designed to enhance their safety and visibility on the road such as lights and reflectors, action cameras, rearview mirrors, and navigation and communication devices that allow them to alert their position to other road users (98). However, given the potential of ADAS systems, more effort could be devoted to designing devices that could be used by cyclists themselves to alert them to road hazards in real-time, providing them with information that would allow them to adapt as far as possible, their behavior to the road scenario.

Another promising approach is the implementation of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) sensor and communication systems (99). These advanced technologies focus on creating a real-time information network involving all traffic components, which could revolutionize road safety for the benefit of all road users, including cyclists. V2V communication allows vehicles to exchange critical data, such as position, speed, direction, and operational status (100). When applied to situations with cyclists, these systems can detect cyclists in close proximity and provide warnings to drivers. On the other hand, V2I communication involves the interaction of vehicles with road infrastructure, such as traffic lights and traffic signals (101). This could enable the synchronization of traffic lights to ensure safe passage for cyclists or the detection of cyclists at dangerous intersections, which could result in automatically triggered warning signals to protect cyclists.

Complementary to the application of technology, other sources claim (from the non-technological point of view) the need for promoting both drivers' training on potential road conflicts and awareness about the importance of sharing the road safely with cyclists (102). The implementation of driver assistance devices is a significant step, but responsibility and mutual respect on the road are equally essential to ensure the safety of all users. In fact, Wood et al. (103) point out the importance of training for both drivers and cyclists, as it is indicated that the two user groups have divergent perceptions of responsibility for car-cyclist collisions. Therefore, road safety education programs and communication campaigns on cyclist safety, supported by real-time information systems and applications, can play a key role in reducing accidents. In fact, research suggests that different preventive measures significantly increase their effectiveness when implemented in a coordinated and complementary manner (104).

In summary, although our study reveals a scarcity of developed evidence on the effectiveness of Advanced Driver Assistance Systems (ADAS) for preventing car-cyclist crashes, particularly in a limited number of countries, especially those with high income, literature uniformly emphasizes that the rise in the number of crashes involving cyclists is a global problem affecting all regions of the world. The implementation of driver assistance devices that alert to the presence of cyclists or act upon interaction with these users is presented as an effective solution to improve road safety in many driving scenarios. When implemented effectively, this technology can reduce conflicts and risks associated with overtaking cyclists and save lives globally. However, as previously mentioned, driver perception and experience influence their willingness to use ADAS systems, as well as their behavior once alerted. Therefore, it is equally important to encourage education and respect between drivers and cyclists in order to create a safe and harmonious driving environment for everyone.

4.4 Limitations of the systematic review

This systematic review was performed following the PRISMA procedure to avoid possible biases in the selection and/or recording of data. In addition, the eligible articles are part of relevant indexes and databases recognized by the scientific community and the CASP instrument has been applied to guarantee, as far as possible, the quality of the research. Despite their methodological rigor, all systematic reviews have some inherent limitations that should be taken into account.

On the one hand, publication bias may occur, especially highlighting the fact that studies with positive results tend to be more likely to be published than those reporting inconclusive results (105). Therefore, there may be studies with negative or non-significant results that, since they are not published, cannot be included in the review performed. Moreover, previous studies have remarked on the relevance of addressing selection bias (e.g., gender and outcome-related bias) as a confounding factor, which consists of the selective inclusion of studies based on certain criteria stipulated by those responsible for searching and selecting the articles (105, 106). This bias has been minimized by all the authors of the article carrying out this process individually and independently. Additionally, bias occurs in matters of language and region of publication (107). The present systematic review focuses on research published in English and Spanish, so potential studies relevant to the research topic that have been published in other languages have not been included. Further, it is noteworthy that key issues such as ADAS-related behavioral ergonomics or their usage patterns over time (e.g., from a longitudinal point of view) remain understudied, implying an active need for further research and developments in this field.

Finally, it is worth addressing the fact that, in the discourse analysis conducted with the VOSviewer tool, the absence of combining synonyms and the use of different notations for some terms imposes limitations on lexical richness. For example, and among many others, electric bikes may be labeled across literature sources as e-bike, e-bicycle, electric bicycle, electronic bicycle, and so on. These acute but relevant differences may compromise the full word clustering process and its holistic interpretation, leading to a loss of linguistic subtleties. In addition, specialized scientometric sources (68) emphasize that the precision of bibliometric analyses is significantly contingent on both the breadth and quality of data. Given the current reliance on a limited number of available sources, this can influence the overall accuracy. Furthermore, interdisciplinary research, as observed in the present study, often involves different paradigms and approaches, introducing additional challenges to the precision of scientometric and bibliometric analyses. This must be considered when interpreting the outcomes of the present research.

5 Conclusion

This systematic literature review aimed to analyze the evidence regarding the effectiveness of in-vehicle Advanced Driver Assistance Systems (ADAS) in preventing car-cyclist collisions. The results of this review lead to the following conclusions:

First, in terms of the volume of scientific production, there are relatively few studies that specifically address this topic with cyclists. Most studies tend to focus on pedestrians or motorcyclists. However, the overall quality of the available studies has been reasonably good, as determined by the selected evaluation methods.

Secondly, the literature supports the value of in-vehicle ADAS for preventing car-cyclist crashes. Nonetheless, these studies also highlight potential side effects, including unrealistic expectations of these systems and drivers' overconfidence or desensitization, which should be regarded as latent threats.

Thirdly, regarding complementary non-technological factors that could enhance the effectiveness of ADAS in preventing car-cyclist crashes, there is a need to increase driver awareness and address potential inter-user conflicts through educational and training initiatives.

Finally, future research should encompass emerging issues such as behavioral ergonomics and the long-term effectiveness assessments of ADAS in preventing car-cycling crashes and their subsequent injuries.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SU: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. MF: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. FA: Conceptualization, Funding acquisition, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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The effects of ambient temperature on road traffic injuries in Jinan city: a time-stratified case-crossover study based on distributed lag nonlinear model

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Objectives: The impact of climate change, especially extreme temperatures, on health outcomes has become a global public health concern. Most previous studies focused on the impact of disease incidence or mortality, whereas much less has been done on road traffic injuries (RTIs). This study aimed to explore the effects of ambient temperature, particularly extreme temperature, on road traffic deaths in Jinan city.

Methods: Daily data on road traffic deaths and meteorological factors were collected among all residents in Jinan city during 2011–2020. We used a time-stratified case-crossover design with distributed lag nonlinear model to evaluate the association between daily mean temperature, especially extreme temperature and road traffic deaths, and its variation in different subgroups of transportation mode, adjusting for meteorological confounders.

Results: A total of 9,794 road traffic deaths were collected in our study. The results showed that extreme temperatures were associated with increased risks of deaths from road traffic injuries and four main subtypes of transportation mode, including walking, Bicycle, Motorcycle and Motor vehicle (except motorcycles), with obviously lag effects. Meanwhile, the negative effects of extreme high temperatures were significantly higher than those of extreme low temperatures. Under low-temperature exposure, the highest cumulative lag effect of 1.355 (95% CI, 1.054, 1.742) for pedal cyclists when cumulated over lag 0 to 6 day, and those for pedestrians, motorcycles and motor vehicle occupants all persisted until 14 days, with ORs of 1.227 (95% CI, 1.102, 1.367), 1.453 (95% CI, 1.214, 1.740) and 1.202 (95% CI, 1.005, 1.438), respectively. Under high-temperature exposure, the highest cumulative lag effect of 3.106 (95% CI, 1.646, 5.861) for motorcycle occupants when cumulated over lag 0 to 12 day, and those for pedestrian, pedal cyclists, and motor vehicle accidents all peaked when persisted until 14 days, with OR values of 1.638 (95% CI, 1.281, 2.094), 2.603 (95% CI, 1.695, 3.997) and 1.603 (95% CI, 1.066, 2.411), respectively.

Conclusion: This study provides evidence that ambient temperature is significantly associated with the risk of road traffic injuries accompanied by obvious lag effect, and the associations differ by the mode of transportation. Our findings help to promote a more comprehensive understanding of the relationship between temperature and road traffic injuries, which can be used to establish appropriate public health policies and targeted interventions.

KEYWORDS

ambient temperature, extreme temperature, road traffic injuries, case-crossover study, distributed lag nonlinear model

1 Introduction

Road traffic injuries (RTIs) has not only become a social safety problem that cannot be ignored worldwide (1, 2), but a huge challenge to economic development and public health as well (3), with the development of motorization rapidly. The Global Status Report on Road Safety 2018 showed that around 1.35 million people worldwide died from RTIs each year, and 50 million people suffered non-fatal injuries from traffic crashes, some disabled as a result among them (4). RTIs can lead to permanent injuries, such as traumatic brain injury, spinal injury, amputations, which might have devastating, lifelong effects on road users (5, 6). The global economic cost resulted from RTIs is estimated at $1.8 trillion in 2015–2030, equivalent to 0.12 percent of global gross domestic product (7). RTIs are more severe in developing countries than in developed countries, and 93 percent of road traffic deaths occur in low-income and middle-income countries (6).

World Health Organization reported that one-fifth of global road traffic deaths occurred in China (8). RTIs are the leading cause of accident deaths in China and have been on the rise in China since the end of 1980s (9). In recent years, although some studies have reported that RTIs showed a downward trend attributed to road safety laws and various policies in China, the mortality of RTIs is still much higher than that in developed countries (9–11). As a result, it is still a very serious problem in China that should be paid more attention to (2, 12).

In addition to human behaviors, road conditions and vehicles, environmental factors are one of the important reasons leading to RTIs. In recent years, accompanying for the increasing of global warming and air pollution, more and more researches pay attention to the influence of ambient temperature on people's health. Extreme temperature is currently considered to be an important risk factor for RTIs, which has a direct or indirect impact on the occurring of traffic injuries (13, 14). Weather changes can affect the vehicle itself, road conditions, the judgment and reaction of the driver during the driving process, and the riding environment of the driver and passenger on varying degrees. However, much less studies have focused on the impact on RTIs, especially on RTIs fatalities and the epidemiological evidence for its exact impact is not uniform due to the limitations of traditional research methods (15, 16). To reduce the incidence and mortality of RTIs under extreme temperature conditions, It is urgent need to study the relationship between extreme temperature and RTIs specifically.

A time-stratified case-crossover design approach for distributed lag nonlinear model can be used to study the relationship between environmental factors and health outcomes, overcome multiple biases, and make full use of information from sample data, maximally close to the truth to achieve unbiased estimates. In this study, we used a time-stratified case-crossover design based on distributed lag nonlinear model to examine the relationship between extreme temperature and the risk of RTIs' deaths, on the basis of 10-year traffic accident statistics from Jinan city, Shandong Province in China. The study will help to develop public health policies and interventions to reduce the negative impacts of climate change on RTIs fatalities in extreme weather conditions.

Abbreviations: df, Degree of freedom; RTIs, Road traffic injuries; OR, Odds ratio; CI, Confidence interval.

2 Materials and methods

2.1 Study area and data collection

Jinan is the capital city of Shandong Province, located at the east coast of China an mid-latitudes. It's a temperate monsoon climate, characterized by four distinct seasons with warm and rainy summer, cold and dry winter and comfortable spring and autumn transition season.

We collected individual road traffic death records among all inhabitants in Jinan city during 2011–2020 from the Shandong Provincial Death Registration Information Reporting System. Data information were extracted such as date of death, sex, age, and underlying cause of death. The underlying cause of road traffic death was coded by the International Classification of Diseases (version 10), which the coding range was V00-V89. In this study, Road traffic deaths were classified into walking, bicycle, motorcycle, motor vehicle (except motorcycle) and other subtypes according to the mode of transport. Due to the small sample size, deaths caused by injuries in other transportation accidents were excluded from the statistical analysis.

The meteorological data for the same period was obtained from the China Meteorological Data Sharing Service System,[1] including daily mean temperature (°C), relative humidity (%), wind speed (m/s), and barometric pressure (hPa). To adjust for the potential impacts of air pollutants, daily concentrations of PM2.5 (μg/m^3), PM10 (μg/m^3), SO2 (μg/m^3), NO2 (μg/m3), CO (mg/m^3), and O3 (μg/m^3) were extracted from the National Environmental Monitoring Center (NEMC) of China.

2.2 Statistical analysis

A time-stratified case-crossover design (15) was used in this study to assess the effects of extreme temperature on RTIs, which is

1 http://data.cma.cn/

equivalent to a time-stratified self-matched case–control study. Poisson regression was achieved by setting dummy variables (e.g., year, month, day of the week), with the same day of the week of the same month in the same year as the control day (up to 4 control days per case). It can not only control the influence of time trend (such as seasonality and the "day of the week" effect) and meteorological factor, etc., at the same time, the bias caused by individual-level confounders (such as age, intelligence, heredity, etc.) between cases and controls can be avoided, thus the unbiased estimation of parameters can be obtained.

Considering the possible nonlinear relationship between daily mean temperature and RTIs (13, 16, 17), we used conditional Poisson regression with Distributed Lag Non-linear Models (DLNM) to estimate the exposure-response and exposure-lag associations between temperature and RTIs deaths (18–20). The results were reported as odds ratios (OR) and 95% confidence interval (CI). A lag period up to 14 days was used to adequately respond to exposure effects and lag effects. Based on generalized cross-validation (21), we fitted the exposure-response and exposure-lag associations using natural cubic spline with 2 degrees of freedom (df). To avoid potential meteorological and pollutant confounders in the association between ambient temperature and RTIs (22), a natural cubic spline with 3 df was used to control for the effect of relative humidity, and that with 2 df was used to control for pollutants. All data were analyzed using R software (Version 4.2.2), where "gam" and "dlmn" software packages were used to fit the conditional Poisson regression models and exposure-lag-response curves, respectively. The reference temperature, namely minimum-mortality temperature, was determined as the temperature corresponding to the lowest death risk in the exposure-response curve. Extremely low and high temperatures were defined as the 1th and 99th percentile of temperature, respectively.

2.3 Sensitivity analyses

We carried out a series of methods to test the robustness of the results. First, the number of lag days in this study was changed from 0–14 days to 0–7 days and 0–21 days so as to test whether a 14-day lagging was sufficient for exposure-response and exposure-lag effects. Second, The df of meteorological confounders were varied from 2 to 4 to check the robustness of the fitted model. Last, the 2.5th or 10th percentile of temperature, defined as extreme low temperature, and the 97.5th or 90th percentile of temperature, defined as extreme high temperature, respectively, were used to fit the temperature-road traffic death lag response curve to check for changes in the model results.

3 Result

3.1 Descriptive analysis

Table 1 shows the descriptive statistics for daily deaths related to RTIs in Jinan city. A total of 9,794 road traffic injury deaths were collected during 2011–2020 and the daily mean deaths were 3. The percentage of deaths was much higher in male (73.01%), those aged 35–64 years (57.31%), and pedestrians (45.9%) than in female (26.99%), those with other age groups, and those by other transport mode, respectively.

Table 2 presents the results of descriptive statistics about the daily levels of meteorological indicators and air pollutants. The mean daily mean temperature was 15.13°C, and the daily mean minimum and maximum temperatures were − 12.4°C and 33.8°C, respectively.

Spearman correlation tests were used to identify the correlation between meteorological and air pollution indicators, and the correlation coefficients r were showed in Table 3. $R \geq 0.6$ was regarded as strong correlation. The daily mean temperature showed a strong correlation with the daily maximum 8-h average ozone and daily atmospheric pressure.

3.2 Relationship between ambient temperature and road traffic injuries

As shown in Figure 1, the cumulative exposure-response relationship between daily mean temperature and RTIs deaths presented an inverted U-shaped curve. The minimum-mortality temperature (MMT) was −12.4°C when the death risk of RTIs was the lowest. With increasing daily mean temperature, the death risk of RTIs increased gradually, reached the highest at 17.6°C (OR = 2.09, 95% CI: 1.66, 2.63), and then decreased. We found an obviously nonlinear relationship between daily mean temperature and RTIs fatalities from the exposure-lag-response 3D and contour plots. High and low temperatures were found to have "protective" effects on RTIs deaths on the current day. However, with the increase of lag days, both high and low temperature could increase the death risk of RTIs. The death risk reached highest when the lag day was 14th day, and was obviously higher in high temperature than that in low temperature.

The exposure-lag-response curves were plotted, when the 1st (−6°C) and 99th (32°C) percentile of daily mean temperatures as regarded to the temperature thresholds for extremely low and high temperatures, respectively (Figure 2). The results showed that the effects of extreme low temperature and high temperature on RTIs deaths showed a similar trend with the change of lag time and the death risks of extreme temperature had obviously lag effects on RTIs fatalities. Both extreme high temperature and low temperature were not associated with RTIs deaths on the current day and up to 10 lag days, while the association appeared until 11th lag day, and then cumulatively reached highest over lag days of 14. The effect of extreme high temperature on RTIs fatalities was obviously higher than that of extreme low temperature, no matter single-day effect or cumulative effect.

The results have shown that exposure to low temperature has a significant lag effect on the risk of death from different types of RTIs. When exposed to low temperature, the cumulative effect of road injury mortality risk for pedestrians and motorcycle riders was significant on Lag11 and Lag13, respectively, and the maximum single-day effect was appeared on Lag14, with OR values of 1.227 (95% CI: 1102, 1.367) and 1.453 (95% CI: 1.214, 1.74). The risk of death for cyclists was occurred on Lag3 and reached the maximum on Lag6 (OR = 1.355, 95% CI: 1.054, 1.742), disappeared after 6 days, then reappeared on Lag12 and reached the maximum on Lag14. The mortality risk for passengers of motor vehicles was statistically significant on Lag14 (OR = 1.202, 95% CI: 1.005, 1.438). Exposure to high temperatures also has a lag effect on the risk of RTIs death among residents. The cumulative effect of high temperature on the risk of

TABLE 1 The descriptive statistics for daily deaths on RTIs among residents with different characteristics in Jinan city, 2011–2020.

		Mean	Minimum	25%	Median	75%	Maximum	Total number
Sex	Male	2	0	1	2	3	9	7,151 (73.01%)
	Female	1	0	0	1	1	6	2,643 (26.99%)
Age	0–34	0	0	0	0	1	5	1810 (18.48%)
	35–64	2	0	1	1	2	9	5,613 (57.31%)
	≥65	1	0	0	0	1	6	2,371 (24.21)
Transport mode	Walking	1	0	0	1	2	9	4,495 (45.9%)
	Bicycle	0	0	0	0	1	4	1,474 (15.05%)
	Motorcycle	0	0	0	0	1	5	1,654 (16.89%)
	Motor vehicle	0	0	0	0	1	8	1,591 (16.24%)
	Other	0	0	0	0	0	3	580 (5.92%)
Total		3	0	1	2	4	12	9,794 (100%)

TABLE 2 Descriptive statistics about daily level of meteorological and air pollution indicators in Jinan city, 2011–2020.

	Mean	Minimum	25%	Median	75%	Maximum
DMT (°C)	15.1	−12.4	5.7	16.6	24.4	33.8
RH (%)	55	14	40	55	70	100
BP (hPa)	997	975	989	997	1,004	1,022
WS (m/s)	2.4	0.2	1.7	2.2	2.9	8.4
PM2.5 (μg/m^3)	79	3	42	65	99	443
PM10 (μg/m^3)	142	5	90	126	174	693
NO2 (μg/m^3)	48	9	33	44	58	165
CO (mg/m^3)	1,200	363	811	1,046	1,408	6,555
SO2 (μg/m^3)	50	5	17	35	62	429
O3-8h (μg/m^3)	106	5	58	98	148	269

DMT, Daily mean temperature; RH, Relative humidity; BP, Barometric pressure; WS, Wind speed; PM2.5, Particulate matter with aerodynamic diameter less than 2.5 μm; PM10, Particulate matter with aerodynamic diameter less than 10 μm; NO2, Nitrogen dioxide; CO, Carbon monoxide; SO2, Sulfur dioxide; O3-8h, Ozone for 8 h.

TABLE 3 Correlation coefficients between meteorological and air pollution indicators in Jinan city, 2011–2020.

	DMT	PM2.5	PM10	NO2	SO2	CO	O3-8h	RH	BP	WS
DMT	1	−0.268	−0.240	−0.498	−0.393	−0.404	0.814	0.182	−0.888	0.089
PM2.5		1	0.863	0.648	0.679	0.807	−0.265	0.116	0.212	−0.154
PM10			1	0.674	0.661	0.694	−0.181	−0.149	0.206	−0.036
NO2				1	0.649	0.771	−0.485	−0.078	0.528	−0.347
SO2					1	0.699	−0.364	−0.209	0.342	0.055
CO						1	−0.448	0.188	0.346	−0.317
O3-8h							1	−0.112	−0.694	0.165
RH								1	−0.245	−0.342
BP									1	−0.140
WS										1

All the correlation coefficients were statistically significant with $p < 0.001$.
DMT, Daily mean temperature; RH, Relative humidity; BP, Barometric pressure; WS, Wind speed; PM2.5, Particulate matter with aerodynamic diameter less than 2.5 μm; PM10, Particulate matter with aerodynamic diameter less than 10 μm; NO2, Nitrogen dioxide; CO, Carbon monoxide; SO2, Sulfur dioxide; O3-8h, Ozone for 8 h.

death for pedestrians, cyclists, and motor vehicle passengers all reached the maximum on Lag14, with OR values of 1.638 (95% CI: 1.281, 2.094), 2.603 (95% CI: 1.695, 3.997), and 1.603 (95% CI: 1.066, 2.411), respectively. The mortality risk for motorcycle riders increased significantly on Lag6, reaching a maximum OR of 3.106 (1.646, 5.861) on Lag12 (Figure 3; Table 4).

3.3 Results of sensitivity analysis

The results of the sensitivity analysis were robust, as described in Supplementary material. The exposure-response curves and relative risks were similar when changing the maximum lag days from 14 to 7 and 21, respectively (Supplementary Figure S1). The effects of confounders with different df on RTIs remained unchanged when exposed to extreme low and high temperature, respectively, over lag day 0–14 (Supplementary Table S1). The associations between extreme low and high temperature and RTIs fatalities were stable over lag days 0–14 using different threshold values of extreme temperature (Supplementary Figure S2).

4 Discussion

In this study, we examined the association between ambient temperature, particularly extreme temperatures, and road injury deaths in Jinan city. The results confirmed that extreme high and low temperatures were positively associated with the risk of RTIs fatalities with a significant lag effect. Meanwhile, the effect of extreme high temperature on RTIs fatalities was significantly higher than that of extreme low temperatures. In addition, the effects of extreme high temperature on RTIs fatalities were obviously stronger among cyclist and motorcyclist than those among pedestrians and motorized vehicle (except motorcycles) personnel.

Our study provided evidence for the association between extreme temperatures and road accident deaths in Jinan city, Shandong Province. The present study found an inverted U-shaped curve in the relationship between daily mean temperature and RTIs fatalities, with the highest risk occurring at moderate temperatures (17.6°C). Similar to our findings, a study in Beijing (China) found that accidental injuries and deaths occurred more frequently on warm days, with the highest likelihood of emergency treatment for accidental injuries occurring at 26°C instead of extreme temperatures (23). An Italian study also found that the peak of workplace accidents occurred at hot but not extreme temperatures (24). The increased risk of RTIs in warm temperatures may be related to the increased frequency with which people go out or traveling (25). With the rapid development of road transportation and urban service industry, increased traffic jams and poor self-protection of non-motor vehicles make road traffic injuries more likely to occur (26).

Previous study have shown that high and low temperatures were obviously correlated with RTIs, and the effect of extreme hot weather was significantly higher than that of extreme cold weather (27), which was consistent with the results of this paper on the impact of high temperatures. Wu et al. (16) showed that there was a significant positive correlation between fatal traffic accidents and heat waves in the United States. Bergel-Hayat et al. (28) believed that small temperature changes will have a significant impact on the risk of traffic accidents. For every 1°C increase in monthly mean temperature, the number of collisions increases by 1–2%. These studies all suggested an association between ambient temperature and RTIs. In a study of meta-analysis using daily mean temperatures, higher temperatures was found to increased the risk of traffic injuries by 2.4% (RR = 1.024, 95% CI 0.939, 1.116) (29). Basagaña et al. (30) found that for every 1°C increase in maximum temperature, there was a significant increase in the estimated risk (OR = 1.1, 95% CI: 0.1, 2.1) of crashes due to the driver performance factor. The susceptibility to crashes exposing to high-temperature was related to multiple mechanisms, such as human behavior, vehicle conditions, and environmental factors (31). Higher temperatures may lead to reduced vigilance and inattention which directly resulted in the poor driving behaviors (32–35). At the same time, high temperatures may increase the likelihood of dangerous behaviors such as running red lights and driving in the wrong lane (36). In addition, changes in ambient temperatures may also result in the occurrence of disease, which increased the risk of traffic accidents for road users when they traveled (37). These reasons ultimately lead to an increase in the risk of road collisions in high-temperature environments.

Our study found that, pedestrians, cyclists and motorcyclists are at greater risk of injury than motorized vehicle (except motorcycles) personnel, regardless of exposure to low temperature or high temperature, which is in line with the results of the World Health Organization report on vulnerable groups of road traffic injuries. In our study, pedestrians, bicyclists and motorcyclists were the vulnerable groups of road traffic injuries, accounting for more than half of all RTIs deaths (77.84%). It may be related to their occupations and the modes of transport they used. For example, with the rapid

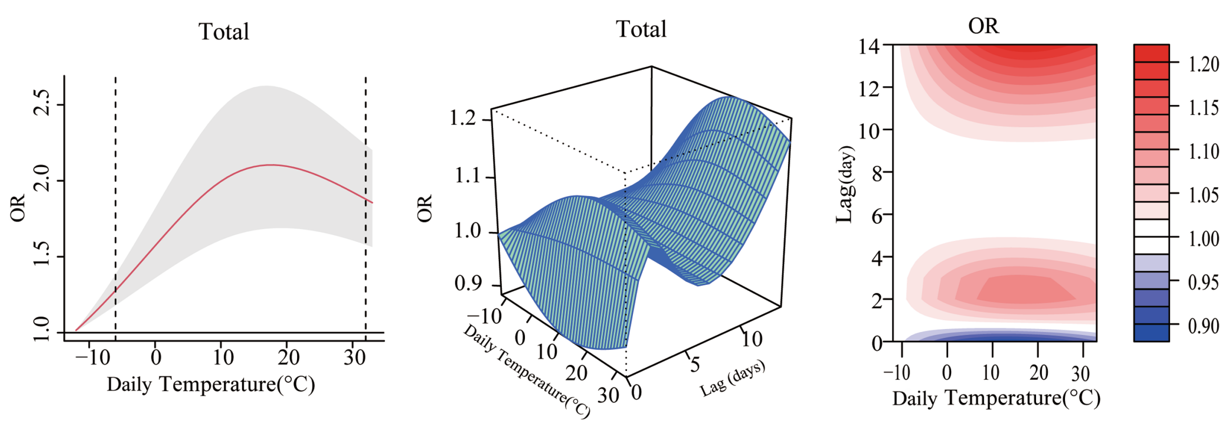

FIGURE 1
Exposure-response relationship between total RTIs deaths and daily mean temperature in Jinan city, 2011–2020. **(A)** Exposure-response curve. **(B)** 3D effect plot. **(C)** Contour plot.

TABLE 4 Cumulative effect estimates of extreme low temperature and high temperature related to RTIs fatalities over lag days 0–14 by different mode of transportation.

	Walking OR (95% CI)	Bicycle OR (95% CI)	Motorcycle OR (95% CI)	Motor vehicle OR (95% CI)
Extreme low temperature (−6°C)				
Lag01	0.924 (0.800, 1.066)	1.097 (0.855, 1.408)	0.981 (0.774, 1.243)	0.935 (0.736, 1.188)
Lag02	0.957 (0.834, 1.097)	1.193 (0.941, 1.511)	1.047 (0.835, 1.313)	0.917 (0.730, 1.152)
Lag03	0.993 (0.864, 1.140)	**1.277 (1.005, 1.623)**	1.116 (0.886, 1.405)	0.901 (0.715, 1.135)
Lag04	1.016 (0.879, 1.174)	**1.331 (1.037, 1.709)**	1.166 (0.916, 1.485)	0.886 (0.696, 1.128)
Lag05	1.025 (0.885, 1.186)	**1.354 (1.052, 1.744)**	1.197 (0.937, 1.529)	0.873 (0.684, 1.114)
Lag06	1.026 (0.887, 1.187)	**1.355 (1.054, 1.742)**	1.215 (0.953, 1.549)	0.865 (0.679, 1.102)
Lag07	1.024 (0.885, 1.185)	**1.341 (1.043, 1.725)**	1.224 (0.959, 1.562)	0.863 (0.677, 1.101)
Lag08	1.024 (0.882, 1.189)	**1.321 (1.021, 1.710)**	1.231 (0.960, 1.579)	0.870 (0.678, 1.116)
Lag09	1.028 (0.881, 1.199)	1.301 (0.998, 1.696)	1.240 (0.960, 1.602)	0.887 (0.686, 1.146)
Lag010	1.040 (0.891, 1.214)	1.286 (0.985, 1.679)	1.256 (0.971, 1.624)	0.915 (0.707, 1.185)
Lag011	1.063 (0.917, 1.234)	1.28 0(0.990, 1.653)	**1.282 (1.002, 1.640)**	0.958 (0.748, 1.227)
Lag012	1.101 (0.963, 1.258)	**1.285 (1.02, 1.619)**	**1.322 (1.059, 1.650)**	1.018 (0.815, 1.271)
Lag013	**1.154 (1.029, 1.294)**	**1.304 (1.07, 1.591)**	**1.378 (1.139, 1.666)**	1.098 (0.908, 1.327)
Lag014	**1.227 (1.102, 1.367)**	**1.34 (1.111, 1.615)**	**1.453 (1.214, 1.740)**	**1.202 (1.005, 1.438)**
Extreme high temperature (33°C)				
Lag01	0.833 (0.493, 1.408)	1.079 (0.442, 2.633)	1.397 (0.595, 3.283)	0.838 (0.348, 2.020)
Lag02	0.939 (0.574, 1.535)	1.204 (0.522, 2.773)	1.552 (0.696, 3.463)	0.804 (0.353, 1.833)
Lag03	1.049 (0.65, 1.691)	1.319 (0.586, 2.968)	1.710 (0.780, 3.748)	0.773 (0.347, 1.721)
Lag04	1.105 (0.68, 1.795)	1.393 (0.611, 3.176)	1.888 (0.849, 4.203)	0.739 (0.327, 1.667)
Lag05	1.105 (0.681, 1.795)	1.427 (0.626, 3.253)	2.087 (0.938, 4.645)	0.707 (0.314, 1.592)
Lag06	1.073 (0.665, 1.729)	1.439 (0.639, 3.241)	**2.298 (1.045, 5.054)**	0.683 (0.307, 1.519)
Lag07	1.029 (0.640, 1.654)	1.445 (0.644, 3.240)	**2.510 (1.148, 5.492)**	0.673 (0.304, 1.488)
Lag08	0.991 (0.613, 1.603)	1.459 (0.644, 3.305)	**2.711 (1.229, 5.981)**	0.679 (0.304, 1.516)
Lag09	0.973 (0.598, 1.585)	1.495 (0.652, 3.431)	**2.884 (1.293, 6.432)**	0.707 (0.313, 1.598)
Lag010	0.985 (0.608, 1.596)	1.567 (0.689, 3.565)	**3.016 (1.365, 6.662)**	0.764 (0.342, 1.710)
Lag011	1.038 (0.662, 1.629)	1.689 (0.783, 3.647)	**3.093 (1.474, 6.488)**	0.860 (0.406, 1.824)
Lag012	1.147 (0.780, 1.685)	1.882 (0.972, 3.645)	**3.106 (1.646, 5.861)**	1.011 (0.533, 1.919)
Lag013	1.334 (0.993, 1.791)	**2.173 (1.304, 3.620)**	**3.051 (1.87, 4.978)**	1.244 (0.764, 2.026)
Lag014	**1.638 (1.281, 2.094)**	**2.603 (1.695, 3.997)**	**2.930 (1.939.4.429)**	**1.603 (1.066, 2.411)**

The bold values means statistically significant results.

development of takeaway, express delivery industry, bike-sharing and other industries, the use of bicycles and motorcycles has been increasing. Road crashes and injuries are more likely to occur resulted from increased traffic jams and the poor self-protection performance of road users in above travel modes (38). In addition, ambient temperature has a greater effect on two-wheeler (bicycle and motorcycle) users than four-wheeler vehicle users due to their direct exposure to the external environment. A study in Belgium has shown an increase in the frequency of road traffic accidents among two-wheeled vehicle (bicycle and motorcycle) users in warm weather (39). Daanen et al. (40) noted that in extremely cold environments, the driving status of motorcyclists become worse due to the cold, thus increasing the risk of traffic accidents. Similarly, studies have shown that motorcyclists will distract their attention because of coping with thermal stress under high temperature exposure, and then indirectly reduce their ability to cope with various traffic conditions (41). Moreover, the temperature may affect resident's choice of travel mode so as to make more appropriate travel decisions. Gan found that the effect of temperature on the number of bicycle trips was significant. Compared with spring, the number of bicycle trips increased in autumn, but decreased in summer and winter (42). Hu thought that residents in cold areas could reduce the use of bicycles and electric vehicles, and more use of motor vehicles to travel (43).

There are inconsistent evidences regarding to the lag effects of ambient temperature on RTIs. Some studies suggested that the risk of traffic injuries was significantly associated with high and low temperatures, with significant lag effects, which was consistent with the findings in our study (17, 27). A study in Dalian, China, using distributed lag nonlinear model found that both high (RR = 1.198, 95% CI: 1.017–1.411) and low temperatures (RR = 1.017, 95% CI:

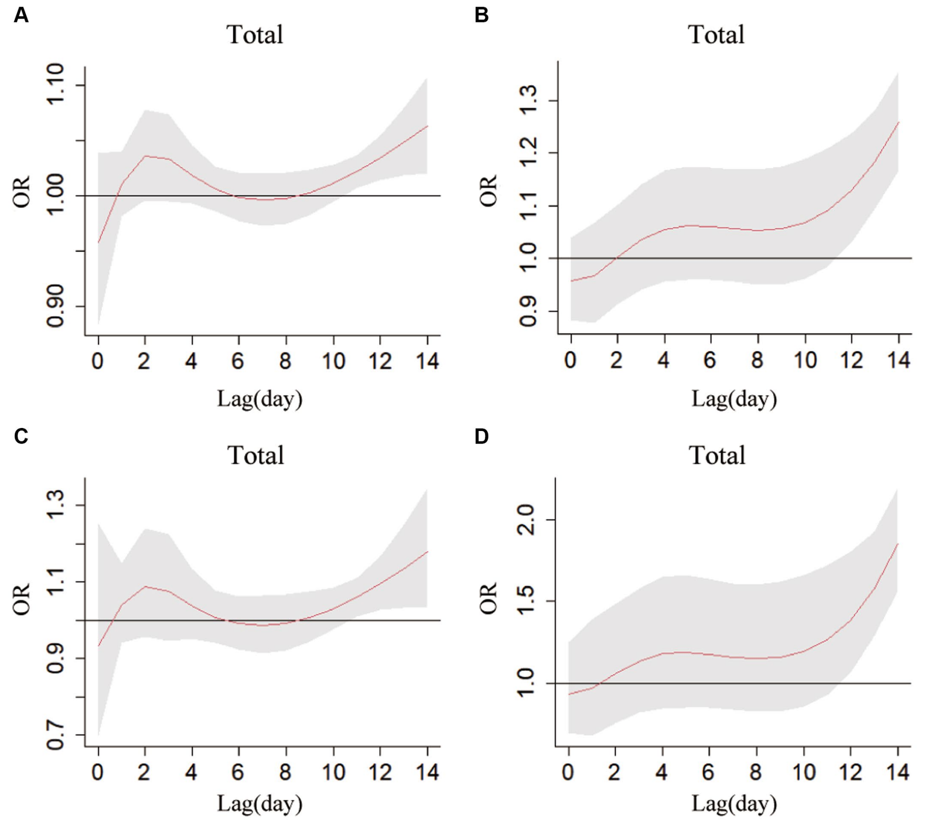

FIGURE 2
The lagged-response curves for association between Daily Mean Temperature and RTIs fatalities in Jinan City, 2011–2020. **(A)** Single-day lagged low temperature. **(B)** Cumulative lagged low temperature. **(C)** Single-day lagged high-temperature. **(D)** Cumulative lagged high-temperature.

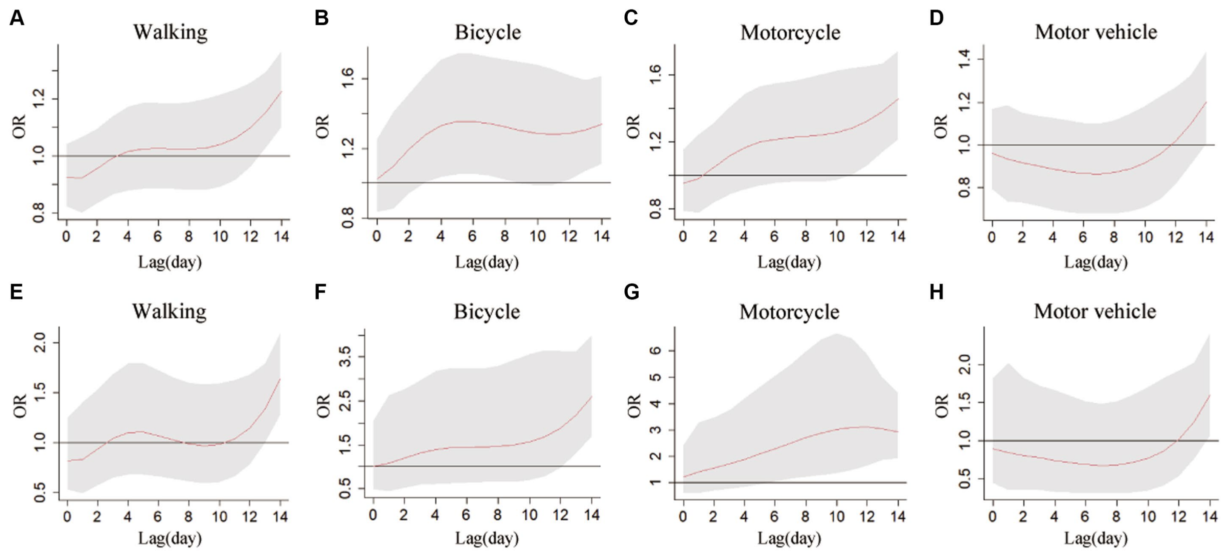

FIGURE 3
Cumulative Effects of extreme low-temperature and high-temperature on RTIs fatalities over lag days 0–14 in different subtypes of transport mode, in Jinan city, 2011–2020. **(A)** Cumulative effect at extreme low temperature (−6°C) on pedestrian injuries in transport accidents. **(B)** Cumulative effect at extreme low temperature (−6°C) on cyclist injuries in transport accidents. **(C)** Cumulative effect at extreme low temperature (−6°C) on motorcyclist injuries. **(D)** Cumulative effect at extreme low temperature (−6°C) on motor vehicle (except motorcycles) occupant injuries in transport accidents. **(E)** Cumulative effect at extreme high temperature (32°C) on pedestrian injuries in transport accidents. **(F)** Cumulative effect at extreme high temperature (32°C) in cyclist injuries in transport accidents. **(G)** Cumulative effect at extreme high temperature (32°C) on motorcyclist injuries in transport accidents. **(H)** Cumulative effect at extreme high temperature (32°C) on motor vehicle (except motorcycles) occupant injuries in transport accidents.

1.001–1.035) increased the risk of RTIs, with a cumulative lagged effect that beyond day 7 (44). This indicates that the effects of ambient temperature on human health may continue to affect road users for several days, resulting in a lagged effect of ambient temperature on traffic injuries. The mechanism of the lagged response between temperature and road traffic accidents is not completely clear. Some scholars believed high temperatures can result in prolonged heat stress and sleep disturbances to increase the risk of daytime fatigue driving, and ultimately lead to road traffic accidents (45). Ma et al. (23) pointed out that extreme temperature leaded to the changes in the body 's immune system and body temperature system, and the intensity of its regulation indirectly affected the state of road users over a period of time. In addition, high temperatures may lead to 5-hydroxytryptamine dysfunction (46) and brain damage (47), which will have a negative impact on people's decision-making ability in the long term and increase the risk of road traffic accidents. However, some other studies have shown that there is no or less lag in the effect of temperature on RTIs. Lee et al. showed that the effect of high temperature on RTIs reached the maximum on the same day, while the effect of low temperature was significant with 2-days lag (14). The inconsistence in research findings may be due to differences in the definition of injury types, subgroups of the target population, and meteorological and geographical conditions. Focusing on the lag effect will help us better understand the impacts of environmental temperature, especially extreme temperature, on RTIs, so as to effectively control and prevent temperature-related traffic injuries.

There are some limitations in this study. First, there may be some error in the measurements of temperature at the time of death from road accidents because the measurements of daily temperature were collected from fixed monitoring sites in Jinan city, and therefore may not have been the actual temperature of the location where the deceased patient was exposed. Second, we did not distinguish ally the road traffic injuries related to occupations in our study. Given that most previous studies on unintentional injuries have focused on occupational injuries, direct comparisons may have had some impact on the results. Third, we did not consider the impact on lag effects of high and low temperatures caused by the possible intervention of early warning systems for heat or cold waves. In addition, the impact of rainfall on traffic accidents is evident, however, due to the unavailability of data, this study did not consider the confounding effects of rainfall on temperature. And last, The results may be given rise to some bias in subgroup analysis due to the small sample sizes for each subgroup of road traffic injuries. In the future, more large-scale and meticulous studies are needed to determine the correlation between temperature and road traffic injuries.

5 Conclusion

In summary, extreme low and high temperature were positively associated with the increased risk of road traffic fatalities in Jinan city, with a significant lag effect, and the effect of extreme high temperature on RTIs fatalities was significantly higher than that of extreme low temperatures. The risk association and days of lag effects were different between extreme temperatures and RTIs fatalities in subtgroups of transportation mode. This study helps to develop public health policies and interventions to reduce the negative impacts of climate change on road traffic injuries in extreme weather conditions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

YL: Writing – original draft, Writing – review & editing, Data curation, Formal analysis, Methodology, Visualization, Software. JR: Writing – review & editing, Project administration. WZ: Writing – review & editing, Supervision. JD: Writing – review & editing, Project administration. ZL: Writing – review & editing, Data curation, Formal analysis. ZZ: Writing – review & editing, Data curation. XG: Writing – review & editing, Conceptualization, Data curation, Funding acquisition, Project administration, Validation. JC: Writing – review & editing, Conceptualization, Data curation, Funding acquisition, Project administration, Validation. AX: Writing – review & editing, Conceptualization, Funding acquisition, Project administration, Validation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1324191/full#supplementary-material

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Road traffic accidents and the contributing factors among drivers of public transportation in Mizan Aman town, Ethiopia: a Community-Based Cross-Sectional Study

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Background: Traffic accidents on the road is an accident is a terrible accident that causes death, injury, and property damage. However, limited studies were addressed to investigate the prevalence of traffic accidents on the road and the contributing factors among drivers that help in developing strategies to cop-up the incidence within the research domain in Ethiopia, particularly in the study area.

Objective: This study aimed to assess the prevalence of road traffic accidents and the contributing factors among drivers of public transportation in Mizan Aman town, Ethiopia.

Methods: A community-based cross-sectional survey was employed among 376 drivers of public transportation. Every research subject was selected by using a simple random sampling technique. Semi-structured and open-ended questionnaires which comprised demographic characteristics, risky personal behaviors and lifestyles, driver's factors, vehicle condition, and environmental conditions were used to gather data. And then after, data was collected through interviewer-administered using KoBo Collect tools. Completed data were edited and cleaned in the Kobo collect toolbox and then exported for additional analysis to a statistical tool for social science statistics version 26. The descriptive statistics were displayed as figures, tables, and texts. Binary logistic regression was analyzed to identify the contributing factors. Statistically significant was decided with a p-value of ≤ 0.05.

Results: The results showed that the prevalence of road traffic accidents among drivers of public transportation in Mizan Aman town was 17%. The study identified factors influencing traffic accidents on the roads including marital status (being single), employee condition (permanent), monthly income (1001-2500 Ethiopia Birr), alcohol use, vehicle maintenance (not), road type (non-asphalt), and weather conditions (being windy).

Conclusion: The overall prevalence of road traffic accidents among drivers of public transportation in Mizan Aman town was relatively low. Despite this, sociodemographic characteristics, driver factors, vehicle conditions, and environmental conditions [road type and weather conditions] were the predicting factors of traffic accidents in town. Therefore, reduction strategies should be the highest priority duty for concerned bodies like Mizan Aman town road and transport office, Bench Sheko zone transport and logistics office, and Southwest Ethiopia People Regional State (SWEPRS) transport bureau in the study area.

KEYWORDS

road traffic accidents, contributing factors, drivers, Mizan Aman town, Ethiopia

1 Introduction

A road traffic accident (RTA) is an incident that involves at least one moving vehicle during transportation and leaves one or more people injured or dead (1, 2). The World Health Organization (WHO) defined RTA as any injury, whether fatal or non-fatal, sustained in an accident on a public road (3). There are several scenarios in which a collision may occur (4, 5). It involves at least one moving vehicle or pedestrian, and the crash occurs on a path or street that is accessible to public transportation (3). It could result in the deaths or serious injuries of one or more people, and at least one moving car is involved (6). In most times, vulnerable road users include cyclists, motorcyclists, and pedestrians (7). If adequate measures are not taken to reduce road traffic injuries, they will become a serious public health and development concern and can damage a person's quality of life (8). In addition to having an impact on an individual's health, traffic accidents can also place an economic burden on households as they struggle to pay for long-term effects such as medical care, rehabilitation, and the loss of the family's primary provider (4). Traffic accidents can also put a tremendous amount of pressure on the national healthcare systems, which already have a tragically low amount of funding (9). Furthermore, RTAs cost most nations 3% of their gross domestic product (7).

Traffic accidents continue to be a major global health and development issue, particularly in developing nations, including Ethiopia, since the road is the major route for transportation. These accidents kill close to 1.35 million people annually, ranking as the 8th most common cause of death overall, and is the leading cause of death for youth and young adults aged 5–29 years. Ethiopia has three times higher death rates due to RTAs when compared to other low-income nations (26.7 in South East Asia and 26.6 in Africa per 100,000 people) (10–12). Worldwide, approximately 90% of road deaths occur in middle-class and lower-income nations (7, 9, 13). Despite being the least motorized of the six major world regions, Africa has the highest rates of RTAs with fatality rates of 24.1/100,000 compared to the global average of 18/100,000 fatalities (14). Ethiopia reports a significant incidence of RTAs, despite having a low road network density and low automobile ownership (15). In addition, the WHO revealed a loss of approximately 400 to 500*1000,000 Ethiopian Birr (ETB) and nearly 2,000 deaths involving pedestrians (48%), passengers (45%), and drivers (7%) due to RTAs in Ethiopia (16). Furthermore, according to an Ethiopian demographic and health survey, RTAs were the second-most common accident and injury (22.8%) after unintentional falls (15).

Pieces of evidence from studies have revealed that drivers of public transportation are vulnerable to professional working groups. For instance, stressful working conditions have been associated with health and lifestyle-related outcomes among professional drivers (17). In turn, work stress in professional drivers is positively associated with traffic collisions (18). Consequently, professional drivers have suffered accidents due to work stress, and their safety has also been compromised (19). Moreover, work stress is also related to addictive behaviors such as regular alcohol consumption and smoking, which are the aggravating factors for traffic collisions among drivers (20). As a result, drivers are at more risk of suffering from muscular–skeletal, cardiovascular, gastrointestinal, and psychological problems due to specific working conditions (21).

Various prevalence of RTAs have been reported across the globe. According to a systematic research by Khatib et al., the frequency of traffic accidents resulting in injury or death varied between 11.1 and 42.6% for individuals in the 20–30 age group and between 4.6 and 97.2% for male subjects (22). Furthermore, a study conducted in Nigeria (38.3 and 35.3%) (23, 24), Vietnam (20%) (25), and Saudi Arabia (63%) (26) revealed the prevalence of RTA. Furthermore, in the national context, different studies have revealed repeated occurrences of RTA with different magnitudes. For instance, the prevalence of RTA is as follows: Hawassa (55.1%) (27); East Wollega zone (33%) (28); University of Gondar referral hospital (33.6%) (1); residents of Ethiopia (3%) (8); Amhara region (51%) (29); Wolaita zone (62.5%) (30); Bahirdar city (16.3%) (31); Chuko Town (23.5%) (32); Mekelle Town (26.4%) (33); Sidama region (55.1%) (27); Jigjiga Town (32.8%) (34); Addis Ababa (56.9%) (35); and Dilla town (39.9%) (36). Moreover, RTA causalities included drivers (21.9%), passengers (35.0%), and vulnerable road users (36.0%), of which 21.0, 12.1, and 2.9% were motorcyclists, pedestrians, and cyclists, respectively (15).

Pieces of evidence from the scientific community suggest that different contributing factors play an important role in the occurrence of RTA, which include sociodemographic characteristics and driver factors such as sex (23), age (1, 24, 27, 28), educational status (8, 24), prior punishment (28, 36), place of residence (15, 28), income status (8, 15), use of alcohol and khat (8, 24, 37, 38), personality of the

Abbreviations: AOR, Adjusted odd ratio; CI, Confidence interval; COR, Crude odd ratio; ETB, Ethiopian Birr; RTA, Road traffic accident; SWEPRS, Southwest Ethiopia People Regional State; WHO, World Health Organization.

driver (28), use of safety seatbelts (39), and traffic infringement (40). Stress-related working conditions (work stress, social support, and effort or reward imbalance) are relevant predictors of risky driving (41). Furthermore, risky behaviors or lifestyles of drivers were associated with driving experience, positive driving behaviors, social desirability, and perceived stress (42). Another factor that predicts traffic accidents is environmental conditions, including adverse weather conditions (37), road types (27), light conditions (43), and time of accidents (37). Other significant factors are vehicle conditions like types of vehicles (44), maintenance conditions (36), and mechanical problems.

Despite RTA being a terrible incident that causes death, injury, and property damage; there is limited information available about traffic accidents on the road and contributing factors among drivers of public transportation in developing countries, including Ethiopia. The primary sources for estimating the extent of road traffic injury in low-income countries are hospital registry data and police records; however, underreporting affects both sources (45). Previous studies addressed the prevalence of RTA among victims through a retrospective study design, which could not give significant information to decision-makers due to the design itself (45). In addition, pieces of evidence from quantitative studies revealed the prevalence of RTA (23, 28, 31, 33–36, 40, 46); in Ethiopia, particularly in the study area, there is a paucity of information regarding the contributing factors among drivers of public transportation to the occurrence of traffic accidents on the roads and public health concerns. Moreover, little was known about the prevalence of traffic accidents on the roads and the contributing factors among drivers of public transportation with a community-based cross-sectional study design. Identifying black spots and comprehending the factors contributing to traffic accidents on the roads are essential for developing remedies for public health issues (27, 47). Therefore, obtaining the magnitude and associated factors among drivers who are directly involved in the task would reveal their contribution to the occurrence of traffic accidents on the road. The study aimed to fill the gaps shown in the above pieces of literature.

The current research added a unique contribution to existing literature via a proposed approach that generated realistic findings because the study was well equipped to assess the prevalence of traffic accidents on the roads and the contributing factors among drivers of public transportation in Mizan Aman town, Southwest Ethiopia People Regional State (SWEPRS). In this regard, the rationale of the study is as follows: First, findings from the study might be used as baseline information to design effective strategies to alleviate the problems. In addition, traffic accidents are a major but mistreated public health challenge that requires determined efforts for effective and sustainable prevention; second, information from the study points out the issue regarding traffic accidents on the roads in the study area, which, in turn, primarily invites those interested volunteers to address or tackle the traffic-related problems. Moreover, information regarding the cause of traffic accidents and precautions that need to be taken by drivers was informed, promoted, and disseminated on behalf of road traffic officers; and the third and last rationale of the study was that the result obtained from the study would provide full information for readers, researchers, and policymakers to design an effective interventional strategy in the area.

1.1 Objectives of the study

- To determine the magnitude of traffic accidents on the road among drivers of public transportation in Mizan Aman town.
- To identify the contributing factors of traffic accidents on the road among drivers.
- To offer specific recommendations to tackle the problems based on the findings obtained from the study for responsible bodies at different levels, including Mizan Aman town, Bench Sheko zone, and Southwest Ethiopia People Region.

2 Methods and supplies

2.1 Study location, plan, and time frame

In Mizan Aman town, a community-based cross-sectional study was carried out between March and April 2023. Mizan Aman town is the capital of the Bench Sheko zone, SWEPRS. It is situated 564 kilometers away from Addis Ababa, the capital of Ethiopia. There are four Kebeles in Ethiopia, which are the smallest units of government. The total population of Mizan Aman town is 96,353, with 47,694 men and 48,659 women based on estimates from the 2007 Central Statistics Agency. Mizan Aman town is linked by an extensive road network to other cities, divisions, and regions such as Oromia and Gambela. Different interregional and regional bus transportation providers served the community of Mizan Aman town. In reality, there were 1,063 cars or vehicles registered in different unions established by the Mizan Aman town administration that provided public transportation service. Those unions include Bajaj unions ($N = 754$) in which Zenbaba ($N = 274$), Mango ($N = 313$), Aman Boeing ($N = 167$), and Taxi union (Irgib) ($N = 55$), and all vehicles were ranked from one to three based on the level of unions [Gacheb 1st rank ($N = 53$), Zihon 2nd rank ($N = 84$), and Mizan 3rd rank ($N = 117$)] (48).

2.2 Source and study population

All public transportation drivers found in the Mizan Aman town administration were the source population. The selected public transportation drivers were registered in the office of the Mizan-Aman town administration road transport and logistics and were considered the study population.

2.3 Determining the sample size and sampling methods

Using the standard formula for a single population proportion, the sample size was calculated. By taking into account 33.4% of traffic accidents on the roads due to bad road conditions in Chuko Town, Ethiopia (32), at a 95% confidence interval (CI).

$$n = (Z\alpha / 2)^2 \left(\frac{P(1-P)}{d^2} \right)$$

$$n = \frac{(1.96)^2 * 0.334(1-0.334)}{(0.05)^2} = 342,$$

where n = size of the sample; $Z\alpha/2 = 1.96$ standard scores, with a 95% confidence interval; d = level margin of error to be tolerated (5%); and p = proportion of RTAs. The sample size would increase to $n = 376$ when a 10% non-response rate was taken into account.

All vehicle unions found in the Mizan Aman town were a part of the study. Information about public transport drivers and vehicles found in town was obtained from the Mizan Aman town road transport and logistics office. A total sample size was allocated to each vehicle union with their respective number of drivers being proportionate to their population size. The lists of public transport drivers in the Mizan Aman town road and transport office were the sampling frame. The entire sample size was distributed based on the real number of cars registered in the unions, namely, Bajaj unions (Mango, Zenbaba, and Aman Boeing) and Taxi union (Irgib), and all vehicles were ranked from first to third based on the level of unions (Gacheb 1st rank, Zihon 2nd rank, and Mizan 3rd rank). Then, every driver was assigned or coded with an identification number called number plate, and we entered each identification number into a database from 1 to 1,063. A random number generator was used to select 376 drivers of public transportation. Finally, a basic random selection method was used to choose each research subject. To control sampling bias in the study, we carefully defined the target population (all public transportation drivers who are serving the community in Mizan Aman town) and the sampling frame (list of drivers from the different vehicle unions from which the study subject would be drawn). In addition, the researchers made the survey accessible and short. Finally, they monitored those non-responders.

2.4 Inclusion and exclusion criteria

The drivers who met the following criteria were included in this study: (a) they had to be at least 18 years old; (b) they had to have been driving professionally for a minimum of a year; and (c) they had to be registered with the town's transport and logistics office to serve the public and community through transportation.

2.5 Study variables

2.5.1 Dependent variable

The dependent variable was traffic accidents on the roads.

2.5.2 Independent variables

Demographic characteristics [sex, age, level of education, marital status, monthly income, family size, employee condition, level of driving, experience of driving, and owner of the vehicle]; risky personal behaviors [use of alcohol, khat, and cigarettes, prior punishment by traffic police, and habit of checking vehicles]; driver factors [type of vehicle he/she drives, working hours per day, information about traffic safety (media, training, friends, and traffic police), traffic-related safety training, and use of a safety belt]; vehicle conditions [types of vehicles, service of a vehicle, maintenance of vehicles, and mechanical problems]; and environmental conditions [weather conditions (rain, wind, and fog), road type (non-asphalted vs. asphalted roads), time (day, afternoon, night, and midnight), and type of collision].

2.6 Operational definitions

Accident time: This variable indicates the time during the day (24 h) when there was a high volume of traffic on the roads (49).

Driver: Individuals operating vehicles other than bicycles and two-wheeler vehicles (34).

Passengers: Any occupants of a vehicle other than the driver, including additional passengers and pillion riders.

Pedestrians: Individuals who use the sidewalk or streets to push, ride, or walk bicycles (34).

Road: Any public road system, including city streets and state, regional roadways, and local roadways (34).

Traffic accidents on the road include collisions or crashes involving several cars, pedestrians, animals, or physical or architectural barriers, as well as crashes that occur on a route or roadway that is accessible to the general public (3, 4, 34).

Users of the road: Pedestrians and all occupants of vehicles (driver, rider, and passengers) (34).

Taxi: A car that is driven by a professional driver and used to carry people and their small belongings across short distances (34).

Vehicle: Any device with three or more wheels that is used to transport people or things from one location to another (34).

Vehicle type refers to the various vehicle kinds, including pick-up, bus, minibus, truck, Isuzu, ambulance, car, and automobile (49).

Driving speed: When a driver exceeds the posted speed limit (34).

Chewing on Khat: A cab driver does so while operating a vehicle (34).

Driving while intoxicated: A cab driver who operates a vehicle after consuming alcohol within 3 h (34, 36).

Experience of the driver: This denotes the driver's experience, namely, the amount of time the driver spends operating a vehicle (49).

Vehicle service year denotes the year the owner of the vehicle receives servicing (34, 49).

Weather conditions describes the weather at the time of the accident, including whether it was cloudy or foggy, windy, sunny, or wet (49).

2.7 Tools and methods for data collection

The tools used in this study were adapted from different published articles (27–29, 32, 34, 40) and modified to make them suitable for the study context. These tools comprise a structured and open-ended questionnaire that includes the following variables: demographic characteristics [sex, age, educational and marital status, monthly income, family size, employee condition, driving license level, the experience of the driver, and possession of a car]; risky personal behaviors [alcohol use, chewing khat, cigarette smoking, prior punishment by traffic police, and the habit of checking vehicles]; driver factors [working hours per day, information sources about traffic safety (media, training, and friends vs. traffic police), traffic-related safety training, use of a safety belt]; vehicle conditions [vehicle type, service years of a vehicle, maintenance condition, and mechanical problems encountered], and environmental conditions [weather conditions like rain, windy, fog or cloudy; road type (non-asphalted vs. asphalted); time (day, afternoon, night, and midnight), and type of collision].

Three data collectors with prior experience in data collection and who were fluent in speaking and reading in Amharic and English language were hired, and collection of the survey data underwent two-day training sessions from 14 March 2023 to 15 March 2023, on the informed consent and data collection procedures for the use of KoBoCollect.

Once the data collecting tool's contents were finalized, Microsoft Excel was used to compute the electronic form utilizing the XLSForm standard. Range, checks for logic, and rationale for skipping were incorporated into the electronic form. To verify syntax, XLSForm Online v2.x was used. After the verification, the XLSForm was uploaded via the KoBo Toolbox website. With its web-based form builder, KoBo Toolbox also facilitates form design. Throughout the entire data collection period, we allocated each of the three Android devices running KoBoCollect version 2022.2.3 to a single data collector. A Google account and a KoBo account were created for each smartphone to link the data collected to a particular smartphone and data collector. Each data collector downloaded the blank form to their smartphone from the KoBo Toolbox server. The completed form data were transferred from the smartphones to the server (administer account) after each day of data collection. In conclusion, the technology provides an additional degree of protection by prohibiting smartphones from accessing the aggregated collected data from the server (50).

2.8 Data quality assurance

Professionals with linguistic backgrounds who hold a Bachelor of Arts (BA) degree in Amharic translated the tools from English into the national language, Amharic, and then backtranslated to English for accuracy. Tools were adapted from published articles (27–29, 32, 34, 40) and were pretested among 5% (19 study participants) in Bonga Town, Kaffa Zone, before data collection, and any corrections made after the pre-test or not were stated. To guarantee the accuracy, consistency, and completeness of the data collected, data collectors received orientation and rigorous oversight. The consistency and completeness of the collected data were verified. Before analysis, a first analysis was performed.

2.9 Data processing, analysis, and interpretation

The completed aggregate of collected data from the server was downloaded, edited, and cleaned. After that, it was exported to Statistical Package for the Social Sciences, version 26 to be further examined. Frequency and percentage were used to summarize descriptive data presented in texts, tables, and figures. To evaluate the contributing factors, logistic regression analysis was performed. To control the impact of confounders, multivariable logistic regression was performed for the variables in the bivariable logistic regression that had a p-value of ≤ 0.25. Hosmer and Lemeshow statistical tests were carried out to check the goodness of fit. The variables were selected using a backward stepwise regression (LR) method. The degree of the connection was assessed by computing the adjusted odds ratio (AOR) with 95% confidence intervals. For variables in the final models, p-values less than 0.05 denote statistical significance.

2.10 Ethical considerations and participant consent

The study was carried out following ethical approval granted by the institutional review committee of the Mizan Aman Health Science College under reference no: PN003/2023. Furthermore, informed consent was requested from the relevant entity verbally and in writing. The individuals' privacy and the overall information collected from them were kept completely confidential by using codes. Regarding ethical issues, the voluntary participation of key informants was respected, informed consent was obtained, and no harm to human beings was addressed. To stop the spread of COVID-19, personal protective equipment such as masks was used.

3 Results

3.1 Sociodemographic characteristics

A total of 376 people in all, or 100% of the respondents, took part in the research. Nearly 371 (98.7%) study participants were men. The mean age of the study participants was 28.12 ± SD of (6.322). Nearly 227 (60.4%) and 149 (39.6%) of the study participants were married and single. More than three-quarters of the respondents 326 (86.7%) attended secondary school. In terms of working conditions, 255 (67.8%) of the study participants were employed permanently. In addition, the majority of drivers (257, 68.4%) have fewer than 5 years of experience. A total of 359 (95.5%) drivers had less than or equal to five family members. The mean monthly income of respondents was 4859.04 ± SD of (2733.149) ETB (Table 1). The majority, 124 (33%), of drivers reported that they have a monthly income range of 2,501–5,000 ETB (Figure 1).

3.2 Drivers factors and vehicles conditions

In this study, nearly 373 (99.2%) of the respondents replied that they received traffic-related safety training, of which approximately 316 (84.0%) engaged in traffic-related safety training before starting a job. Accordingly, approximately 372 (98.9%) drivers replied that they have a habit of checking vehicles. Of which 333 (88.6%) reported that they have a habit of checking their vehicle in the morning. More than half, 193 (51.3%), of the drivers use a safety belt while driving, of which 157 (41.8%) reported that they always use a safety belt (Table 2).

In the present study, approximately 180 (27.9%) and 117 (31.1%) Bajaj and Taxi/Dolphin types of vehicles were the most public transport serving the community, respectively. Of those, approximately 290 (77.1%) of the vehicles' service years were of category 1–4 years. Furthermore, nearly half of the vehicles, 185 (49.2), serving the public in the study area have not been maintained in recent years. Similarly,

TABLE 1 Socio-demographic characteristics of drivers of public transportation in Mizan Aman town, Bench Sheko zone, SWEPRS, Ethiopia, 2023 ($n = 376$).

Variables	Category	Frequency	Percent
Sex	Male	371	98.7
	Female	5	1.30
Age in years	18–24	124	33.0
	25–34	189	50.3
	35–44	54	14.4
	≥45	9	2.4
	Mean	28.12 ± SD of (6.322)	
Marital status	Single	149	39.6
	Married	227	60.4
Educational status	Attended primary school	37	9.8
	Attended secondary school	326	86.7
	Attended college and above	13	3.50
Employee condition	Permanent	255	67.8
	Part time	121	32.2
Driving experience in years	<5	257	68.4
	5–10	83	22.1
	>10	36	9.60
Level of driving license	Taxi	146	38.8
	Public-1	155	41.2
	Public-2	75	19.9
Family size	≤5	359	95.5
	>5	17	4.50

approximately 230 (61.2%) respondents reported their vehicles were encountered with mechanical problems (Table 2).

In addition, 309 (82.2%) drivers have the habit of driving above the recommended speed (Table 2). The frequency of driving above the recommended speed among those drivers was always (40%), usually (26%), seldom (18%), and sometimes (16%) (Figure 2). The major sources of information about traffic safety for the study participants were training (89.4%) and traffic police (66.2%) (Figure 3).

3.3 Risky personal characteristics

Regarding addiction-related risk factors, approximately 80 (21.3%) and 264 (70.2%) drivers were alcohol users and khat chewers, respectively, in this study. The majority of drivers [356 (94.7%)] were punished by traffic police for disregarding traffic rules (Figure 4). Moreover, the frequency of alcohol consumption/use among drivers shown below (Figure 5) was sometimes (47%), usually (24%), always (19%), and seldom (10%) whereas the frequency of chewing Khat among drivers shown below (Figure 6) were always (54.5%), usually (22.7%), sometimes (17%), and seldom (5.7%) in the study area.

3.4 Prevalence of traffic accidents on the road among drivers

The prevalence of traffic accidents on the road among drivers of public transportation in the last 3 years was 17% (95% confidence interval: 13.0–21.0) (Table 3). The resulting consequences were injury 44 (68.8%), property damage 29 (45.3%), and death 6 (9.40%) (Figure 7). Most of the accidents happened in the afternoon 37 (57.8%) and morning 26 (40.6%). The majority, 56 (87.5%), of the reported accidents happened on asphalt, whereas 33 (51.6%) occurred during windy weather conditions (Table 3). The major root causes for the occurrence of reported accidents were collisions, pedestrians, road conditions, mechanical problems, and weather conditions 40 (62.5%), 11 (17.2%), 6 (9.4%), 5 (7.8%), and 2 (3.10%) (Figure 8).

3.5 Factors associated with the prevalence of traffic accidents on the road

In bivariable logistic regression, variables including marital status, employee condition, monthly income, engagement in traffic-related safety training, chewing Khat, maintenance of a vehicle, vehicle encountered with mechanical problems, road type, and weather conditions were significant. In the multivariable logistic analyses, marital status, employee condition, monthly income, alcohol use, vehicle maintenance, road type, and weather conditions were found to be significantly associated with traffic accidents on the roads at a significance level of $p = 0.05$ (Table 4).

Compared to part-time workers, drivers with permanent jobs had a three times higher risk of being involved in traffic accidents on the roads (AOR = 3.343; 95% CI: 1.587, 7.041). Drivers who consumed alcohol had four times higher odds of being involved in traffic accidents on the roads than those who did not (AOR = 4.083; 95% CI: 1.415, 11.780). Additionally, according to this study, drivers who operate poorly maintained vehicles are almost three times more likely than their peers to be involved in traffic accidents on the road (AOR = 3.250; 95% CI: 1.483, 7.120). Drivers who had driven on non-asphalted road types had three times higher odds of being involved in traffic accidents on the road than drivers who had driven on asphalted road types (AOR = 3.222; 95% CI: 1.400, 7.414). Drivers who have experienced driving in windy weather conditions were 89.6% less likely to suffer from traffic accidents on the roads than drivers who experienced driving in foggy weather conditions (AOR = 0.104; 95% CI: 0.038, 0.284) (Table 4).

4 Discussion

This is the first study that has assessed the prevalence of traffic accidents on the roads and contributing factors among drivers of public transportation in Mizan Aman town, Bench Sheko zone, SWEPR, Ethiopia.

In the current study, the prevalence of traffic accidents on the roads among drivers of public transportation in the past 3 years was found to be 17%. This result is consistent with results reported in previous studies conducted in different countries: Ibadan, Nigeria (16.2%) (46), Hanoi, Vietnam (20%) (25), and Ethiopia [Bahirdar city and Amhara national regional state] (16.3 and 20%) (31, 51). The

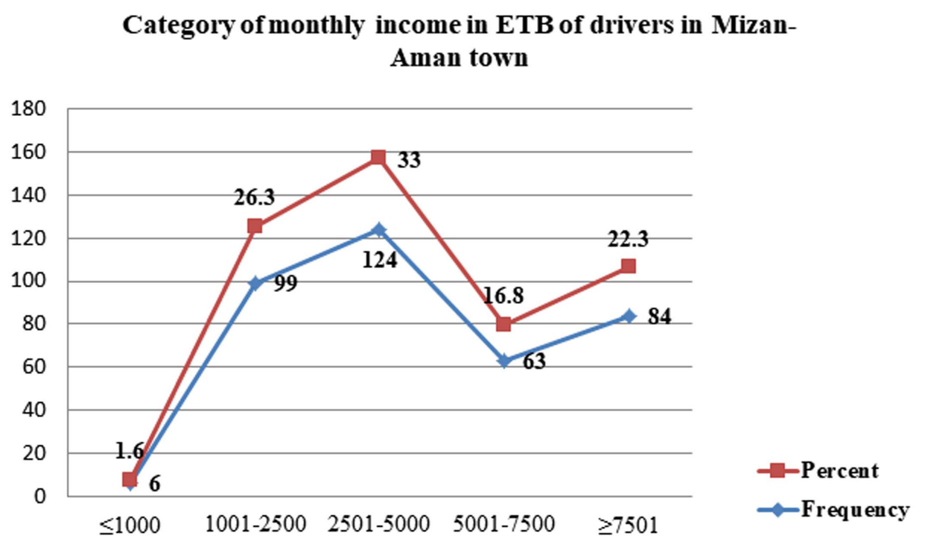

FIGURE 1
Monthly income category among drivers in the Mizan-Aman town, Bench Sheko zone, SWEPRS, Ethiopia, 2023 (*n* = 376).

main reasons for the occurrence of the accidents might be due to stressful working conditions (17), job stress (18), safety compromised by job stress (19), job stress related to addictive behaviors (regular alcohol consumption and smoking) (20), and psychological problems (anxiety, depression, and post-traumatic stress disorder) (21). Implementation of strategies to combat RTAs includes road safety training courses for young people and adults aimed at raising awareness and changing the attitudes of their participants, influencing the intention to change behaviors toward more appropriate and less risk factors among drivers, and evaluations of different types of programs regarding road traffic, which specifically focused on resilience, risk detection, and decision-making that have proven to be the most useful (52).

However, the result is somewhat lower than the study results reported in Mekelle Town (26.4%) (33), Chuko Town (23.5%) (32), and Ethiopia (21.9%) (15). The observed variation may be attributed to variations in the data sources, study participants, study settings, and sample size (15, 32, 33). The other reason that caused the variation might be the source of obtained information related to the occurrence of traffic accidents on the roads in the form of questionnaires in which some respondents purposely close or hide some important information. On the other hand, the figure is higher than the result reported from an Ethiopian study from 2015 using the STEPS survey, in which 3% of the participants had been in a traffic accident (8). This significant disparity may result from variations in the study population, the study period and conditions, the sampling strategy, methods for analyzing descriptive data, and sociodemographic traits. Moreover, the result is lower than what is reported in different countries having a history of traffic accidents on the roads in the past years: Bauchi State, Nigeria (38.3%) (23), Hail, Saudi (63%) (26), and Ethiopia [Sidama region, Jigjiga town, Nekemte town, Dilla town, and Addis Ababa] (55.1, 32.8,33, 39.9, and 56.9%) (27, 28, 34–36). The difference might be due to differences in sample sizes such as of Addis Ababa (840), East Wollega Zone (400), and Saudi Arabia (208), respectively (26, 28, 35). In addition, the reasons for the difference could be because of a large population or over-crowdedness in previous studies (23, 34, 35) and the environments for study, the research subjects and design, the technique of sampling, and the data source (27).

This study's findings show that sociodemographic attributes of public transport drivers were strongly correlated with the occurrence of traffic accidents on the roads in the town. Regarding marital status, those drivers who were single were 56% less likely to be involved in the occurrence of traffic accidents than drivers who were married. This might be because married drivers were responsible for taking care of their families as the only source of income, so they run timelessly for extra income, which leads them to be more involved in the occurrence of traffic accidents on the roads. Moreover, a study conducted in Vietnam (40) and another in Dilla Town (36) showed that taxi drivers who had been married were not significantly involved in road traffic accidents. This may be the result of variations in the sample population and the type of vehicle involved in the study. In other words, the study conducted in Vietnam was limited to taxi drivers (40), but in this study, all public transport service providers were included.

Compared to part-time workers, drivers with permanent jobs had a three times higher risk of being involved in traffic accidents. Risk is the probability of getting harm (injury, illness, death, damage, etc.) that may occur from exposure to a hazard. In this scenario, drivers being full-time employed were more exposed to hazards, which might lead them to be involved in RTA. In addition, permanent drivers may be under social and economic pressure because of inflation. This finding was inconsistent with a study result reported in Vietnam in which taxi drivers employed as part-time were 2.22 times more likely to be involved in RTA than drivers employed full-time (40). In addition, a study carried out in Nigeria among drivers employed by state institutions revealed that drivers with part-time occupations were 2.6 times more likely to be involved in RTA than those without such professions (46). This discrepancy might be due to the additional need for income sources because of high expenditure on social needs such as education and health and economic competition driven by the need of drivers who were employed part-time in Vietnam (40). Since

TABLE 2 Driver's factors and vehicle conditions related with the prevalence of traffic accidents on the roads among drivers of public transportation in Mizan Aman town, Bench Sheko zone, SWEPRS, Ethiopia, 2023 ($n = 376$).

Variables	Category	Frequency	Percent
I. Driver's factors			
Working hours per day	≤8 h	118	31.4
	>8 h	258	68.6
Traffic-related safety training	Yes	373	99.2
	No	3	0.80
Engaged in traffic-related safety training	Before starting job	316	84.0
	After engaged job	57	15.2
The habit of checking vehicles	Yes	372	98.9
	No	4	1.10
Time of checking vehicles	At the morning	333	88.6
	Throughout the day	39	10.4
Use a safety belt	Yes	193	51.3
	No	183	48.7
Frequency of safety belt use	Always	157	81.3
	Usually	2	1.00
	Sometimes	34	17.6
Drive above the recommended speed	Yes	309	82.2
	No	67	17.8
II. Vehicle conditions			
Type of vehicle	Bajaj	180	47.9
	Minibus/Midbus	117	31.1
	Bus	79	21.0
Service of years of a vehicle	1–4	290	77.1
	5–9	75	19.9
	10–14	8	2.10
	≥15	3	0.80
Owner of the vehicle	Self	46	12.2
	Family	125	33.2
	Others	205	54.5
Maintenance of vehicles	Yes	191	50.8
	No	185	49.2
Mechanical problems encountered in vehicles	Yes	146	38.8
	No	230	61.2

the RTA is a sudden phenomenon, full-time drivers were more exposed to RTA than part-time drivers.

This study finding showed that drivers with a monthly income of 1,000–2,500 ETB were 63% less likely to be encountered in RTA than those below 1,000 ETB and above 2,500 ETB. This result is in line with those of studies conducted in Vietnam and Ethiopia, which disclosed that inadequate revenue collection was strongly linked to RTA, and households with annual incomes exceeding 30,000 ETB were the most engaged in RTA (8, 40). In addition, the result is also in line with that of a study conducted in Addis Ababa, Ethiopia (38). The research carried out in the Amhara region revealed that being wealthy and in the middle-income strata were 8 and 40% less likely to be involved in the occurrence of RTI, respectively (51). However, the findings in Dilla Town among drivers were not significant with respect to RTA (36). This discrepancy may be brought about by the sociodemographic traits of the research subjects in the study region. It is supported by a qualitative finding that showed that economic pressure on the safety of drivers had contributed to RTA (53).

In fact, the use of alcohol is one of the risky personal behaviors that expose drivers to traffic accidents on the roads. A study conducted in North Gondar disclosed that driver's behavior contributes (67%) more than other factors in causing RTA (54). Similarly, an Iranian study found that the primary risk factors for the incidence of RTAs were the actions of drivers inside the transportation system (55). The results of this study showed that the likelihood of experiencing a traffic collision on the roads was 4.08 times higher for those who used or consumed alcohol. This result is consistent with previous study results reported in different countries: Ibadan, Nigeria (24), Ethiopia, Addis Ababa (38), and Mekelle town (33). It is further bolstered by another research study carried out in Dilla town, which showed that involvement in traffic accidents was over eight times higher among drivers who exhibited risky driving behaviors compared to those who did not (36). Despite this finding, a result reported in the United States showed that alcohol consumption as a cause of RTA causalities was less likely (56). This disparity may result from variations in the research settings, the sociodemographic makeup of the populations, transportation laws or policies among the nations. Similarly, a study conducted in Eastern Wollega and Vietnam showed that the habit of alcohol consumption was not significant for the occurrence of RTA (28, 40). This could be because of variations in the research area or environments, the sociodemographic makeup, transportation laws, or policies among the nations.

This study found that drivers who operate poorly maintained vehicles are almost three times more likely than their peers to be involved in traffic accidents on the road. This result is corroborated by those reported in Vietnam (28) and Dilla Town, Ethiopia (36).

Road conditions play a pivotal role in the occurrence of traffic accidents on the road. Drivers who had driven on non-asphalted road types had three times higher odds of being involved in traffic accidents on the road than drivers who had driven on asphalted road types. This result aligns with a result reported in Hawassa, Ethiopia (27), which might be due to similarities in the geography of the study area. The road features are, in turn, determined by natural topography, the quality of roads by themselves, the absence of roadside traffic signals, and the absence of speed breakers, especially on sloppy roads.

The likelihood of traffic accidents occurring on the roads was 89.6% lower when windy weather prevailed compared to rain, fog, and overcast conditions. This might be because the weather conditions of the study area, particularly SWEPRS, were most likely rain, fog, and overcast conditions, rather than windy. The finding aligns with that of research conducted at the Burayu town police stations in Ethiopia, which indicated rainy weather conditions that caused the fatality in RTAs (39). It is also supported by findings reported in the United States (56). A review of factors that cause RTA in Africa identified that environmental factors cause one-fourth of the accidents in the region (57). According to a systematic review conducted by Jakobsen et al., external factors were found to have an influence on occupational risk factors for road traffic crashes among professional drivers (58). Moreover, a study carried out in Pakistan showed weather conditions such as rain, wind, and fog as a determinant factor for the occurrence of traffic accidents (59). A similar finding in Iran indicated that unsupportive environmental conditions contribute to RTAs (60). This inference is reinforced by the findings of a qualitative study conducted in an industrial city in India, which demonstrated that inclement weather not only exacerbates poor road conditions but also reduces visibility for motorists traveling in the opposite direction (61). However, Dajun Dai revealed that weather conditions were not significant risk factors for the occurrence of RTA (43).

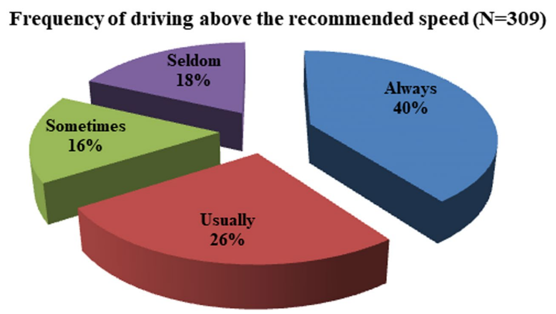

FIGURE 2
Frequency of driving above the recommended speed among divers in the Mizan-Aman town, Bench Sheko Zone, SWEPRS, Ethiopia, 2023.

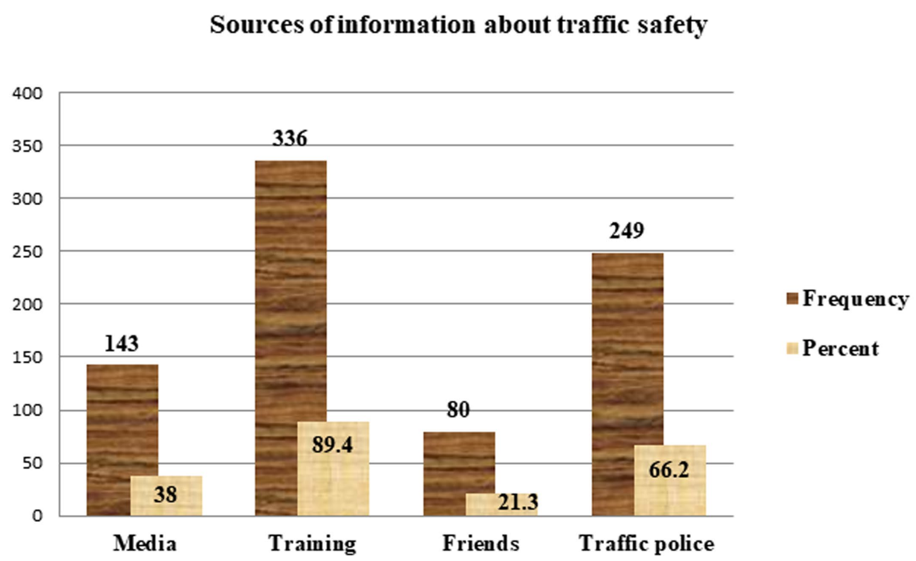

FIGURE 3
The sources of information about traffic safety among divers in the Mizan-Aman town, Bench Sheko Zone, SWEPRS, Ethiopia, 2023.

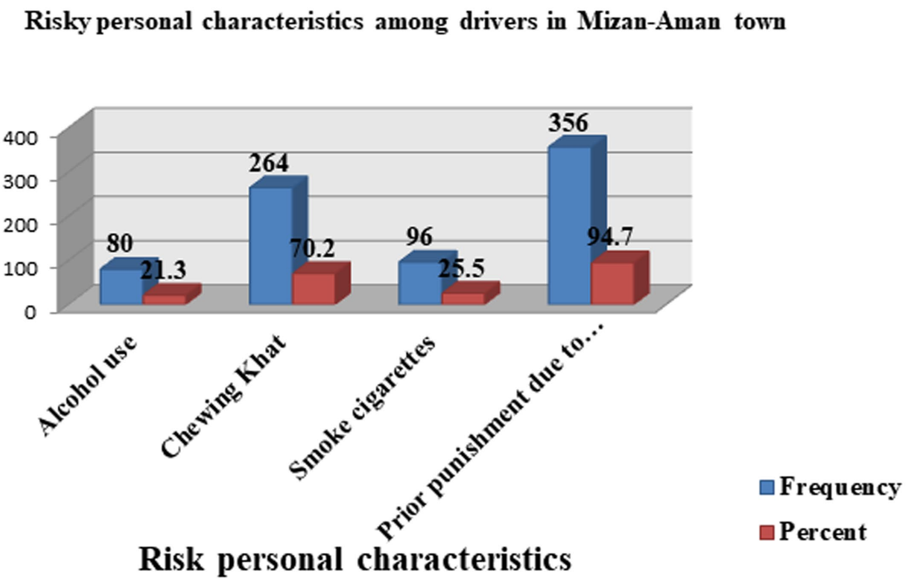

FIGURE 4
Risky personal characteristics among drivers in the Mizan-Aman town, Bench Sheko zone, SWEPRS, Ethiopia, 2023 (*n* = 376).

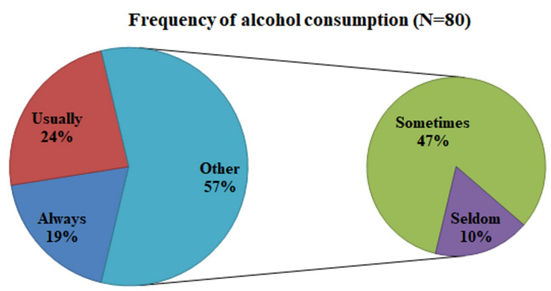

FIGURE 5
Frequency of alcohol use among drivers in the Mizan-Aman town, Bench Sheko zone, SWEPRS, Ethiopia, 2023.

Despite these predicting factors such as age (24, 27, 28, 34, 46); driving above the recommended speed (27, 33); mechanical problems encountered on the vehicle (33); chewing khat (8, 34), and attending traffic safety-related training (36) investigated in previous studies, there is no observed statistical association with RTA in the current study.

4.1 Limitations of the study

First, there was no control over characteristics that would have limited the ability to draw conclusions about causality or advocate policies based on the findings because the study participants had access to all pertinent information. Second, bias because of the study's design relied on interviewers to get self-reported data and information from participants; these data may be influenced by social desirability or recollection bias. Third, limited availability of data – data obtained from previous studies, reports, or databases may not provide the most updated or comprehensive information about traffic accidents on the roads – may limit the accuracy and generalization of the findings. Finally, there was lack of qualitative data, which should be incorporated into future studies.

5 Conclusion

Incidence of traffic collision on the road among drivers of public transportation in Mizan-Aman town is 17%. Some predictive factors were found to be associated with the likelihood of traffic accidents, including weather, road type, marital status, alcohol consumption, and car maintenance.

Therefore, implementation of reduction strategies for RTAs like speed breakers, alcohol tracing, and strong traffic safety guidelines and laws ought to be the highest priority for concerned bodies such as the regional transport office, zonal transport office, and road safety and traffic police to mitigate these problems in the study area. In addition, enhancing awareness about road safety rules and regulations should be given to drivers as well as to the community.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The study was conducted after ethical clearance was approved with reference PN003/2023 by the institutional review committee

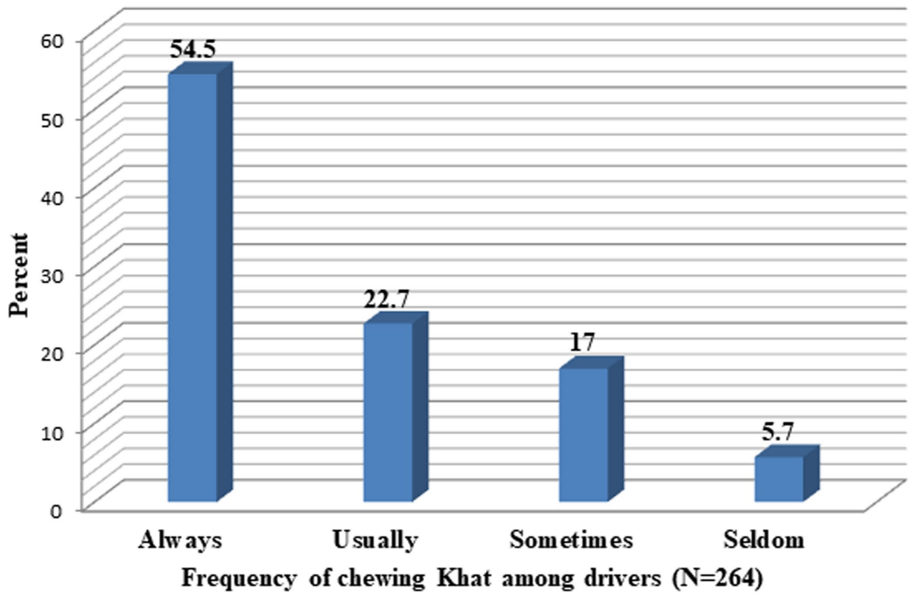

FIGURE 6
Frequency of chewing Khat among drivers in the Mizan-Aman town, Bench Sheko zone, SWEPRS, Ethiopia, 2023.

TABLE 3 Prevalence of traffic accidents on the roads among drivers of public transportation in Mizan Aman town, Bench Sheko zone, SWEPRS, Ethiopia, 2023.

Study variables	Category	Frequency	Percent
Traffic accidents on the roads in the last 3 years	Yes	64	17.0
	No	312	83.0
If the cause of the accident is a collision, the type of collision ($N=40$)	Head-on collision	28	70.0
	Rear-ended	11	27.5
	Rear-ended a vehicle in front of you	1	2.5
Injured happened on whom	Passenger	19	29.7
	Pedestrian	33	51.6
	Driver	17	26.6
The death happened on whom	Passenger	2	33.3
	Pedestrian	4	66.7
Place of accident	In the city	35	54.7
	Outside of city	29	45.3
Weather conditions during the accident	Rain	24	37.5
	Windy	33	51.6
	Fog	11	17.2
The road type where the accident happened	Asphalt	56	87.5
	No asphalt	8	12.5
A time when the accident happened	Morning	26	40.6
	After noon	37	57.8
	Night	1	1.6

of Mizan Aman Health Science College. Furthermore; both oral and written informed consent were sought from the concerned body. The overall information obtained from the study participants and their privacy was kept strictly confidential using codes.

Author contributions

ME: Conceptualization, Data curation, Methodology, Writing – original draft. AG: Writing – original draft, Writing – review & editing. TA: Conceptualization, Data curation, Formal analysis, Funding

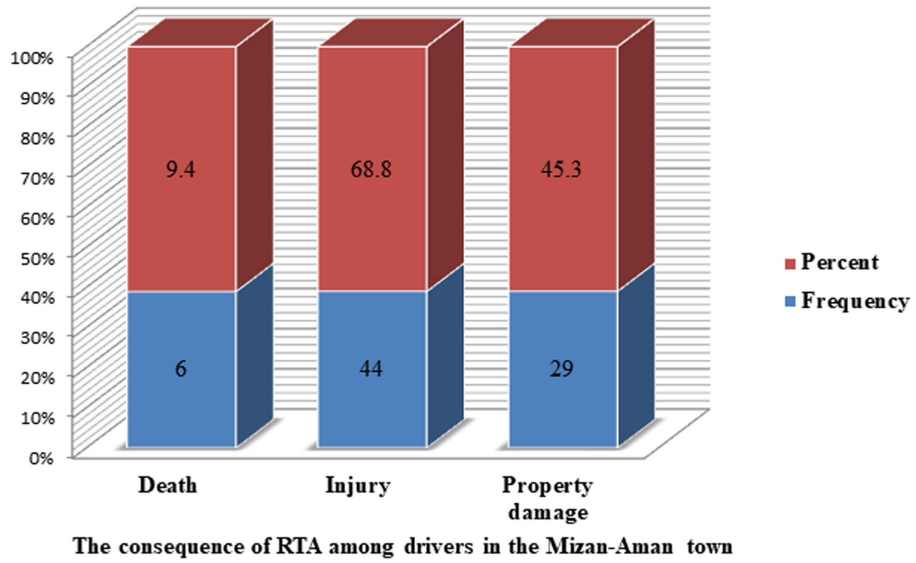

FIGURE 7
The consequence of RTA in the last 3 years among drivers in the Mizan-Aman town, Bench Sheko zone, SWEPRS, Ethiopia, 2023.

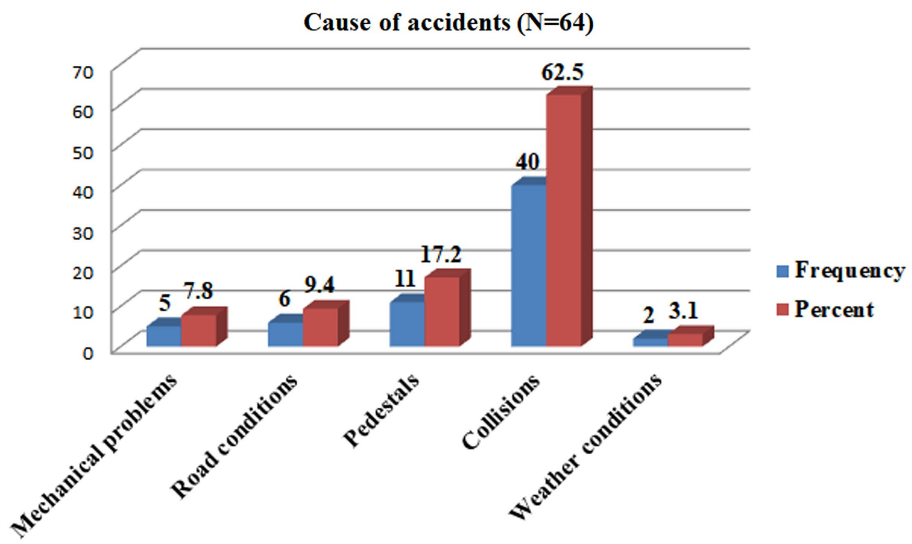

FIGURE 8
The reasons for the occurrence of RTA in the last 3 years among drivers in the Mizan-Aman town, Bench Sheko zone, SWEPRS, Ethiopia, 2023.

acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. SKA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. MB: Writing – original draft, Writing – review & editing. MZ: Writing – original draft, Writing – review & editing.

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TABLE 4 Factors associated with traffic accidents on the roads among drivers of public transportation in Mizan Aman town, Bench Sheko zone, SWEPRS, Ethiopia, 2023 ($n = 376$).

Study variables	Category/ response	Prevalence of traffic accidents on the roads		COR (95% CI)	AOR (95% CI)	*p*-value
		Yes	No			
Age in years	18–24	18	106	2.944 (0.675, 12.847)	0.137 (0.015, 1.278)	0.081
	25–34	32	157	2.453 (0.583, 10.324)	0.274 (0.032, 2.361)	0.239
	35–44	11	43	1.955 (0.421, 9.081)	0.514 (0.057, 4.616)	0.552
	≥45	3	6	1	1	1
Marital status	Single	17	132	2.027 (1.114, 3.689)	0.448 (0.202,0.994)	0.048*
	Married	47	180	1	1	1
Employee condition	Permanent	26	229	4.032 (2.307, 7.049)	3.343 (1.587, 7.041)	0.001*
	Part time	38	83	1	1	1
Monthly income in Ethiopian Birr	≤1,000	1	5	1.087 (0.118, 9.992)	0.616 (0.032,12.006)	0.749
	1,001–2,500	24	75	0.679 (0.330, 1.400)	0.377 (0.143, 0.992)	0.048*
	2,501–5,000	10	114	2.478 (1.055, 5.823)	2.271 (0.773, 6.672)	0.136
	5,001–7,500	14	49	0.761 (0.337, 1.719)	0.483 (0.171, 1.363)	0.169
	≥7,501	15	69	1	1	1
Family size	≤5	63	296	1	1	1
	>5	1	16	0.294 (0.038, 2.255)	–	–
Working hours per day	≤8 h	16	102	1	1	1
	>8 h	48	210	0.686 (0.372, 1.267)	–	–
Traffic-related safety training	Yes	62	311	1	1	1
	No	2	1	0.100 (0.009, 1.116)	–	–
Engaged in traffic-related safety training	Before starting job	61	283	1	1	1
	After engaged job	1	28	6.035 (0.806, 45.213)	–	–
Alcohol use	Yes	10	70	1.562 (0.756, 3.226)	4.083 (1.415,11.780)	0.009*
	No	54	242		1	1
Chewing Khat	Yes	52	212	0.489 (0.250, 0.957)	–	–
	No	12	100	1	1	1
Drive above the recommended speed	Yes	49	260	1.531 (0.799, 2.933)	–	–
	No	15	52	1	1	1

(Continued)

TABLE 4 (Continued)

Study variables	Category/ response	Prevalence of traffic accidents on the roads		COR (95% CI)	AOR (95% CI)	*p*-value
		Yes	No			
Maintenance of vehicles	Yes	41	150	1	1	1
	No	23	162	1.925 (1.103, 3.360)	3.250 (1.483, 7.120)	0.003*
Mechanical problems encountered on the vehicles	Yes	36	110	0.424 (0.245, 0.731)	–	–
	No	28	202	1	1	1
Road type	Asphalt	30	104	1	1	1
	Not asphalt	34	208	1.765 (1.024, 3.042)	3.222 (1.400, 7.414)	0.006*
Weather conditions	Rain	21	200	1.323 (0.594, 2.943)	1.325 (0.516, 3.402)	0.558
	Windy	33	40	0.168 (0.075, 0.377)	0.104 (0.038, 0.284)	0.000**
	Fog (cloudy)	10	72	1	1	1

COR, Crude Odd Ratio; AOR, Adjusted Odd Ratio; 1: Reference category. *: Statistically significant at $p < 0.05$, **: Statistically significant at $p = 0.000$.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1307884/full#supplementary-material

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Trends in injury-related mortality among residents of Jiangsu Province from 2012 to 2021: an age-period-cohort analysis

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Objective: We investigated the temporal trends and examined age-, period-, and cohort-specific effects of injury-related deaths among residents in Jiangsu to provide evidence for future injury prevention.

Methods: This study included 406,936 injury deaths from the Jiangsu provincial population death registration system. The average annual percent change (AAPC) in age-standardized mortality rates (ASMRs) was analyzed using joinpoint regression. Age-period-cohort models were generated to explore the effects of age, period, and birth cohort effects on mortality risk.

Results: ASMRs for all injuries (AAPC = −2.3%), road traffic accidents (AAPC = −5.3%), suicide (AAPC = −3.8%), and drowning (AAPC = −3.9%) showed a downward trend during 2012–2021(all $p < 0.05$), while unintentional falls showed an upward trend (AAPC = 5.1%, $p < 0.05$). From 2012 to 2021, the age-standardized mortality rates (ASMRs) for four primary types of injuries consistently exhibited higher among males compared to females, with rural regions displaying higher ASMRs than urban areas. Trends in ASMRs for road traffic accidents, drowning, and unintentional falls by sex and urban/rural areas were consistent with overall trends. Significant age, cohort, and period effects were identified in the trends of injury-related deaths for both sexes in Jiangsu. The age effect showed that the highest age effect for injury-related deaths was for the ages of 85 years and above, except for suicide, which was for the ages 80–84 years. Between 2012 and 2021, the period effect on road traffic accidents declined, while that on accidental falls increased. Initially, the period effect on suicide decreased but then rose, peaking in 2012 with a Relative Risk (RR) of 1.11 (95% *CI*: 1.04–1.19). Similarly, the period effect on drowning initially declined before rising, with the highest effect observed in 2013, at an RR of 1.12 (95% *CI*: 1.07–1.19). The highest cohort effects for road traffic accidents were observed in the 1957–1961 group, for accidental falls in the 1952–1956 group, and for both drowning and suicide in the 1927–1931 group.

Conclusion: The mortality rate of unintentional falls has been increasing. Older adults are at high risk for the four leading injuries. The improvements in mortality rates can be attributed to advancements in education, urbanization, and the promulgation and implementation of laws and policies.

KEYWORDS
epidemiology, injury, age-period-cohort analysis, mortality, trend

1 Introduction

Injuries represent a significant global public health concern, due to their prevalence and high rates of disability and mortality. They seriously affect the health and quality of life of individuals causing substantial burdens for both society and families (1, 2). According to the World Health Organization (WHO) estimated, approximately 4 million people die from injuries worldwide every year (3). In China this figure is particularly striking, with an estimated 700,000–800,000 fatalities from various injuries annually (4). With rapid social development, injuries have become the fifth leading cause of death, following malignant tumors, cerebrovascular diseases, respiratory diseases, and heart disease (5). Various types of injuries have distinct characteristics. Despite a noticeable reduction in recent decades (6, 7), road traffic injuries continue to be the leading cause of both death and premature mortality on a global scale. In low- and middle-income countries, unintentional fall-related deaths account for more than 80%, and over 90% of drowning deaths occur. In China, the most populous country in the world, suicide is the leading cause of death among people aged 15–34 years and ranks as the fifth leading cause of death in the general population (8).

Over the past few decades, China has experienced profound social transformations in its economy, demography, health, and politics, which have influenced mortality rates associated with major types of injuries (9, 10). The study findings suggest that age, period, and cohort effects may all play a role in injury-related mortality, with variations observed across countries likely attributable to differences in racial, sociocultural, educational, and legal factors (11–13). Jiangsu Province, located on the east coast of China, has experienced robust economic development and significant social advancement, resulting in overall improvements in population health. However, Jiangsu faces challenges including an increased risk of falls among the older adult due to its aging population, transportation-related accidents due to the high vehicle traffic, injuries associated with manufacturing activities such as firearm and cutting incidents, and a heightened risk of drowning due to numerous water bodies within the province. While previous studies have examined the trend of injury-related mortality rates at the national level (14–16), evidence at the subnational level in mainland China remains insufficient. The understanding of injury-related mortality trends in Jiangsu Province, including variations across different age groups, periods, and populations, is not yet clear. Therefore, this study aimed to analyze the trends of four injury-related mortality rates—road traffic accidents, unintentional falls, suicide, and drowning—in Jiangsu's population from 2012 to 2021 using joinpoint regression models. An age-period-cohort model was used to estimate the effects of age, period, and cohort on these four injury-related mortality rates to provide scientific information for future injury interventions.

2 Method

2.1 Study population

The study collected death data from 2012 to 2021 through the Jiangsu provincial population death registration system, which is maintained by the Jiangsu Province Centers for Disease Control and Prevention (CDC). Demographic details, including age and sex, were obtained from the public security household registration department of each municipality. Concurrently, the underlying causes of death, as documented in medical records or certified by relevant certificates, were ascertained by professionals.

Suqian city accounts for about 6% of Jiangsu's population. From 2012 to 2014, the death data from Suqian city was excluded from the study due to non-compliance with the Jiangsu Provincial Data Quality Control Standards. Since 2014, the death surveillance data from all counties and districts of Jiangsu province have been qualified and included in the analysis.

2.2 Ascertainment of outcomes

The cause of death was classified according to the International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10). We examined all injuries (V01-Y89) and four specific severe injuries with high mortality rates, namely, road traffic accidents (V01-V04, V06, V09-V80, V87, V89, V99), unintentional falls (W00-W19), drowning (W65-W74), and suicide (X60-X84, Y87.0) (17).

2.3 Statistical analysis

A joinpoint regression model was used to describe the continuous changes in the temporal trends of four types of injuries among residents in Jiangsu from 2012 to 2021, using joinpoint regression program software version 4.9.1.0 (National Cancer Institute). The basic principle of the joinpoint regression model is to describe trends by connecting several different line segments at "joinpoints" and identifying points where the linear slope of a trend changes in a statistically significant way over time (18). In order to assess the magnitude of the time trends for mortality rates, the annual percent change (APC) and average annual percent change (AAPC) were calculated (19). A two-tailed p-value of less than 0.05 was considered to indicate statistical significance.

The age-period-cohort model evaluates mortality risk within a population for a specific year, by examining both the cumulative impact of risk factors from birth and also allowing for the analysis of the independent effect of age, period, and cohort on temporal trends in injury mortality (20). The age-period-cohort model provides a useful parametric framework that complements standard nonparametric description methods. In this model, the collected data were stratified into consecutive 5-year age groups and successive 5-year intervals. Injury-related mortality rates were recorded for consecutive 5-year age groups, consecutive 1-year periods, and corresponding consecutive 5-year birth cohorts. Age-period-cohort analysis using the eigenvalue estimator method provided estimated coefficients for the impact of age, period, and cohort effects. These coefficients were converted to exponential values [exp(coef.) = e^coef.], indicating the relative risk (RR) of mortality for a particular age, period, or birth cohort relative to the average of all ages, periods, or birth cohorts combined. The analysis was implemented by the APCG1 package in R programming language.

3 Results

A total of 406,936 injury deaths were included in the study, comprising 134,794 deaths from road traffic accidents, 115,969 deaths from unintentional falls, 41,286 deaths from suicide, and 37,757 deaths from drowning. The ASMRs of injury-related deaths in Jiangsu province from 2012 to 2021 were shown in Table 1. Generally, there was a downward trend in the death rate from traffic accidents, suicide, and drowning ($t = -8.9$ to -2.5, AAPC = −5.3% to −3.8%, $p < 0.05$), while the rate of unintentional falls increased ($t = 17.7$, AAPC = 5.1%, $p < 0.001$).

We analyzed the changes in the ASMRs for the four categories by joinpoint regression, as shown in Table 2. Between 2012 and 2021, fatalities from suicide and drowning declined more rapidly among females, while those from road traffic accidents decreased more quickly among males. Additionally, the increase in fatalities from accidental falls was greater among females compared to males. Rural areas experienced a more significant decline in fatalities from road traffic accidents and drowning than urban areas. Conversely, the risk of accidental falls is increasing in urban areas. Suicide mortality is decreasing in rural regions but is on the rise in urban areas. Notably, 2014 marked the convergence point for changes in road traffic accident mortality rates across genders.

The age, period, and cohort effects on four types of injury-related deaths varied among the population of Jiangsu. As shown in Figure 1A, the greatest age effect for death from road traffic accidents was observed in those aged 85 years and above, with an effect coefficient of 1.65 and a RR of 5.21 (95% CI: 4.31–6.30). The trends in age-period-cohort (APC) effects on road traffic accident mortality by sex were generally consistent with those of the entire population. In Figure 1B, the highest age effect for death from unintentional falls was observed in individuals aged 85 years and above, with an effect coefficient of 3.86 and a RR of 47.67 (95% *CI*: 36.28–62.63). In Figure 1C, the most notable age effect for death from suicide was found in the 80–84 years age group, with an effect coefficient of 0.57 and a RR of 1.78 (95% *CI*: 1.48–2.13). In Figure 1D, the highest age effect for death from drowning was also observed in individuals aged 85 years and above, with an effect coefficient of 1.60 and a RR of 4.98 (95% *CI*, 4.04–6.13).

In Figure 2A, the period effect for road traffic accidents showed a gradual decrease, from an effect coefficient of 0.28 in 2012 to −0.17 in 2021. In Figure 2B, the period effect for unintentional falls indicated a steady increase, with the effect coefficient rising from −0.29 in 2014 to 0.23 in 2020. In Figure 2C, the period effect for suicide experienced a significant change in 2012, reaching the highest observed effect that year, with a relative risk (RR) of 1.11 (95% *CI*: 1.04–1.19). In Figure 2D, the peak period effect for drowning was observed in 2013, with an RR of 1.13 (95% *CI*: 1.07–1.19).

In Figure 3A, an increasing cohort effect for traffic accidents was observed among individuals born between 1927 and 1957, with the peak effect occurring around the cohorts born from 1957 to 1961, showing a RR of 3.17 (95% CI: 2.73–3.67) for the 1962 cohort. In Figure 3B, the mortality cohort effect for unintentional falls showed an initial increase followed by a subsequent decrease from the 1927 cohort onward, with the highest effect noted for the 1952–1956 cohort, having an RR of 2.63 (95% *CI*: 2.17–3.18). Notably, age effects were more pronounced in women aged 60 years and older and were relatively weaker in women compared to men. In Figure 3C, the mortality cohort effect for suicide showed a decrease followed by an increase from the 1927 cohort onward, with the highest cohort effect observed for the 1927–1931 cohort, which had an RR of 4.48 (95% *CI*: 3.46–5.81). Figure 3D displayed the mortality cohort effect for drowning, which also initially decreased and then increased from the 1927 cohort onward, with the highest cohort effect seen for the 1927–1931 cohort, exhibiting an RR of 2.33 (95% *CI*: 1.86–2.92).

4 Discussion

To the best of our knowledge, this was the first published study to explore the effects of the APC model on four leading injuries in

TABLE 1 Leading injury mortality rate in Jiangsu from 2012 to 2021 (/10^5).

Year	Total		Road traffic accident		Unintentional falls		Suicide		Drowning	
	CMR	ASMR	CMR	ASMR	CMR	ASMR	CMR	ASMR	CMR	ASMR
2012	49.72	35.69	24.12	18.63	9.15	5.33	7.54	5.06	6.84	5.44
2013	51.97	35.93	23.20	17.52	10.26	5.71	6.98	4.75	6.72	5.31
2014	45.88	30.18	20.27	15.09	11.62	6.02	6.44	4.24	5.39	4.00
2015	49.68	31.06	19.94	14.42	13.77	6.59	6.28	4.19	6.06	4.36
2016	53.53	31.17	19.24	13.13	15.62	6.96	6.26	4.03	5.98	4.27
2017	55.20	31.40	20.49	13.77	17.22	7.61	6.10	3.88	5.77	3.97
2018	54.92	30.28	19.79	12.70	18.37	7.84	5.99	3.90	5.78	4.01
2019	56.18	29.91	19.69	12.23	19.52	7.99	5.67	3.82	5.80	3.85
2020	58.31	30.09	19.70	11.77	20.12	8.24	5.38	3.67	6.19	4.29
2021	60.32	29.51	20.37	11.62	21.34	8.18	5.10	3.63	5.94	3.86
AMR	43.12	25.96	20.68	14.09	15.70	7.05	6.17	4.12	6.05	4.34
AAPC(%)	2.6	−2.3	−2.1	−5.3	9.9	5.1	−3.7	−3.8	−1.7	−3.9
p-value	0.001	<0.001	0.009	<0.001	<0.001	<0.001	<0.001	<0.001	0.084	0.014

Injury: includes injury, poisoning and other specific consequences of external causes; AAPC, average annual percentage change; AMR, average mortality rate; CMR, crude mortality rate; ASMR, age-standardized mortality rate.

TABLE 2 Changes in the trends of leading injury-related deaths by sex and urban/rural area in Jiangsu Province from 2012 to 2021.

Type	Trend 1			Trend 2			AAPC(95% *CI*)	*p*-value
	Year	APC (95% *CI*)	*p*-value	Year	APC (95% *CI*)	*p*-value		
Male								
Road traffic accident	2012–2014	−10.6 (−19.0 ~ −1.4)	0.033	2014–2021	−4.3 (−5.5 ~ −3.0)	<0.001	−5.7 (−7.5 ~ −4.0)	<0.001
Unintentional falls	2012–2018	5.7 (2.2 ~ 9.3)	0.008	2018–2021	2.5 (−7.2 ~ 13.3)	0.547	4.6 (1.5 ~ 7.9)	0.004
Suicide	2012–2014	−6.1 (−12.0 ~ 0.2)	0.054	2014–2021	0.7 (−0.2 ~ 1.6)	0.090	−0.8 (−2.0 ~ 0.4)	0.169
Drowning	2012–2021	−12.7 (−26.8 ~ 4.1)	0.104	2014–2021	−0.6 (−2.9 ~ 1.8)	0.560	−3.4 (−6.5 ~ −0.2)	0.039
Female								
Road traffic accident	2012–2014	−10.8 (−20.3 ~ −0.1)	0.049	2014–2021	−1.9 (−3.4 ~ −0.5)	0.020	−4.0 (−6.0 ~ −1.9)	<0.001
Unintentional falls	2012–2017	9.2 (6.2 ~ 12.3)	<0.001	2017–2021	5.5 (1.5 ~ 9.8)	0.017	7.6 (5.7 ~ 9.5)	<0.001
Suicide	2012–2014	−10.0 (−17.5 ~ −1.8)	0.027	2014–2021	−1.3 (−2.5 ~ −0.2)	0.032	−3.3 (−4.9 ~ −1.7)	<0.001
Drowning	2012–2014	−13.4 (−28.1 ~ 4.2)	0.102	2014–2021	−0.9 (−3.3 ~ 1.6)	0.405	−3.8 (−7.1 ~ −0.4)	0.028
Urban								
Road traffic accident	2012–2014	−7.4 (−15.9 ~ 2.0)	0.098	2014–2021	−2.6 (−3.9 ~ −1.3)	0.003	−3.7 (−5.4 ~ −1.9)	<0.001
Unintentional falls	2012–2014	−0.5 (−4.1 ~ 3.2)	0.735	2014–2021	8.1 (7.6 ~ 8.6)	<0.001	6.1 (5.4 ~ 6.9)	<0.001
Suicide	2012–2014	−2.6 (−11.5 ~ 7.3)	0.520	2014–2021	3.6 (2.2 ~ 4.9)	0.001	2.2 (0.3 ~ 4.0)	0.020
Drowning	2012–2014	−8.6 (−20.8 ~ 5.4)	0.165	2014–2021	0.8 (−1.1 ~ 2.8)	0.311	−1.3 (−4.0 ~ 1.3)	0.320
Rural								
Road traffic accident	2012–2015	−9.1 (−14.1 ~ −3.8)	0.008	2015–2021	−3.3 (−5.2 ~ −1.5)	0.006	−5.3 (−6.9 ~ −3.6)	<0.001
Unintentional falls	2012–2017	7.5 (6.6 ~ 8.4)	<0.001	2017–2021	2.3 (1.0 ~ 3.5)	0.005	5.1 (4.6 ~ 5.7)	<0.001
Suicide	2012–2014	−8.7 (−12.8 ~ −4.5)	0.004	2014–2021	−2.3 (−2.9 ~ −1.7)	<0.001	−3.8 (−4.6 ~ −3.0)	<0.001
Drowning	2012–2014	−13.3 (−27.0 ~ 2.9)	0.085	2014–2021	−1.1 (−3.3 ~ 1.2)	0.279	−3.9 (−7.0 ~ −0.8)	0.014

APC, annual percentage change; AAPC, average annual percentage change; CI, confidence interval.

Jiangsu, China. There was a downward trend in injury-related deaths except for unintentional falls over the period 2012–2021, which was consistent with the trend in a study of the national monitoring level over the period 2010–2019 (21). The study period experienced economic and structural developments accompanied by consequential social changes. These advances included urbanization, demographic changes, internal migration, education pursuits, poverty reduction efforts, health insurance implementation, and establishing related regulations and legislation (22). Changes in those factors may have contributed to an enhanced awareness of injury prevention (11), reduced exposure to hazardous situations (16), and prompt provision of assistance (22), hence resulting in the decline of injury-related mortality in Jiangsu Province.

The APC model showed that each of the factor of age, period and cohort had a specific association with injury-related deaths. Death risk increased significantly with age, and the risk of all four leading injuries was high in older people aged ≥60 years. On the one hand, older adult individuals' hearing, eyesight, activity coordination, balance, risk judgment, and ability to handle emergencies were reduced, making them prone to injury, and the degree of injury was more serious (23). On the other hand, older adult people living alone, who lacked care from their children and performed more unhealthy behaviors than did married older adult individuals (24). In 2020, the average life expectancy of the Jiangsu population was 79.3 years (25), which was higher than the national life expectancy (77.3 years) (26). Thus, the aging population of Jiangsu province bears a heavy burden. The age effect on traffic accident mortality in this study is similar to that in India and South Korea (13, 27). Older adult people not only have poor physiological reserves but also limited ability to adapt to trauma. When there is a delay in trauma care after a road traffic accident, the risk of adverse outcomes for the older adult may be higher, hence the mortality rate is relatively higher (28). Pedestrians constitute the primary demographic among road users succumbing to traffic accidents in Jiangsu Province, comprising approximately 47.33% of fatalities resulting from such incidents. Both this study and the national results show that the mortality effect of falls for the older adult increases rapidly with age after 60 years old, which may be related to the gradual decline in physiological functions of the older adult, including weakened of muscle strength, decreased balance ability, and reduced sensory organ function (14, 29). According to our study, suicide was an important type of injury in the 20–60-year-old age group and the risk of death from suicide increased with age,

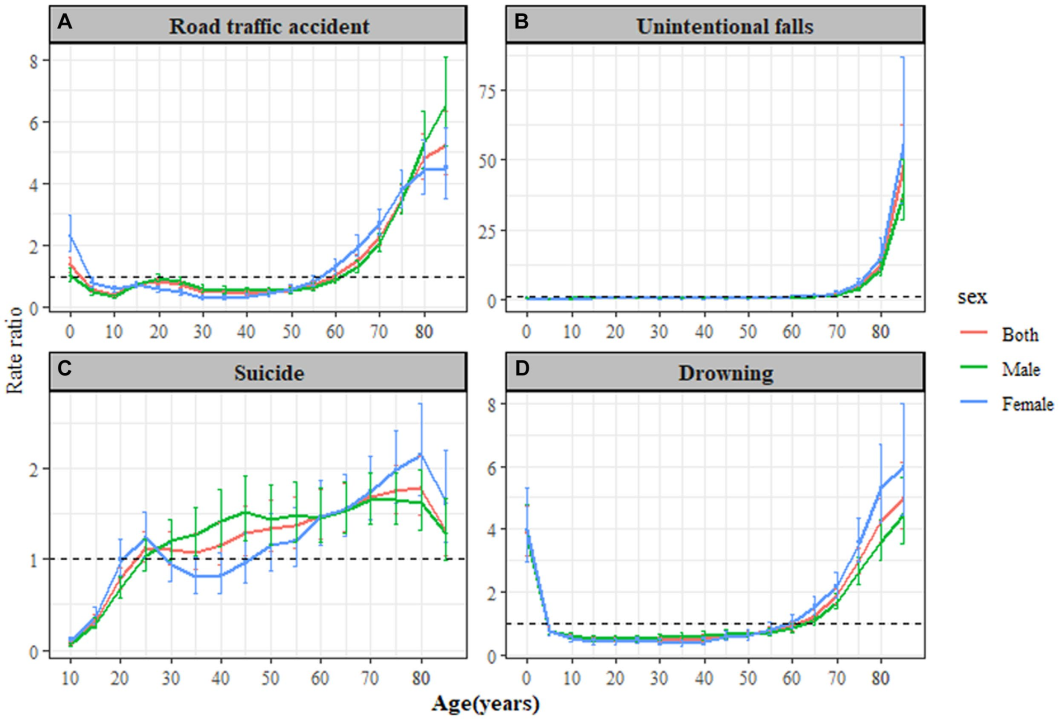

FIGURE 1
Longitudinal age curves of leading injury-related deaths rate by gender in Jiangsu Province, from 2012 to 2021. **(A)** Road traffic accident, **(B)** Unintentional falls, **(C)** Suicide, and **(D)** Drowning.

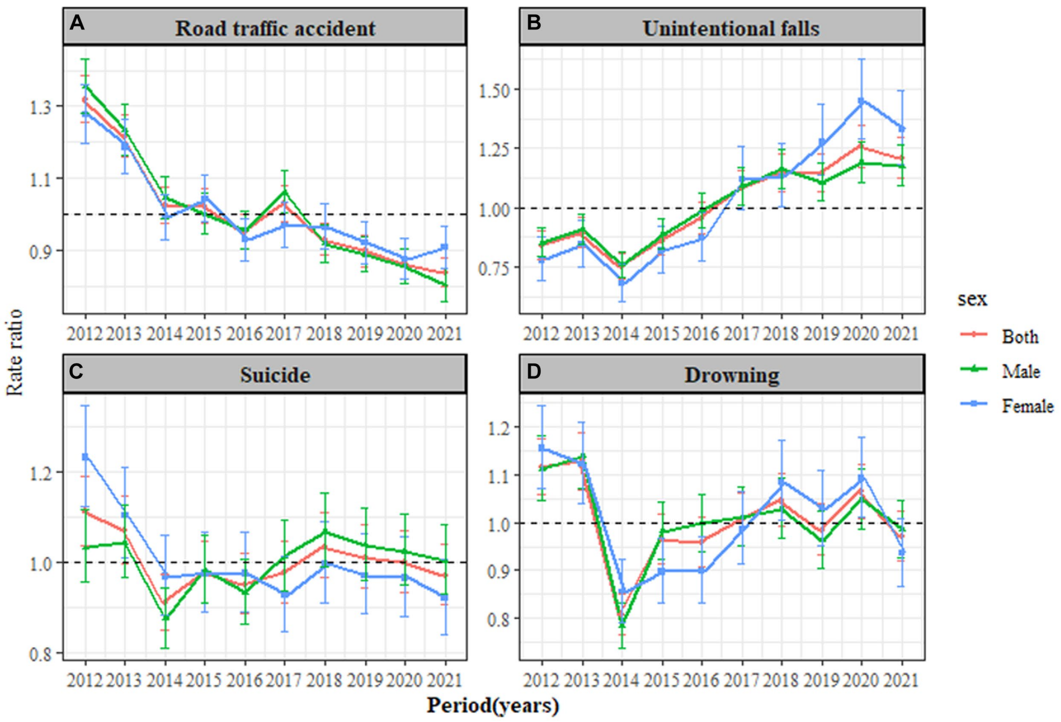

FIGURE 2
Period RRs of leading injury-related deaths rate by gender in Jiangsu Province, from 2012 to 2021. **(A)** Road traffic accident, **(B)** Unintentional falls, **(C)** Suicide, and **(D)** Drowning.

especially for men. Studies on gender differences in suicide have shown that men had stronger suicidal intent than women and that they used lethal means, even when the same methods were used, resulting in a higher lethality rate than women (30–32). The increased susceptibility to suicide among the older adult may stem from diminished social connections post-retirement, limited economic

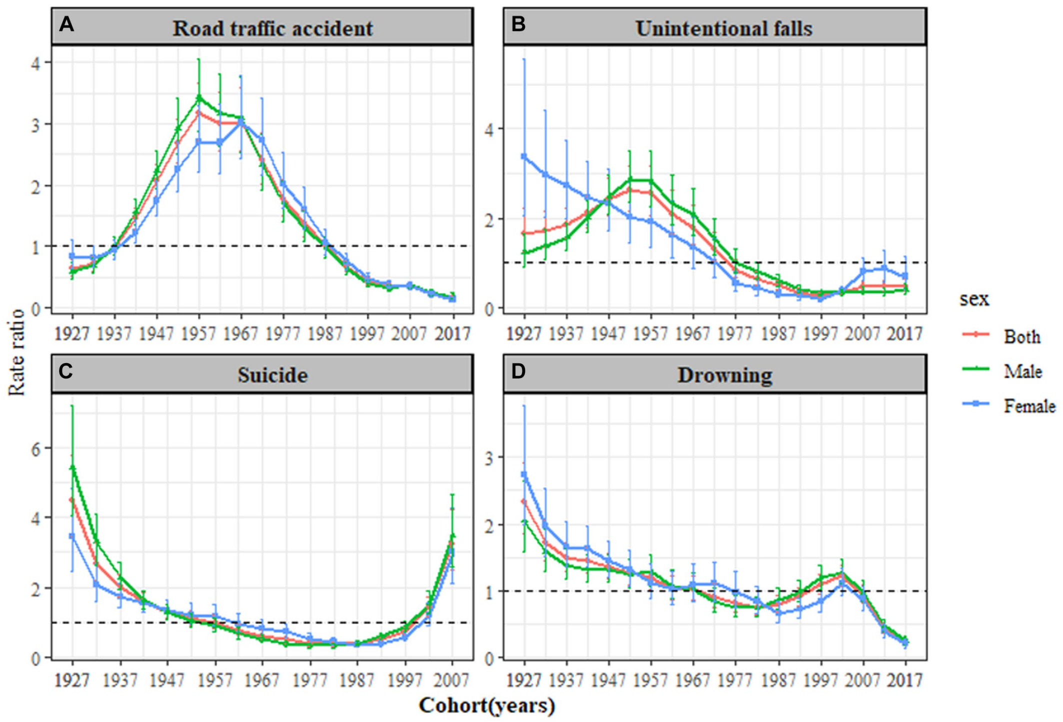

FIGURE 3
Cohort RRs of leading injury-related deaths rate by gender in Jiangsu Province, from 2012 to 2021. **(A)** Road traffic accident, **(B)** Unintentional falls, **(C)** Suicide, and **(D)** Drowning.

resources, and exposure to both internal stressors (such as illness or disability) and external stressors (such as verbal abuse), rendering them more vulnerable to suicidal tendencies (33, 34). Consistent with the results of the Canadian study, older people in Jiangsu have replaced younger people as having the highest drowning mortality rate of any age group (35). Factors contributing to the risk of fall-related drowning fatalities among older individuals encompass pre-existing medical conditions affecting both physical and cognitive capacities, reduced mobility, heightened frailty, and specific environmental hazards (36). Older adult individuals are more likely to drown in environments such as bathtubs and pools due to their weakened physical functions (35). Meanwhile, studies have shown that drowning was a common form of suicide among older individuals (37).

The utilization of the joinpoint regression model allowed us to effectively capture the changing trends. The 2014 showed a significant turning point in the age-adjusted road traffic accident mortality rates among males, likely due to the second revision of the Road Traffic Safety Law that made drunk driving a criminal offense (38). A previous study has shown that the most effective interventions in preventing road traffic death was drink-driving enforcement, credited with saving over 60,000 lives annually (37). The overall suicide mortality rate in Jiangsu Province was on a downward trend, which could be attributable to the implementation of a series of government policies. In 2002, the Chinese government issued a directive to cease the production of certain highly toxic pesticides (39). Subsequently, the Regulations of the People's Republic of China on the Administration of Pesticides implemented in 2008 established regulations governing the production, importation, transportation, storage, and sale of pesticides. Fatalities from road traffic injuries decreased between 2020 and 2021, presumably attributable to diminished exposure resulting from pandemic control measures (40). Additionally, there was a marginal decrease in suicide rates, plausibly linked to heightened mental health support during the pandemic (41). However, the incidence of drowning fatalities increased in 2020, consistent with patterns observed in Australia and the United States (42, 43), potentially due to disruptions in swimming and water safety education caused by lockdown measures, leaving a considerable portion of the population, particularly children, inadequately prepared for safe aquatic interactions (42).

This study found inverted V-shaped curves between cohort effects and injuries, with the highest risk of road traffic accidents observed in the birth cohort population from 1957 to 1961, and unintentional falls were observed in the birth cohort population from 1952 to 1956, consistent with previous studies (13, 14). This group was also the most active in social mobility and industrialization endeavors. China has experienced rapid development in the past few decades, with the number of motor vehicles increasing from approximately 1.7 million in 1980 to 11.5 million in 1996 (9, 44). Additionally, environmental pollution is a risk factor for fall-related injuries (14). There was evidence of an association between environmental pollutants and death from cardiovascular disease, cerebrovascular disease, lung cancer, and pneumonia (45). These diseases are strongly associated with the risk of fall-related injuries (46). The declining trend of the cohort RRs of mortality due to the four leading injuries for both sexes in the younger birth cohort was likely related to better education and urbanization. Previous studies have supported the association between lower educational attainment and a higher risk of injury mortality due to increased exposure and unsafe behavior (16, 47). People with better educational backgrounds often take more protective measures, such as safety training or learning personal rescue skills. With the development of urbanization and the improvement of infrastructure, people can receive timely treatment after injuries occur, and the chance of exposure to dangerous water, toxic substances, and other dangerous factors is reduced, so the mortality rates from various injuries decrease.

There are several limitations of this study. First, the study is primarily limited by the quality of the Jiangsu provincial population death registration system. Despite many efforts to validate the quality of the data and the widespread use of the dataset, the data may still be subject to underreporting and misclassification in reporting practices, making it possible that the completeness and accuracy of mortality data may be biased to some extent. Second, the period was just 10 years, which means that crossover was possible in assessing age, period, and cohort effects, and the distinction between age and period effects may not be clear (48). Third, similar to other APC studies, the influence of ecological fallacy was inevitable since interpreting results from population levels does not necessarily apply to individuals (47).

5 Conclusion

Although injury-related mortality in Jiangsu Province has decreased in the past 10 years, it is still relatively high. Injuries remain an important public health problem, seriously threatening the lives of residents in Jiangsu Province. Injury mortality varies with injury type, gender, age, and urban–rural distribution. The trend of injury mortality in Jiangsu Province has significant age, period, and cohort effects. With the arrival of an aging society, fall mortality in Jiangsu Province rose. Meanwhile, the older adult were also the focus of other injuries, and the risk of death increased with age. The improvement of mortality benefits from the improvement of education level, urbanization development, and the promulgation and implementation of laws and policies. Injuries can be prevented and controlled. We should take targeted measures to reduce the disease burden of injuries.

Data availability statement

The original contributions presented in the study are included in the article material, further inquiries can be directed to the corresponding author.

Author contributions

WD: Methodology, Writing – original draft, Formal analysis. RW: Methodology, Writing – original draft. XF: Writing – review & editing, Methodology. XW: Writing – review & editing. JY: Writing – review & editing. JZ: Supervision, Writing – review & editing. HY: Data curation, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Quality of life of survivors following road traffic orthopaedic injuries in Rwanda

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Background: Road traffic injuries (RTI) pose a global public health threat, especially in low- and middle-income nations. These injuries typically cause orthopaedic problems that may negatively impair a person's physical and mental health and quality of life. Our study examined the quality of life of road traffic orthopaedic injuries (RTOI) survivors.

Methods: A cross-sectional study at five Rwandan referral hospitals, included 369 adult RTOI victims. Two years post-injury, participants completed the European Quality of life 5 Dimension 5 (EQ-5D-5L) and Visual Analogue Scale (VAS) Questionnaire between June 2 and August 31, 2022, with informed consent. Three EQ-5D-5L-VAS scores were used: low (0–40%), fair (41–60%), and excellent (61–100%). We used logistic regression analysis with a significance threshold of $p < 0.05$ to determine odds ratios (OR) and 95% CI.

Results: The RTOI victims had a mean age of 37.5 ± 11.26 years with sex ratio M:F:3:1. Usual activities (66.8%) and mobility (54.8%) were the most affected EQ-5D-5L dimensions. Residence, hospital stay, rehabilitation, and return to work affected mobility, usual activities, pain/discomfort, and anxiety/depression. The EQ-5D-5L/VAS score showed 34.95% poor QoL (0–40%) and 35.50% good QoL. Factors affecting QoL include level of education (OR = 1.66, $p < <0.01$), type of intervention (OR = 1.22, $p = 0.003$), rehabilitation (OR = 2.41, $p < 0.01$) and level of disability (OR = 196.41, $p < 0.01$). Mobility, self-care, usual activities, pain, comfort, anxiety, and depression vary moderately on Shannon's index.

Conclusion: The study highlights the significant impact of road traffic orthopaedic injuries (RTOI) on survivors' quality of life in Rwanda, revealing challenges in mobility and daily activities. Factors influencing quality of life include education level, medical intervention type, rehabilitation, and disability degree. The findings emphasize the need for tailored rehabilitation strategies and policy interventions to improve long-term outcomes for RTOI survivors.

KEYWORDS

disability, EQ-5D-5L, quality of life, road traffic orthopaedic injuries, Rwanda

Background

Road traffic injuries (RTIs) are a significant global public health issue, causing substantial physical, psychological, and social consequences for individuals involved (1). Each year, approximately 50 million people are involved in road traffic injuries globally, resulting in 1.2 million fatalities. Additionally, 30% of survivors endure permanent disabilities, while 14% are unable to resume work (2). Survivors of RTIs often experience long-term impairments and disabilities that can affect their overall quality of life (QoL) (3). Assessing the QoL outcomes of RTI survivors is crucial for understanding the impact of these injuries and developing appropriate interventions to enhance survivors' well-being and social reintegration (4).

Research has demonstrated that achieving positive results for these injuries relies on prompt medical attention, including accurate diagnosis and suitable surgical treatment, as well as thorough postoperative monitoring that includes rehabilitation, as well as social and economic assistance. However, these aspects remain difficult to implement in many low- and middle-income countries (LMICs) (5). Lack of sufficient and effective medical attention following an injury has a detrimental effect on the victims' ability to function and their overall quality of life. This is a significant problem in low- and middle-income countries (LMICs) (6–8).

Studies to investigate the QoL of RTI typically utilize validated QoL assessment tools to measure different domains such as physical functioning, psychological well-being, social interactions, and overall life satisfaction (9). The findings from these studies provide insights into the challenges faced by RTI survivors, the effectiveness of healthcare interventions, and the need for support services to improve their Health-Related Quality of Life (HRQoL) (10).

As per international figures, disabilities arising from road traffic injuries are costly for both society and individuals. The annual costs of road traffic injuries in low and middle-income countries are estimated to be between US$65–100 billion, more than the total yearly amount received in development aid affecting both the wellbeing of the victims and their families (11, 12). In 2011, a study conducted on motorcycles injuries in Rwanda estimated the individual and social cost to be around1.3$ million without counting the long-term disabilities' costs (13).

In 2019, the Rwanda National Police documented a total of 4,661 injuries and 700 deaths resulting from RTI. For these injuries, half had orthopaedic problems, 35.6% permanent disabilities and 36% of victims were unable to return to work. Age, gender, socioeconomic status, the severity of the injury, rehabilitation, and hospital length of stay affect the level of disability and social reintegration of the road traffic orthopaedic injuries in Rwanda (14, 15).

Currently, the predominant emphasis in systematic data collecting is in the acute phase of trauma care, namely within the confines of a patient's duration of stay in the trauma centre. The gathering of data regarding post-discharge outcomes is predominantly limited to small studies (16). Managing these injuries poses significant challenges for both the physician and the nursing team, who must provide continuous care for the patients (17, 18). This constraint impedes our comprehension of the potential impact of acute care adjustments on long-term functional outcomes and quality of life for individuals who have experienced trauma (16). The existence of this data gap is particularly widespread in numerous countries, particularly in Low and Middle-Income nations (LMICs).

Orthopaedic injuries resulting from road traffic accidents can lead to long-term physical, psychological, and socioeconomic consequences for survivors (19). The quality of life of survivors following road traffic orthopaedic injuries in Rwanda is an important aspect to consider in understanding the impact of such injuries on individuals and society. Our study aimed to determine the quality of life of survivors following Road Traffic Orthopaedic Injuries (RTOI) in Rwanda.

Methodology

Study design and sample size

A cross-sectional study on orthopaedic injuries conducted from June 2 to August 31, 2022, included participants 2 years post-injury resulting from road traffic accidents in Rwanda. The study analysed hospital data from five referral hospitals in 2019. Referral and teaching hospitals provide emergency care, orthopaedic services, mental health treatment, and rehabilitation. The study sites included were Centre Hospitalier Universitaire de Kigali (CHUK), Rwanda Military Hospital (RMH), King Faisal Hospital (KFH) in Kigali City, Centre Hospitalier Universitaire (CHUB) in the Southern Province, and Ruhengeri Hospital (RH) in the Northern Province.

We recorded 4,600 post-RTI cases, 1,986 of whom were adult orthopaedic injuries, and we sampled 369 representative RTI victims using Krejcie and Morgan's formula (20). To collect patient data, all hospital records were carefully examined. The study included adult patients (18 years and older) who had orthopaedic injuries from road traffic accidents and were 2 years post-injury, treated at five Rwandan referral hospitals. Participants had to give informed consent and be classified using the Kampala Trauma Score. Exclusions were patients without orthopaedic injuries, those younger than 18, less than 2 years post-injury, lacking informed consent, or with non-compliant hospital records. The remaining qualified individuals were phoned at their homes for demographic information and invited to the hospital for further assessment.

Psychometric properties of the instruments

The EQ-5D-5L is an instrument that evaluates the generic quality of life and was developed in Europe by the EuroQol group. It has been validated in many countries and languages. The EQ-5D-5L demonstrates robust psychometric properties, with studies showing a mean HRQoL score of 0.79 (SD 0.17) and a mean EQ-VAS score of 71.7 (SD 19.4). It effectively detects meaningful health changes, avoiding ceiling effects seen in the EQ-5D-3L. Reliability is confirmed with significant test–retest correlations, and construct validity is supported by correlations with related health measures. The instrument is sensitive across sociodemographic groups, with younger and higher-educated individuals reporting better HRQoL scores (21–23). Permission to use the EQ-5D-5L questionnaire in our study was obtained from the EuroQol group with registration ID: 48658.It is used widely as a self-assessed health-related quality of life questionnaire with five components: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression. It also has five levels, where each one is rated on a scale that describes the degree of problems in that area. The EQ-5D-5L measures five levels: Level 1 indicates no issues, Level 2 minor, Level 3 moderate, Level 4 severe, and Level 5 extreme problems or inability to operate.

The EQ-5D-5L is used in conjunction with EQ-VAS, a visual analogue scale, evaluating self-reported patient general well-being, rated at percentages, from worst, equal to 0 to best, which is equivalent to 100.It is a validated tool for economic evaluation, clinical studies, quality of care, and public health studies (24). The EQ-5D-5L questionnaire underwent rigorous translation by two language experts who translated it from English to Kinyarwanda and back to English to ensure cultural and linguistic equivalence. Orthopedic and rehabilitation experts then reviewed the translation for quality, clarity, and appropriateness for Rwandan participants. This comprehensive feedback process enhanced the questionnaire's reliability and comprehensibility, leading to higher participant engagement and accurate data collection on quality-of-life dimensions. Consequently, the translated questionnaire provided reliable data for healthcare interventions and allowed for comparability with international studies.

The EQ-5D-5L VAS scores range from 0 to 100 but are often grouped for easier analysis and interpretation. The scores are categorized as Very Poor (0–20), Poor (3, 10, 21–38), Fair (41–60), Good (61–80), and Very Good (81–100). In our study, the 'Very Poor' category was merged with the 'Poor' category to form a consolidated 'Poor' category. The category labelled as 'Fair' remained unchanged. Furthermore, we consolidated the 'Good' and 'Very Good' categories into a singular 'Good' category.

The WHODAS 2.0 is a multi-dimensional questionnaire used to measure disability levels across various conditions. Validated in 16 languages across 14 countries, it has adequate internal consistency, construct, and discriminate validity. The tool evaluates a patient's overall disability under the International Classification of Functioning, Disability and Health (ICF). The WHODAS 2.0 is self-reported and administered to participants aged 18 and above (25).

Procedure

We included1,986 patients with orthopaedic injuries following road traffic injuries using the Kampala Trauma Score (KTS) classified as mild, moderate and severe to assess injury severity (26, 27). Participants were invited to the hospital to assess their status 2 years post-RTIs. The EQ-5D-5L/VAS questionnaire was used to measure patients' quality of life. Socioeconomic status was categorized according to the Rwandan government, with categories including impoverished, vulnerable, gainfully employed, employers, and proprietors (28). The primary outcome was quality of life, evaluated using the EQ-5D-5L/VAS scores. Secondary outcomes included demographic data, the KTS score, hospital stay, rehabilitation, return to work, and level of disability, all evaluated through a predesigned questionnaire. Data were collected from patients' files and assessed during the study.

Data management, statistical analysis, and ethical consideration

The data were gathered through questionnaires, inputted into a computer using Google Form's data entry feature, and analysed using R Software. We conducted a descriptive analysis of the patient-reported outcome measure scale EQ-5D-5L and VAS. Categorical variables were summarized using frequencies and percentages, continuous variables with means and standard deviations (SD). We utilized a student's t-test for comparing continuous variables and the Chi-Square test for nominal (categorical) variables. A multivariate logistic regression was used to examine the relationships between risk factors and EQ-5D-5L score categories. We computed Shannon's indices to assess the diversity within our population and a p-value less than 0.05 was deemed statistically significant.

Our study obtained ethical clearance from the University of Rwanda College of Medicine and Health Sciences Institutional Review Board (18/CMHS IRB/2022). It was authorized by the Rwanda National Research Committee under the Ministry of Health (NHRC/2022/PROT/014). Reference 5535/RBC/2022 created collaboration with the Rwanda Biomedical Centre injury department. Five hospital ethics committees approved our study: CHUK (EC/CHUK/051/2022), CHUB (REC/UTHB/089/2022), RH (313/RRH/DG/2022), KFH (EC/KFH/015/2022), and RMH. All research participants gave written agreement after being told the purpose.

Results

Demographic characteristics of the participants vs. EQ-5D-5L VAS score

369 RTOI victims were included (Table 1). 64.5% (238) were CHUK recruits. The participants' average age was 37.5 ± 11.26 years, with the majority aged 31–50. Young adults (18–30) had the best quality of life (47.6%), while those over 45 the worst (42.6%). Men dominated (74.25%). Both men and women with injuries have similar quality of life, suggesting no gender difference. About 41.73% (154), were in business, while 29% (107) were unemployed. Also, motorcycle accidents caused 61.52% of injuries. Primary school was attended by 41.73% (172). The highest quality of life was reported by university graduates (66.10%). 46.34% (171) lived in Kigali (Table 2). Most participants (61.52%, 227) were from socioeconomic class III (Ubudehe).

Clinical factors

52.85% of participants had isolated lower limb injuries and 21.14% polytrauma. The majority had moderate Kampala Trauma Score (KTS) at 66.84%, with mild KTS having a higher success rate. Half of the participants were managed within 1 day, with a mean treatment duration of 30 days. Open Reduction Internal Fixation (ORIF) and Open Reduction External Fixation (OREF) treatments had better outcomes compared to closed reduction +Plaster of Paris (POP). 55.29% were discharged within 14 days, with a mean hospital stay of 30 days. After injury treatment, 37.13% could not undergo rehabilitation, and 36.3% had still not returned to work 2 years after the injury.

EQ-5D-5L frequencies and proportions reported by dimension and level

Figure 1 displays 369 individuals' EQ-5D-5L health scores in mobility, self-care, regular activities, pain/discomfort, and anxiety/depression. Mobility was the most common category with 34.7%

TABLE 1 Demographic characteristics of the participants ($n = 369$).

Factors	EQ-5D-5L VAS score									
	Poor (0–40%) N = 129		Fair (41–60%) N = 109		Good (61–100%) N = 131		Test statistics		Total (Factor)	
	N	%	N	%	N		X^2	p	N	
Age Mean = 37.57(±11.26)							9.653	0.047		
18–30	30	29.41	24	23.53	48	47.6			102	27.71
31–45	70	35.18	64	32.16	65	32.66			199	53.92
>45	29	42.65	21	30.88	18	26.47			68	18.42
Sex							1.87	0.391		
Male	92	33.58	86	31.39	96	35.04			274	74.25
Female	37	39.96	23	24.21	35	36.84			95	25.75
Hospital of treatment							17.22	0.028		
CHUK	78	32.77	72	30.25	88	36.97			238	64.49
CHUB	14	43.75	8	25.00	10	31.25			32	8.67
RH	10	34.48	13	44.83	6	20.69			29	7.85
RMH	6	20.00	7	23.33	17	56.67			30	8.13
KFH	21	56.67	9	22.50	10	25.00			40	10.84
Level of education							35.318	<0.01		
None	12	42.86	10	35.71	6	21.43			28	7,58
Primary	73	42.44	55	31.98	44	25.58			172	41.73
Secondary	35	31.82	33	30.00	42	38.18			110	29.81
University	9	15.25	11	18.64	39	66.10			59	15.99
Residence							6.36	0.041		
Kigali City	55	32.16	61	35.67	36	21.05			46.5	
Secondary cities	22	23.40	37	39.36	17	18.09			25.5	
Other Districts	18	17.48	43	41.75	28	27.18			28	
Occupation							27.10	0.003		
Farmer	9	29.03	15	48.39	7	22.58			31	8.40
Business	44	28.57	46	29.87	64	41.56			154	41.73
Students	2	40.00	2	20.00	2	40.00			5	1.36
Public service	18	31.03	10	17.24	30	51.72			58	15.72
Informal sector	51	47.66	32	29.91	24	22.43			107	29.00
Retired	5	35.71	5	35.71	4	28.57			14	3.79
Socio-economic status (Ubudehe)							2.53	0.638		
I	10	50.00	5	25.00	5	25.00			20	5.42
II	44	36.07	36	29.51	42	34.43			122	33.06
III	75	33.04	68	29.96	84	37.00			227	61.52
Cause of the injury							10.42	0.034		
Motorcycles	70	29.29	77	32.22	92	38.49			239	64.76
Cars	39	43.82	21	23.60	10	32.58			89	24.11
Others	20	48.78	11	26.83	10	24.39			41	11.11

having moderate concerns. However, 29.5% reported no mobility concerns. In Self-Care, 55.56% of participants reported no problems, while 23.04% had minor issues. 38.2% had moderate difficulties with daily duties. 44.4% reported no pain or discomfort, whereas 25.2% experienced mild pain. Most individuals (52.0%) did not express anxiety or depression, although 16.3% had severe symptoms.

TABLE 2 Clinical factors vs. EQ-5D-5L VAS score.

Factors	EQ-5D-5L VAS score									
	Poor (0–40%) (*N* = 129)		Fair (41–60%) (*N* = 109)		Good (61–100%) (*N* = 131)		Test statistics		Total (Factors)	
	N	%	*N*	%	*N*	%	X^2	*p*	*N*	%
Kampala Trauma Score (KTS)							24.61	<0.01		
Mild	1	4.55	3	13.64	18	81.82			22	5.96
Moderate	86	34.82	75	30.36	86	34.82			247	66.93
Severe	42	42.00	31	31.00	27	27.00			100	27.10
Diagnosis							30.23	<0.01		
Upper extremity injuries	11	22.92	13	27.08	24	50.00			48	13.01
Lower extremity injuries	74	37.95	61	31.28	24	50.00			195	52.85
Upper and lower extremity injuries	5	25.00	10	50.00	5	25.00			20	5.42
Polytrauma	35	44.87	21	26.92	22	28.21			78	21.14
Soft tissues injuries	4	14.29	4	14.29	20	71.43			28	7.59
Time before management							13.74	0.008		
≤1 day	62	34.25	64	35.36	36	19.89			182	49.32
2–7 days	20	17.24	45	38.79	28	24.14			116	31.44
8–14 days	3	13.04	11	47.83	6	26.09			23	6.23
15–30 days	7	23.33	11	36.67	7	23.33			30	8.13
>30 days	3	16.67	10	55.56	4	22.22			18	4.88
Intervention							47.27	<0.01		
Closed reduction+POP	7	17.50	16	40.00	17	42.50			40	10.84
ORIF	59	38.06	52	33.55	44	28.39			155	42.01
OREF	33	57.89	13	22.81	11	19.30			57	15.45
Amputation	8	66.67	3	25.00	1	8.33			12	3.25
Other	22	20.95	25	23.81	58	55.24			105	28.46
Length of Hospital Stay							45.92	<0.01		
0–7 days	31	20.81	38	25.50	80	53.69			149	40.38
8–14 days	20	36.36	17	30.91	18	32.73			55	14.91
15–30 days	28	39.44	27	38.03	16	22.54			71	19.24
>30 days	50	53.19	27	28.72	17	18.09			94	25.47
Rehabilitation							42.74	<0.01		
Yes	67	28.88	65	28.02	100	43.10			232	62.87
No	62	45.26	44	32.12	31	22.63			137	37.13
Return to work							45.74	<0.01		
Yes	54	22.98	74	31.49	107	45.53			235	63.68
No	75	55.97	35	26.12	24	17.91			134	36.31
Disability compensation							1.99	0.369		
Yes	53	33.97	52	33.33	51	32.69			156	42.27
No	76	35.96	109	29.54	131	35.50			213	57.72

KTS, Kampala Trauma Score; ORIF, Open Reduction Internal Fixation; OREF, Open Reduction External Fixation; POP, Plaster of Paris; LEFS, Lower Extremity Functional Score.

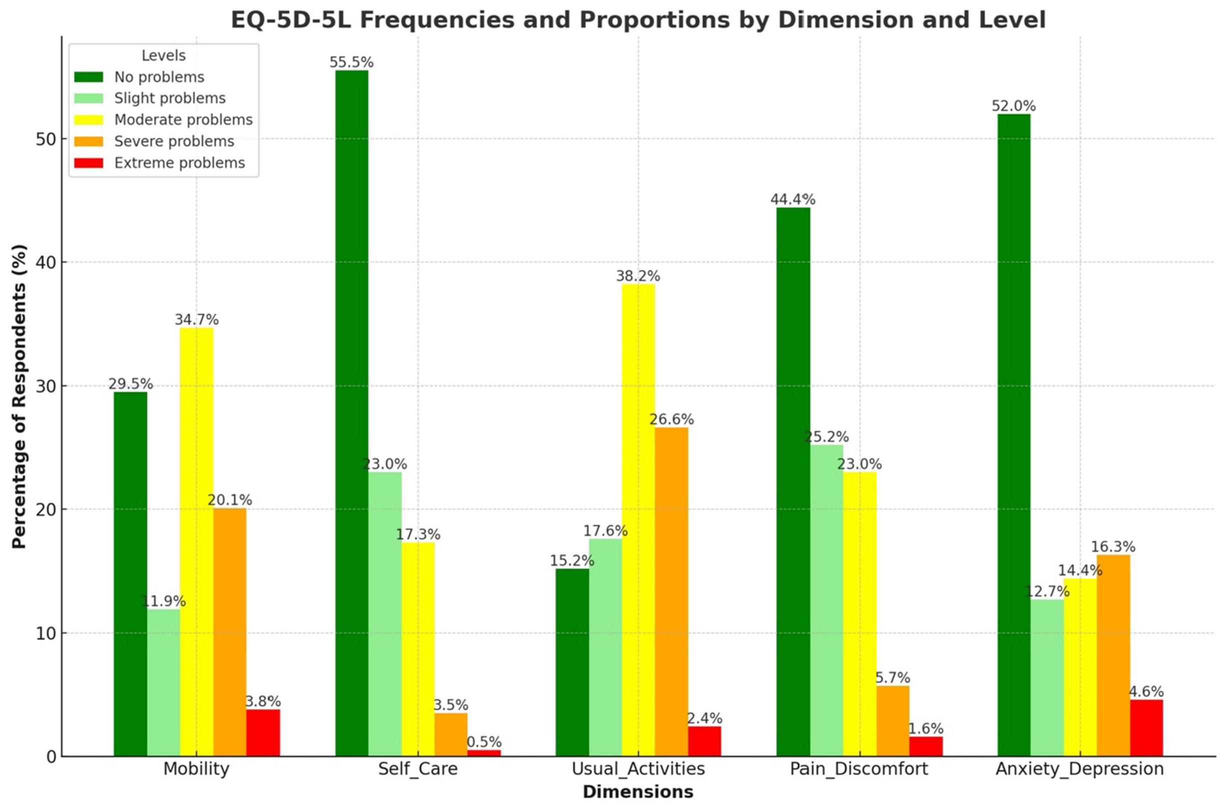

FIGURE 1
EQ-5D-5L frequencies and proportions reported by dimension and level.

Univariate analysis of the predictors and the dimensions of the EQ-5D-5L

Figure 2 shows significant correlations between residence, length of stay, rehabilitation, and return to work with mobility, usual activities, pain/discomfort, and anxiety/depression ($p < 0.005$). The WHODHAS scores are highly significant across all dimensions ($p = 0.000$). Return to work is significantly correlated with mobility, self-care, usual activities, pain/discomfort, and anxiety/depression ($p < 0.005$). Additionally, disability compensation is notably correlated with mobility, which in turn is associated with a favourable quality of life. Predictors like rehabilitation and return to work generally show positive associations with good QoL, suggesting potential improvements or lesser negative impacts on the EQ-5D-5L dimensions ($p < 0.005$). While these correlations suggest possible causal relationships, it is important to note that causality could operate in either direction.

Heatmap of individual profiles of the EQ-5D-5L

The heatmap shows a diverse quality of life among Rwandan road traffic orthopaedic injury survivors. The most common health state is '11111', indicating no issues, but moderate to extreme difficulties are present, especially in mobility and pain/discomfort dimensions. This reflects a range of individual health outcomes across five health dimensions: Mobility, Self-Care, Usual Activities, Pain/Discomfort, and Anxiety/Depression. This highlights the need for tailored healthcare and rehabilitation services (Figure 3).

Multinomial logistics regression EQ-5D-5L/VAS and predictors

The multinomial logistic regression analysis reveals that various factors, including education, cause and type of injury, rehabilitation, physical function, and level of disability, significantly influence the quality of life of survivors of road traffic orthopaedic injuries in Rwanda (Table 3). Higher levels of education are significantly associated with better quality of life outcomes, with each additional unit increasing the odds by 66%. The specific cause of injury has a slight but statistically significant association with quality of life, with a 10% decrease in the odds of better outcomes for certain causes compared to others. The type of surgical or medical intervention received in the operating theatre is also significantly associated with quality-of-life outcomes. Higher levels of disability are strongly associated with poorer quality of life outcomes, almost doubling the odds of worse quality of life.

Health state density curve and health state density index

Figure 4 represent the cumulative frequency curve which is red, and the dashed black line is the line of equality, indicating a perfect

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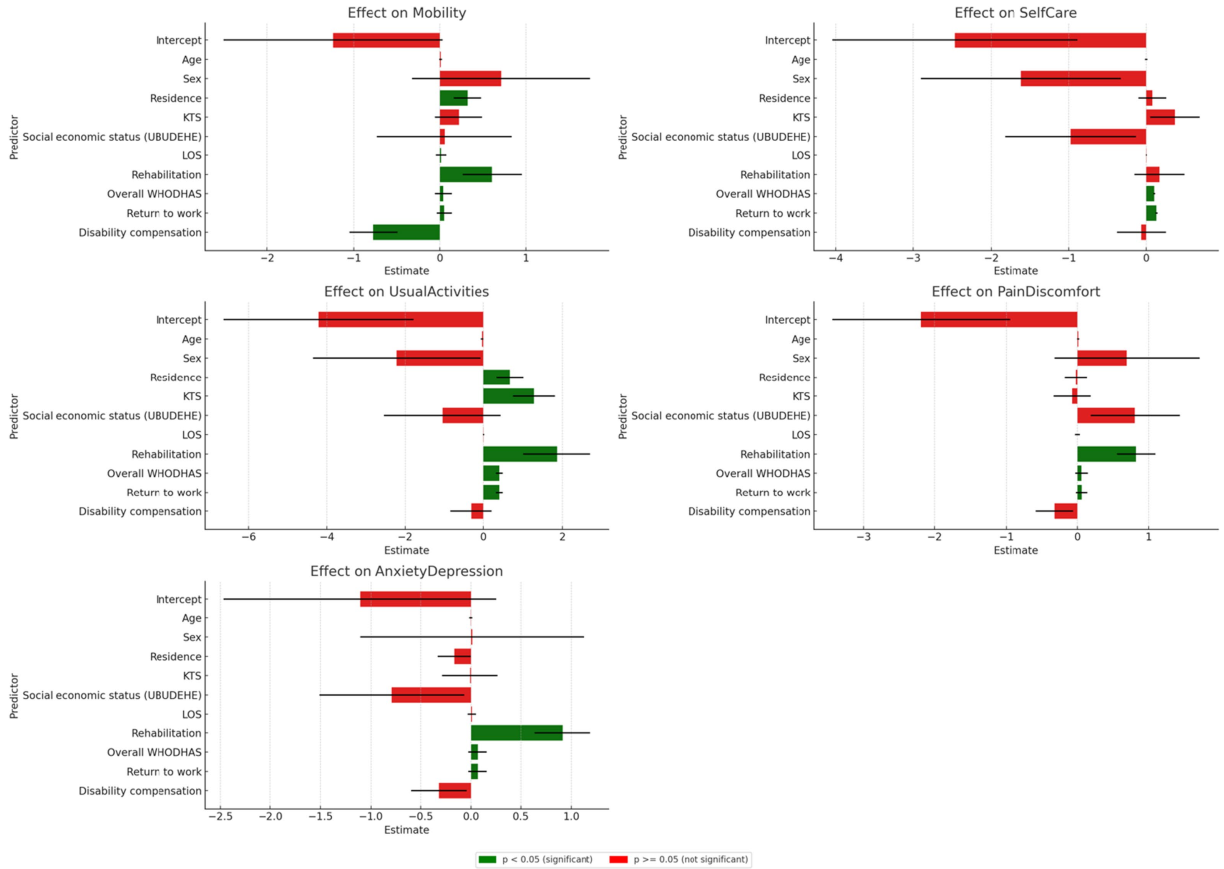

FIGURE 2
Univariate analysis of the predictors and the dimensions of the EQ-5D-5L.

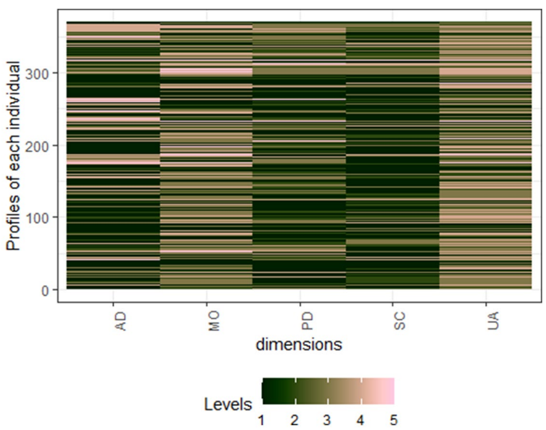

FIGURE 3
Heatmap of individual profiles of the EQ-5D-5L. AD, Anxiety and Depression; MO, Mobility; PD, Pain and discomfort; SC, Self-care; UA, Usual activities. Level 1: No problem, Level 2: Slight problem, Level 3: Moderate problems, Level 4: Severe problems, and Level 5: Extreme problems.

health state distribution. This image's HSDC has a similar curve, with the Health State Density Index (HSDI) between the curve and the line of equality. The displayed curve depicts the vast variety of health statuses with variable frequencies in the text data. The plot's HSDI value (0.56) suggests modest health state inequality among Rwandan road traffic orthopaedic injury survivors, with a concentration of persons in a few health states.

Shannon's indices of road traffic orthopaedic injury survivors

Figure 5 shows Shannon's indices for Rwandan road traffic orthopaedic injury survivors' quality of life. Diversity—the distribution of responses across levels or categories—is measured by these indices. The observed diversity (H′) is moderate, with higher values indicating greater diversity. The observed diversity is 6.68, while the maximum possible diversity (H'max) is 11.61. The J′ (0.58) measure of response distribution equitability ranges from 0.69 to 0.87, indicating moderate evenness. Mobility's moderate diversity is 2.06, maximum potential diversity is 2.32, and evenness is 0.89. Low diversity of 1.61, maximum potential diversity of 2.32, and evenness of 0.69 characterize self-care. Moderate diversity is 2.02, maximum potential diversity is 2.32, and evenness is 0.87 for usual activities. Pain and comfort have 1.84 moderate diversity, 2.32 maximum potential diversity, and 0.79 evenness. Anxiety and depression have 1.9 moderate diversity, 2.32 maximum diversity, and 0.82 evenness.

Shannon's indices show moderate diversity in experiences for Rwandan road traffic orthopaedic injury survivors, with mobility showing high diversity and evenness. Self-care has lower diversity but reasonable evenness. Usual activities, pain, comfort, anxiety, and depression have moderate diversity and high evenness, reflecting a nuanced picture of post-injury quality of life.

Discussion

We evaluated the quality of life of survivors following road traffic orthopaedic injuries (upper limbs and lower limbs injuries) in Rwanda. Factors such as age, gender, level of education, hospital of treatment, residence, occupation, socio-economic status, and cause of the injury were considered.

Our results show that most survivors were male, with a mean age of 37.57 years which is like other studies on road traffic injuries in LMICs (29, 30). The quality-of-life post RTOI in Rwanda is significantly influenced by various demographic factors, including young age (3, 10, 18–42), education level from secondary school to university, urban residence location of the patients, victim's occupation (business), male sex, and socio-economic status class III. Enhanced resilience is fostered by younger people, persons with a university education, and job cultures that provide support. Health-related quality of life, or HRQOL, is a problem not just in Rwanda; studies have shown that clinical aspects during hospitalization and after release are critical components of overall HRQoL (3, 31).

Half of the injured participants received medical treatment within a day. Preventing complications and improving patient outcomes requires prompt intervention. Their average treatment duration was 30 days, indicating prolonged medical care. Due to the complexity and severity of road traffic orthopaedic injuries, extensive treatment and rehabilitation are needed to maximize recovery and minimize long-term disabilities (15, 32, 33). Femur shaft, distal femur, tibia plateau, ankle, Pilon, and bimalleolar fractures were the main lower limb injuries. According to the literature, knee and ankle fractures always result in long hospital stays and permanent disabilities (34, 35). Such findings emphasize the importance of timely and adequate medical intervention in improving road traffic orthopaedic injury survivors' quality of life (36, 37).

Although there are alternative methods available, the EQ-5D-5L tool has gained favor in measuring HRQoL, particularly in trauma patients (10). We have found that the EQ-5D-5L health scores reveal that mobility is the most common concern among individuals recovering from road traffic orthopaedic injuries. Mobility issues are often prominent, impacting daily activities and overall well-being. Self-care difficulties are less prevalent, with over half of participants reporting no problems with self-care. Regular activities are also affected, with more than a third experiencing moderate difficulties. Pain and discomfort are prevalent, but not all participants reported issues.

The psychological impact of orthopaedic injuries is significant, with a significant proportion experiencing severe anxiety or

TABLE 3 Multinomial logistics regression EQ-5D-5L/VAS and predictors.

EQ-5-5D-5L/VAS	Predictors	OR	CI	*p*-value
1	Level of Education	1.66	1.32–2.10	<0.01
2	Cause of injury	0.90	0.83–0.98	0.048
3	Type of intervention in theatre	1.22	1.07–1.40	0.003
3	Rehabilitation	2.41	1.28–1.60	<0.01
4	Return to work	0.235	0.30–0.71	0.001
5	LEFS	1.05	1.00–1.03	0.001
6	Level of Disability (WHODAS2.0 score)	1.96	1.95–1.96	<0.01

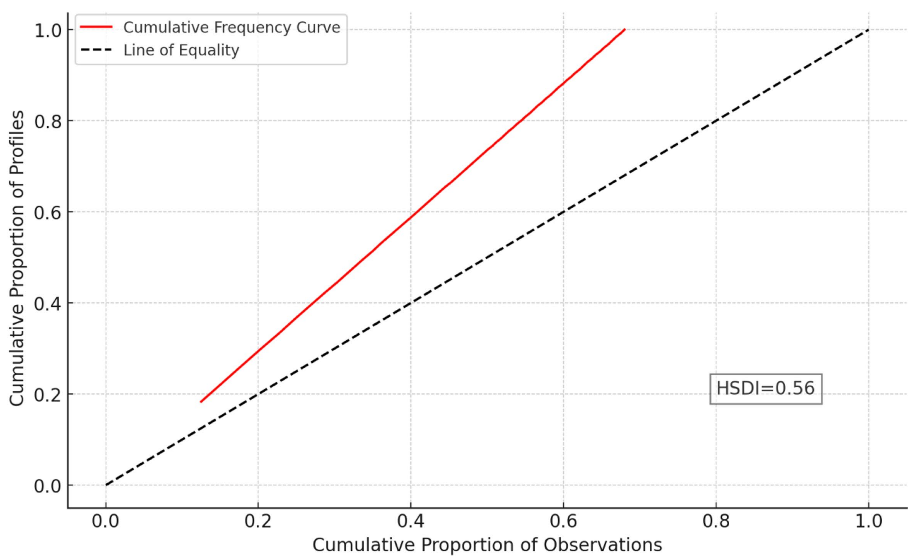

FIGURE 4
Health State Density Curve (HSDC) and Health State Density Index (HSDI).

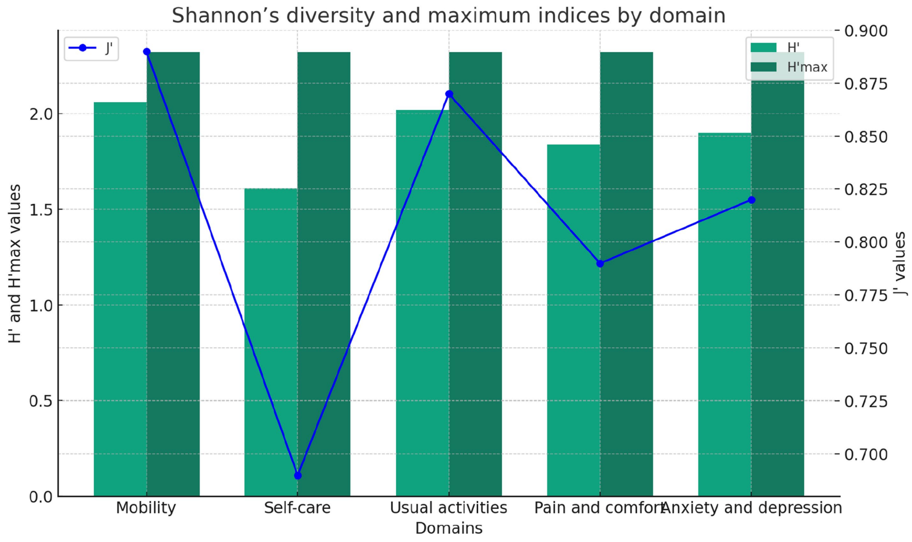

FIGURE 5
Shannon's indices of road traffic orthopaedic injury survivors.

depression. Zahra Emrani et al. (22) in Iran have found that mobility, self-care, and usual activity dimensions were conserved, and many patients had psychological problems (22). Our study emphasizes the importance of addressing both physical and psychological well-being to optimize long-term health outcomes following road traffic orthopaedic injuries.

The findings of our study demonstrate that patient outcomes are influenced by a variety of variables, including mobility, regular activities, pain/discomfort, and anxiety/depression. The factors that have a substantial influence on the EQ-5D-5L dimensions of our participants include residency, duration of hospital stay, rehabilitation, return to work, and disability compensation. Rehabilitation improves mobility, self-care, and overall quality of life. Return to work is crucial for health and well-being, and disability compensation can enhance physical functioning. Several studies assessing the health-Related Quality of Life (HRQoL) have consistently revealed similar characteristics that influence several aspects. However, these studies used various methods to evaluate the Quality of Life (QoL) in Road Traffic Injuries (RTI) (38–40).

In the context of Rwanda, our research on RTOI revealed a heterogeneous distribution of self-perceived health-related quality of life among individuals who had experienced the injury 2 years before. The majority rated their quality of life within the 41–60 range, indicating moderate satisfaction and well-being. However, a smaller percentage reported extreme scores, indicating polarization in their perceived quality of life. These findings highlight the diverse experiences and challenges faced by survivors of RTOI in Rwanda affecting their mental health. In their review, Mahla Babaie et al. (2023) discovered that even in high-income nations with a high prevalence of mental illness, the quality-of-life following RTI results in lifelong handicap (41).

We found a strong correlation between clinical, socioeconomic, and demographic characteristics and patients' self-rated health after road traffic injuries. Young age, marital status, urban residence, hospital stay duration below 2 weeks, return to work status post-therapy, and low disability level were significant predictors of QoL. Rissanen et al. (2020) identified age and gender as the primary determinants of HRQoL in their study, while also highlighting the significance of clinical and socio-economic variables (42). Our study emphasizes the importance of considering a range of variables in assessing and addressing patients' well-being, emphasizing the need for a comprehensive approach to patient assessment and treatment.

Our findings show that high level of education, theatre intervention (ORIF and OREF), LEFS scores, injury aetiology, rehabilitation, and disability levels had a favourable influence on health outcomes in patients recovering from orthopaedic injuries (upper limbs and lower limbs injuries) in Rwanda, as seen in previous studies (3, 19, 22, 43, 44). The findings underscore the significance of specific treatments that target education, rehabilitation, and functional status to enhance health outcomes in RTOI victims.

Our data, analysed using Shannon's indices, indicate modest variance in HRQoL responses among RTOI victims. There is moderate variability in mobility, normal activities, pain, comfort, anxiety, and sadness, whereas self-care shows reduced diversity. The results emphasize the need of considering different aspects of well-being in rehabilitation and support programs. The research conducted by Nena Kruithof et al. (2020) yielded similar results, examining the impact of trauma on health status and psychological outcomes in the Netherlands region.

Our findings revealed a higher prevalence of anxiety and depression compared to other domains (45). Additional study might aid in creating specific interventions to enhance HRQoL outcomes in this group. Using the Health State Density Curve (HSDC) and Health State Density Index (HSDI), we found a modest health state inequality among Rwandan road traffic orthopaedic injury survivors, with a concentration in a few health states. Dipnall et al. (2021) in their study among children and adult have found almost the same where some predictors of health dominant more than others (46).

Our study has some limitations. The cross-section design may introduce recall bias, and self-reported measures may not fully capture the complexity of individuals' experiences. The focus on survivors seeking medical care may overlook those who did not and those who succumbed to their injuries, leading to selection bias. We may not have accounted for all relevant variables influencing quality of life outcomes. The generalizability of the findings may be limited to similar settings with similar healthcare systems and injury profiles. Addressing these limitations is important for advancing understanding and informing targeted interventions. Our study has produced new insights highlighting the necessity for comprehensive interventions. It emphasizes the significance of education and rehabilitation, as well as utilizing Shannon's indices analysis for customized interventions. Although limited, the study provides valuable insights into the challenges faced by survivors.

Based on the study findings, we recommend that policymakers should improve rehabilitation services by modernizing facilities, providing specialized training, and integrating them into primary healthcare. Mental health care should be integrated into routine treatment through screening, training in first aid, and accessible support services. Social and economic reintegration programs should include vocational training, job placement, social support networks, and financial assistance. Rwandan psychological support should involve community-based initiatives, training in first aid, and peer counselling. Culturally sensitive interventions and educational campaigns are crucial for promoting positive attitudes towards rehabilitation and mental health care.

Conclusion

Our study on the quality of life of survivors following Road Traffic Orthopaedic Injuries in Rwanda highlights the importance of addressing both physical and psychological well-being. Factors such as age, education level, residence, occupation, socio-economic status, rehabilitation, level of disability and return to work significantly influenced the quality-of-life post-RTOI. Regaining function was the most common concern among survivors, emphasizing the need for comprehensive interventions targeting education, rehabilitation, and functional status. Shannon's indices showed modest variance in health-related quality of life responses among survivors, emphasizing the need for a holistic approach to patient assessment and treatment.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Ethics statement

The studies involving humans were approved by University of Rwanda College of Medicine and Health Sciences Institutional Review Board (18/CMHS IRB/2022). Our research was authorized by the Rwanda National Research Committee under the Ministry of Health (NHRC/2022/PROT/014). Reference 5,535/RBC/2022 created a collaboration with the Rwanda Biomedical Center injury department. Five hospital ethics committees approved our study: CHUK (EC/CHUK/051/2022), CHUB (REC/UTHB/089/2022), RH (313/RRH/DG/2022), KFH (EC/KFH/015/2022), and RMH. All research participants gave written agreement after being told the purpose. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JA: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. DT: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. JS: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. GU: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. GB: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. SP: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AS: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The Safe System Approach and technology—what works?

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The Safe System Approach is an evidence-based strategy committed to eliminating fatalities and serious injuries among all road users. The Safe System Approach as developed in Sweden, acknowledges that human errors will occur, but the cost of these mistakes should not be death or serious injury. Technology is an integral component of the Safe System Approach and can address equity and reduce human error among other safety benefits. A literature review will be conducted to compare high-income countries leveraging the Safe System Approach and assess opportunities for technology interventions in low- and middle-income contexts. Evidence will be analyzed, as well as implementation considerations of the recent National adoption of the Safe System Approach in the United States. As SSA evolves in a global context, further evaluation is needed on the role of technology and how government policies can restrict or advance its implementation.

KEYWORDS

high-income countries (HICs), low-and lower-middle-income countries, Safe System Approach, technology, injury prevention

Introduction

Road traffic crashes continue to affect lives across the world with traffic crashes being a leading cause of death among children and young people ages 5–29, and the 12th leading cause of death among all ages as of 2019 (1). In 2021, over 1.19 million people died from road traffic crashes with a global estimate of 15 road traffic deaths per 100,000 population (1). Though some regions across the world have continued to be disproportionately burdened by road traffic deaths, other regions have experienced progress in improving road safety (1). Formally adopted by Sweden and the Netherlands in the 1990's, the Safe System Approach (SSA) has significantly contributed to decreasing crashes in the European region and Western Pacific Region (1). The SSA is a revolutionary road safety framework that aims for zero fatalities and serious injuries (3). Adopters of the SSA have shown that preventing and reducing traffic deaths is possible. The European Region is the largest adopter of the SSA and has experienced the largest drop in road traffic deaths since 2010 at 36% (1). Furthermore, as the second largest adopter of the SSA, Western Pacific region experienced similar results with a drop in traffic deaths of 16% since 2010 (1). With technology being a notable component of SSA, this review seeks to understand how technology plays a pivotal role in crash reduction. Furthermore, with 92% of traffic deaths reported occurring in low- and middle-income countries (1), this review will examine gaps, limitations, and opportunities for technology driven by the SSA in regions that continue to be disproportionately burdened by traffic crash deaths.

The safe system framework and technology

The SSA reinforces the idea that death and serious injuries are unacceptable (3). As an interventional framework, SSA refutes the traditional downstream theory of "human error" as a main contributing factor of road traffic injuries. Instead, SSA anticipates human errors by leveraging multi-dimensional countermeasures to achieve optimal safety for all road users (3). The foundation of SSA is based on five principles: "humans make mistakes, humans are vulnerable, responsibility is shared, safety is proactive, reducing risks is vital" (3). Based on these principles, countermeasures also known as "pillars" are defined as "safe road users, safe vehicles, safe speeds, safe roads, and post-crash care" (3). Within these pillars, technology has been known to play a pivotal role in preventing and decreasing crashes (4). According to Tingvall et al., vehicle safety technology can address SSA fundamentals such as "humans make mistakes, humans are vulnerable, and safety is proactive" (4). Technology that involves automation such as automatic braking systems and stability control, are solutions to accommodating human error (4). In-vehicular systems such as airbags, seat belts, and pedestrian detection can help to reduce crash force within human injury tolerance (4). In addition, proactive safety can be achieved by mandating technological safety standards (4).

Within Sweden, technology such as seat belt reminders, alcohol interlocks, and automatic speed cameras, have been recognized as effective in accommodating human error and contributing to improving driving behaviors on Swedish roadways (2). Research has shown that drivers were more likely to use their seat belts in vehicles with seat belt reminders than in vehicles without seat belt reminders (2). Alcohol interlocks have also played a significant role in combatting alcohol- impaired driving crashes (2). In addition, automatic speed cameras are proven to reduce speed- related crashes and injuries in SSA adopted countries (2). In Sweden, spot speed cameras are used to lower speeds and have been shown to "reduce the number of fatalities by 30% and number of people killed or seriously injured by 25%" (2). In the Netherlands, mobile speed cameras are used and have been effective in decreasing injury crashes by 21% and speed offenders from 27.4% to 15.6% on speed enforcement roads (2).

With low- and middle-income countries experiencing traffic deaths at high numbers (1), an SSA approach integrated with technology may help to combat this crisis. A review of databases and gray literature was conducted to search for SSA technology examples. Nigeria, Malaysia, and the United States were selected due to their varying economies, populations, and SSA implementation strategies to examine gaps, opportunities, and successes (Table 1).

SSA technologies across low-middle-high-income countries

Each LMIC has unique contextual factors to consider when implementing the SSA. Factors like technological development and social economic factors cause SSA interventions to vary. High income countries must consider context as well; despite the US having more resources, access, and tech advancement, they have one of the worst per capita fatality rates among developed economies (5). Below, we highlight three countries with varying income statuses that have embraced the SSA. We explore the extent of their incorporation of technology and assess the impact on their road safety outcomes.

TABLE 1 Safe System Approach (SSA) technology case studies.

Country SES	Country	Technology
Low-income	Nigeria	Speed Limiter Devices
		Nigeria Road Assessment Program (nRAP)
		Automated Number Plate Recognition (ANPR)
Middle-income	Malaysia	Automated Awareness Safety System (AwAS) Cameras
		Intelligent Speed Adaptation System (ISA)
		ASEAN New Car Assessment Program (ASEAN NCAP)
High-income	United States	Advanced Driver Assistance Systems (ADAS)
		Automated Enforcement (AE)

Malaysia

Malaysia is an upper-middle-income country with a population of 33.93 million and a Gross Domestic Product (GDP) of 407 billion dollars (6). In 2007, the Ministry of Transport Malaysia established the Malaysian Institute of Road Safety Research (MIROS) as the organization tasked with conducting research, developing objectives, and enhancing knowledge of road safety in Malaysia (7, 8). MIROS also serves as Malaysia's database for crash fatality and injury data (8). Traffic crashes in Malaysia have historically been concerning; 50% of fatalities reported were motorcyclists and at one point Malaysia was described as having the highest fatality risk in the world (9, 10). However, with strategic action taken by leaders toward road safety improvements, fatalities have been steadily declining with a rate of 22.56 per 100,000 people reported in 2016 and 18.9 per 100,000 people reported in 2019 (11). In WHO's 2023 Global Status Report, Malaysia's rate has continued to decrease to 13.9 per 100,000 people (1).

SSA in Malaysia

In 2022, Malaysia released the 2022–2030 Malaysia Road Safety Plan, outlining 10 safety priorities that align with the United Nations' second Global Decade of Action for road safety and the Sustainable Development Goals (SDGs) 3.6 and 11.2 (11–13). This is the second national plan in the last two decades for increasing awareness of road safety and preventing injuries and fatalities (11). Priorities in the 2022–2030 plan include motorcycle safety and leveraging technology such as ABS, Automated Awareness Safety System (AwAS) cameras, and Intelligent Speed Adaptation Systems (ISAs) to reduce speeds and in turn, reduce the severity of crashes (11).

Technology and SSA in Malaysia

1. **Automated Awareness Safety System (AwAS) cameras:** AwAS [formerly known as Automated Enforcement System (AES)] was identified in the 2006–2010 Malaysia Road Safety Plan and was implemented in 2012 (7). AwAS cameras can detect speed and red- light violations and can be strategically placed in high crash-risk locations. Evaluations have been conducted on AwAS technology in Malaysia proving it has been effective in reducing red light violations (14), increasing perception of the probability of receiving tickets, and increasing speed compliance, in accident-prone areas (15).
2. **Intelligent Speed Adaptation System (ISA):** Used by both commercial and private vehicles, ISA alerts drivers when they exceed the speed limit and can automatically limit vehicle speed. An evaluation of an ISA warning system in Malaysia was conducted in 2010 and found a significant reduction in average and maximum speed with no lasting effects once the system was removed (16). The system was preferred over an active accelerator pedal (AAP), which is an in-car speed management system designed to prevent speeding, and participants were willing to continue using the warning system after the trial (17).
3. **ASEAN New Car Assessment Program (ASEAN NCAP):** Malaysia is a member of the ASEAN NCAP, a 10-member cohort of Asian countries established in 2011 (18). In 2014, the ASEAN Transport Minister appointed MIROS as the ASEAN Road Safety Center (18). This center aims to promote and provide knowledge on road safety issues among ASEAN Member States, including road traffic laws and regulations, data management, standards development, and road safety awareness and education (18). The funding for the first phase of this program was provided by Global NCAP (18). This program contributes to the "safer vehicle" component of the SSA since all aspects of the initiative are to improve the safety of cars within the region (18).

Nigeria

Nigeria is a lower-middle-income country (19). The Federal Road Safety Corps (FRSC) is the lead agency for road safety in Nigeria. FRSC was established in 1988 by the Federal Government of Nigeria under Decree No. 45 and is fully funded by the Federal Government of Nigeria through the National budget (20). The FRSC was judged to be one of the outstanding lead agencies within Sub-Sahara Africa responsible for road safety management (21). With a population of over 213 million, Nigeria has some 15.19 million registered vehicles on its roads. Nigeria also has a higher road fatality rate (17 deaths per 100,000 population) compared with the global average of 15 per 100,000 population (1).

SSA in Nigeria

Nigeria, through the FRSC, has adopted the SSA through its medium-term sector strategy referred to as the National Road Safety Strategy (NRSS) 2016–2020 (22). The NRSS was designed to function according to the SSA, as emphasized in the Accra Road Safety Declaration of 2007 and highlighted in the 2010 UN Decade of Action for Road Safety recommendations (23). While the Safe System Approach is acknowledged to be part of the NRSS 2016–2020, there is a notable absence of evidence indicating a solid commitment to its implementation which raises concerns about whether the adoption of the safe system in Nigeria is supported by concrete actions.

Technology and SSA in Nigeria

1. **Implementation of Speed Limiter Devices in Vehicles:** These devices are vehicle-specific and connected to vehicles' throttle control systems. The device prevents a driver from accelerating beyond a set speed (24). In 2016, the Nigerian FRSC adopted and enforced the use of speed limiter devices for fleet operators. These devices control the maximum speeds of equipped vehicles and serve as a tool for speed management (25). The introduction of speed limiter devices by ABC and Peace transport company resulted in significant savings in crash reduction and fuel efficiency (26). The FRSC cited the Nigerian Road Traffic Regulations ACT 2016, as amended, as the legal framework empowering the implementation of speed limiter devices.
2. **Nigeria Road Assessment Program (nRAP):** In February 2021, nRAP was established. Based on the International Road Assessment Program (iRAP), nRAP was created to improve current road safety engineering practices and establish secure road infrastructure for all users. nRAP uses mobile technology to assess roads on a five-star scale. The assessment aims to align with the Global Road Safety Performance Targets drawn from Pillar 2 of the United Nations Decade of Action for Road Safety which establishes the need for all roads to be built to a 3-star or better standard (27).
3. **Automated Number Plate Recognition (ANPR):** ANPR is a type of Automatic Enforcement System used in Nigeria. ANPR utilizes camera to capture license plate information of traffic safety violators. The government of Lagos State, a sub- national unit in Nigeria, launched the implementation of ANPR technology in 2018. In a recently published report, the ANPR captured over 850,000 traffic violations within 15 months (28). One limitation of the ANPR program in Nigeria is that it is not a national program and has only been implemented in Lagos State.

United States

The United States (US) is a high-income country. It is one of the world's most developed countries with a population of 336 million people, a broad network of roads and highways (29), and some 275 million registered vehicles. Despite its relative wealth, the US is confronted with serious road safety challenges with 40,990 fatalities reported in 2023; this represents a 3.6% decrease from 2022, when 42,514 people were killed on US roadways (30). The National Highway Traffic Safety Administration (NHTSA) was established

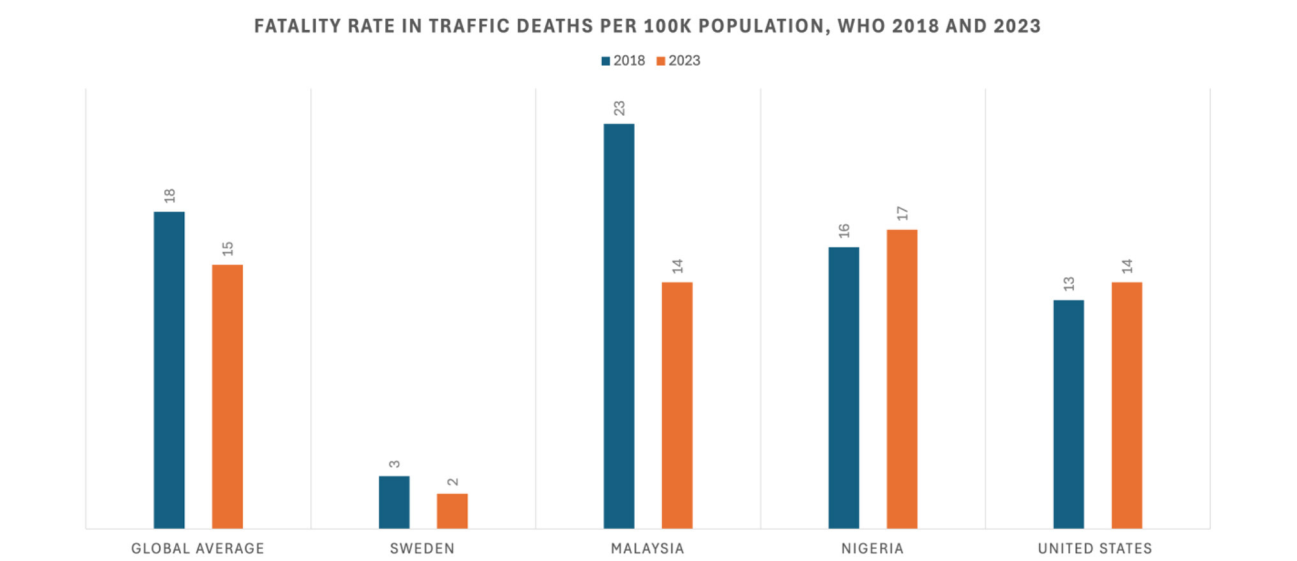

FIGURE 1
Fatality rate in traffic deaths per 100 k population, WHO 2018 and 2023 (1, 51).

by the Highway Safety Act of 1970 (31). NHTSA is the lead agency for road safety in the U.S.

SSA in the U.S.

In alignment with the SSA, the U.S. Department of Transportation has developed the National Roadway Safety Strategy (NRSS), which aims to achieve zero roadway fatalities and serious injuries (32). This strategy includes initiatives focused on infrastructure, human behavior, responsible oversight of the vehicle and transportation industry, and emergency response (32). The implementation of the NRSS is structured around the five elements of the SSA (32).

The US uses the terms Safe System and Vision Zero interchangeably, as does the Swedish practice. However, the definition of both terms can be inconsistent among jurisdictions. Some locations follow the definitions of the concept's originators, others have adopted the name but do not follow every component of the original practice (33).

Technology and SSA in the United States

1. **Advanced Driver Assistance Systems (ADAS):** ADAS includes vehicle safety features like lane departure warning, automated emergency braking, adaptive cruise control, and blind-spot recognition (34). These systems use sensors, cameras, and radar to monitor the vehicle's surroundings and will issue a warning or intervention as needed (34). Studies have shown that ADAS systems reduce crashes significantly, with automatic emergency braking reducing rear-end crashes by 50% (35).
2. **Automated Enforcement (AE):** AE systems operate automatically via cameras that capture offender license plate information and send a citation to the registered owner (36). They have been used in the U.S. since 1987 and the three most common types of technologies include red-light cameras, speed safety cameras, and school bus stop-arm cameras (36). The permitted use of AE systems varies by state and local municipalities and in some places, approval has been rescinded after community concern surrounding citation revenue (36). The World Bank, along with several U.S. safety agencies and road safety organizations have deemed AE effective; one Insurance Institute for Highway Safety (IIHS) study found red-light cameras to reduce fatal red-light running crashes and all fatal crashes at signalized intersections by 21% and 14%, respectively (37–40). Several studies have shown similar improvements with speed safety cameras, and school bus stop arm violators (41, 42).

Discussion

After a review of these SSA countries, technology is shown to be a promising tool to combat serious traffic injuries and fatalities. However, gaps and limitations were recognized across the different country incomes that need to be addressed to effectively intervene in this ongoing crisis. Leaders in SSA adoption, such as Sweden and other Scandinavian countries tend to be higher-income nations (2). Income can be considered an advantage when leveraging technology as a strategy to decrease and prevent serious traffic injuries and fatalities. The United States shows that despite being a high-income country with resources and road safety innovation opportunities, obstacles can exist for safety technologies. The United States has a higher fatality rate than most nations of similar economic levels (5) (Figure 1); while many factors affect traffic fatality rates, the US has lower rates of adoption of certain technologies, such as automated enforcement cameras than other high-income countries (36). Separation of authorities may also be

TABLE 2 Safe System Approach (SSA) technology case studies.

Country SES	Country	Technology	Cost High/medium/low	In country efficacy No/low/empirical
Low-income	Nigeria	Speed Limiter Devices	Medium	No
		Nigeria Road Assessment Program (nRAP)	Medium	No
		Automated Number Plate Recognition (ANPR)	Medium	No
Middle-income	Malaysia	Automated Awareness Safety System (AwAS) Cameras	High	Empirical
		Intelligent Speed Adaptation System (ISA)	High	Empirical
		ASEAN New Car Assessment Program (ASEAN NCAP)	Medium	Low
High-income	United States	Advanced Driver Assistance Systems (ADAS)	High	Empirical
		Automated Enforcement (AE)	High	Empirical

a possible factor in the low adoption of certain SSA technologies in the US. States have legislative powers which allow them to make their traffic safety laws and regulations (43); State DOT's can decide what strategies they are willing to fund and implement, including safety technology (43). Therefore, there are variations in the adoption of traffic safety approaches across 50 states. In addition, local DOT's may not have authority unless granted by the State (43). Therefore, local transportation agencies are usually left to comply with decisions made by State DOTs and face restrictions in funding (44).

While the advantages of high-income nations are clear, this does not preclude lower-income nations from adopting SSA principles. Many levels of technology can be implemented, including low-cost, quick-build solutions that are consistent with SSA principles such as red-light enforcement devices, flashing beacons at stop-controlled intersections etc. (45). Nigeria and Malaysia are examples of LMIC SSA countries that have found ways to implement technology despite GDP level and other challenges. For instance, Malaysian government officials identified AwAS cameras in their 2006–2010 Road Safety Plan, but it was not implemented until 2012; this delay could have been caused by institutional fragmentation and over dependency on limited government funding, which have been identified as challenges in road safety management in Malaysia (46, 47). In Nigeria, Uzondu et al. (48) identified inadequate funding for road safety as a critical challenge, suggesting that it contributes to the country's "overarching difficult" road safety environment (48). This finding aligns with Bishai et al. (49) who demonstrated a negative impact of insufficient road safety funding on overall outcomes (49). Differences in these government structures point out that while the SSA principles remain the same, strategies for the implementation of technology may need to be tailored according to the country's context (e.g., funding, government structure, etc.,). SSA model policy could aid in this implementation and it is recommended that it be explored.

It can be difficult to independently assess the association between technology and safety outcomes in SSA adopted countries however, according to a report by the Johns Hopkins Bloomberg School of Public Health, the Institute of Transportation Engineers, and the FIA Foundation, several nations have experienced significant reductions in traffic fatalities following the implementation of SSA (50). Implementing SSA in LMIC's can reduce road deaths and injuries, this review emphasizes the potential leveraging technology within SSA. Moreover, the affordability of SSA technologies is an important factor for LMICs to consider when designing their SSA interventions. LMICs may prioritize spending on lower-cost SSA technologies as highlighted earlier, while high-income countries may prioritize spending more resources on advanced vehicle technologies (Table 2).

Conclusion

Technology is not the only tool to achieving the Safe System Approach; however, this review found that the potential for safety advancement while leveraging technology exists across socio-economic levels. A factor identified for SSA technology implementation may be differences in leadership structure and funding commitment. There were limitations in the certainty of these conclusions, including a lack of impact analysis, and high-quality evidence on the effectiveness of technology especially in SSA adopted LMICs. As SSA evolves in a global context, further evaluation is needed on the role of technology and how government policies can restrict or advance its implementation.

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Mental health impairment and recovery after a road traffic injury: where do we stand in Europe?

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Individuals sustaining road traffic injuries (RTIs) have been shown to run an increased risk of impaired mental health over time and delayed recovery. It is often the case that mental health symptoms get less clinical attention among individuals sustaining RTIs and therefore psychological support tends to be delayed. Effective management of these aspects in a clinical setting is still challenging in Europe due to health systems' unpreparedness to predict the risk of poor mental health outcomes among survivors and appropriately intervene. Although a considerable amount of research is available in Australia, Canada and the US, the problem is still under-investigated in Europe. This paper reports on a review of the literature, which aims at identifying and presenting the latest research on the predisposing risk factors of poor mental health recovery among individuals sustaining an RTI in Europe. The review identified a huge mental health burden remaining long after the road traffic incident and a complex interplay of factors affecting mental health recovery after an RTI. Several challenges have been identified including the lack of a consistent definition for mental health recovery, the use of heterogeneous instruments and non-consistent epidemiological approaches and the lack of data collection mechanisms in Europe to capture the true impact of injuries. The paper concludes that existing efforts to fully understand the mental health outcomes of RTI patients remain inconsistent in Europe and offers evidence-based solutions to guide public health research and policy.

KEYWORDS

road traffic, injury, mental health, PTSD, depression, recovery, quality of life, disability

1 Introduction

A consistent pattern of mental health outcomes have been recognized in literature among individuals sustaining a road traffic injury (RTI) along with an increased heterogeneity in recovery times (1, 2, 59, 60). In fact, evidence suggests that individuals suffering RTIs may differ in their recovery compared to other traumas in terms of symptoms' onset, variability and chronicity. More precisely, survivors' have been shown to run an increased risk of psychiatric disorder onset (3), frequent changes in their mental health status over time (4) and a high risk of symptoms' chronicity (5). Even minor injuries have been shown to have chronic mental health consequences including reduced health-related quality of life and delayed return to work. In 2020 approximately 5.4 million of Europeans were treated in hospital Emergency Departments for RTIs (6), a substantial proportion of whom will develop a mental health condition post-crash. Despite the associated mental health burden, psychological aspects get less clinical attention as compared with the physical aspects of the injury and therefore psychological support tends to be delayed (7, 8). Effectively managing these issues in a clinical setting is still challenging due to the complex interplay of factors that need to be evaluated under a very busy schedule and a lack of knowledge and expertise (9, 10).

Despite the emerging evidence on the huge and enduring mental health burden, very few trajectories have been investigated in individuals sustaining RTIs (11, 12) and more research efforts have been warranted to identify modifiable risk factors in this population (13, 58). A critical need for more research has been stressed particularly in terms of minor-to-moderate injuries, where evidence is scarce due to underreporting (57). This is a pre-requisite for early identification of individuals at risk of prolonged mental health recovery and a critical step for early access to treatment (14, 15).

In response to this pressing need for additional efforts, a considerable amount of research has been initiated in Australia, Canada and the US during the last decade, toward examining RTIs and their mental health outcomes (5, 13, 16–18, 58) Survivors have been studied in these regions for up to 24-months and have been shown to suffer prolonged psychiatric morbidity at very high rates (almost 50%) (5). Hence, this is not the case for Europe, where research is limited even though RTIs are a major health problem and a leading cause of mortality and disability (19–22). In fact, there have been some collaborative projects aiming at investigating the burden of injuries either on mixed trauma populations or on specific injury types (e.g., Traumatic Brain Injuries, Spinal Cord Injuries), with RTIs remaining understudied. Comprehensive overviews of previous literature on recovery following RTIs have been published in two systematic reviews but evidence from Europe is scarce (10, 23). Therefore, the aim of this paper is to identify and present the latest literature on the predisposing risk factors of poor mental health recovery among individuals sustaining an RTI in Europe. More precisely, the paper reports on: (a) the mental health outcomes after an RTI, (b) the factors associated with mental health recovery after an RTI, and (c) the methodological limitations, research gaps and implications for future research, policy and practice.

2 Research strategy

This systematic review was conducted to explore the current literature on injuries sustained in road traffic crashes and the recovery process with emphasis placed on the mental health sequelae. WHO defines mental health as "a state of well-being in which an individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and is able to make a contribution to his or her community. The current study adopted "mental health" as an umbrella term for common post-crash mental health outcomes acting as predictors of long-term impairment, including post-traumatic stress disorder (PTSD), depression, panic disorder, generalized anxiety disorder, and substance use. A number of key terms were initially searched in PubMed, Scopus and Google Scholar. The search strategy included the following keywords; 'injury' AND 'motor vehicle crash' OR 'traffic accident' AND 'recovery' OR 'disability' AND 'mental health." Articles met the following criteria: published between 2014 and 2023; research papers; published in English language; European region as geographical area of reference. Exclusion criteria: studies not addressing RTIs but mixed-trauma populations, studies on injury mortality, and secondary publications such as opinion pieces. Articles reporting on the same study sample were excluded with those providing more detailed and complete methodological information on our research questions, retrieved for analysis [e.g., (24, 25)]. Reference lists were examined for additional evidence and "citation snowballing" was employed as a complementary process to primary search to ensure that studies, which are "hard-to-find" due to inconsistent use of terminology and reporting, are located and included in the review. Two researchers read abstracts of each retrieved article to determine eligibility.

3 Quality appraisal and synthesis

All the eligible full-text papers were retrieved and screened by two independent reviewers and critically appraised for the quality of the evidence and risk of bias using the Newcastle-Ottawa Scale (NOS) for cohort studies, which considers the case definition, participants' selection, comparability of study groups, exposure and outcome data to calculate a score, based on the reliability of the data. A NOS score of ≥ 6 indicates high quality, with a maximum total score of 9. For the outcome subcategory, a minimum duration of 3 months after the crash was set while for the subcategory of adequacy of follow-up was set to 50 per cent. Other study limitations were considered with particular emphasis placed on the coherent conceptualization of study constructs, the adequacy of study designs and the level of methodological soundness. No studies were excluded based on the quality criteria though the appraisal identified inadequate descriptions of study parameters and risks of bias (see Table 1). Based on the assessment, the overall quality was below the threshold. All the studies confirmed the RTI via medical records and described those lost to follow-up. Common limitations were the lack of non-exposed subjects, poor baseline assessment of mental health state prior to the crash (e.g., self-reported, retrospective or short-term), use of self-reports to assess the outcome and incomplete follow-up.

All studies were then summarized in Table 1 with the following headings: authors; design; purpose; setting/population; mental health outcomes at post-injury; risk factors of poor mental health recovery; study limitations and risk of bias. Decisions about which data to be extracted from individual studies were guided by the review objectives. Meta-analysis was not considered for this review because of the low quality of the identified studies. Meta-analyses would be performed only if more than three studies were above the quality assessment threshold. Therefore, to facilitate interpretation of evidence, we used descriptive information. A narrative summary was used to describe the included studies and their findings, while enabling the identification of patterns across the studies as well as the exploration of relationships within and between studies, based on commonalities in outcomes, study designs and instruments used across the identified studies.

TABLE 1 Characteristics of the four selected studies.

Authors	Design	Purpose	Setting / Population	Mental health outcomes at post-injury	Risk factors of poor mental health recovery	Study limitations and risk of bias*
Nhac-Vu et al. (42)	Prospective study / follow up at 12 months following the RTC	To identify predictive factors of patients' outcomes 1-year post RTCs	All Hospital Units Rhone administrative Department of France /616 road crash victims in France	Rate of PTSD at 1 year (19%)	Age > 24 years, initial injury severity, injury type (spinal or lower limb injuries), socio-economic fragility, involvement of a relative in the accident.	Incoherent conceptualization of recovery and mental health constructs; Weak justification of measurements' selection; Weak framework of analysis due to missing data at follow up, small sample sizes and low statistical power; Mental health outcomes reported for small groups (NOS = 4)*.
Dooh an et al. (24)	Mixed method study (qualitative/ quantitative) / follow up 1 to 3 months following the RTC	To explore physical and mental consequences and injury mechanisms among bus crash survivors and identify aspects that influence recovery.	Swedish Accident Investigation Authority (SAIA; Stockholm, Sweden), Post-crash investigation /56 survivors from a bus crash in Sweden	17 (31%) had a high risk (TSQ ≥ 6) for PTSD.	Higher mental distress among survivors living with moderate to severe physical injuries or with a partner who sustained moderate to severe injuries.	Weak epistemological orientation; Incoherent conceptualization of recovery and mental health constructs; Weak justification of measurements' selection; Short follow up period; Non-validated research instrument; Non-validated framework of combined analysis of mixed method data (NOS = 2)*.
Papadakaki et al. (21, 43)	Prospective study / follow up at 1–6-12 months following the RTC	To examine the psychological and physical consequences of injuries sustained in road traffic crashes in a group of road crash survivors 6 and 12 months after the injury.	7 Hospital Intensive Care Units (ICU) in 3 Countries / 239 road crash victims in Greece, Germany, and Italy	*At 6 months post-injury: 39.6% PTSD, 33.0% Depression. *At 12-month post-injury: 21.1% PTSD, 23.3% Depression *Lower risk of Depression: 79% at 6-months and 88% at one-year. *Lower risk of PTSD: 72% at one-year.	Injury severity (higher scores), injury type (lower limb injury), initial psychological response (higher distress immediately after the injury), age (older), user type (cyclists, pedestrians).	Incoherent conceptualization of mental health constructs; Weak justification of measurements' selection; Mental health state not assessed at pre-injury level; High drop-out rate in one study site (NOS = 5)*.
Kova cevic et al. (20)	Prospective study / follow up at one-month post-injury	To evaluate the quality of life of the RTA survivors and identify factors associated with decreased quality of life after the RTA.	Institute of Emergency Medicine in one County of Croatia/ 200 RTA survivors with and without injuries in Croatia	35.5% (PTSD) 20.0% (Depression) 4.5% (Anxiety)	*Reverse correlation of mental health outcomes with all QoL domains after the RTA. *Mental health after RTI associated with age, self-assessed economic status, poor pre-RTA health (chronic disease, psychiatric disease, previous permanent pain, use of medications), injury-related factors (injury affliction, injury severity self-assessed life-threat pain following the RTA).	Incoherent conceptualization of mental health constructs; Weak justification of measurements' selection; Participant recruitment process not detailed; Short follow up period; Weak assessment of mental health state at pre-injury level; Participants' performance/ mental health outcomes not reported (NOS = 4)*.

*NOS, Newcastle-Ottawa Scale score.

4 Results

4.1 Description of available studies from Europe

A total of 97 articles (23 Scopus, 16 Pubmed, 58 google scholar) were identified (88 unique citations after the removal of duplicates; 2 retrieved for analysis). Four more articles were identified through the review of the reference lists of the eligible articles (3 eligible, 1 removed due to reporting on the same study sample; 2 retrieved for analysis). Four articles in total were retrieved for analysis (see Figure 1 flow diagram).

Studies that were excluded from the analysis were primarily from countries outside of the European region such as Australia [e.g., (2, 13, 26)], United States [e.g., (27, 28)], Canada [e.g., (29, 30)], Asia (31, 32) and Africa [e.g., (33)]. Studies from the European region derived primarily from the Netherlands and Norway and most often were excluded from the analysis due to investigating mixed trauma populations [e.g., (34, 35)] or due to focusing on specific injury types [e.g., (36–38); focus on Traumatic Brain Injuries / (39, 40); focus on Traumatic Spinal Cord Injuries]. Studies from Europe aimed at describing the prevalence and prognostic factors of mental health symptoms, quality of life as well as functional and psychological recovery after injury in clinical trauma populations [e.g., (34, 37, 40)]. They most often employed Emergency Departments (EDs) or Intensive Care Units (ICUs) encounters [e.g., (34, 37, 41)], with the follow up ranging from 6 months [e.g., (38)] to 5 years post-injury [e.g., (36)].

As for the studies that were retrieved for analysis, except for the study of Doohan et al. (24), which constitutes a post-crash investigation of 56 survivors, by a national Swedish Authority, the three remaining studies employed prospective research designs to measure a wide range of physical, psychological and functional outcomes following an RTI with medium sample sizes (ranging from 200 to 886 survivors). The settings in these studies were either Emergency Departments (EDs) (20, 42) or Intensive Care Units (ICUs) (21, 43, 44) and some of the studies focused on specific hospitals while others reported county-wide data. Depending on the study setting, populations differed in terms of injury severity scores with serious or critically injured patients represented more in one

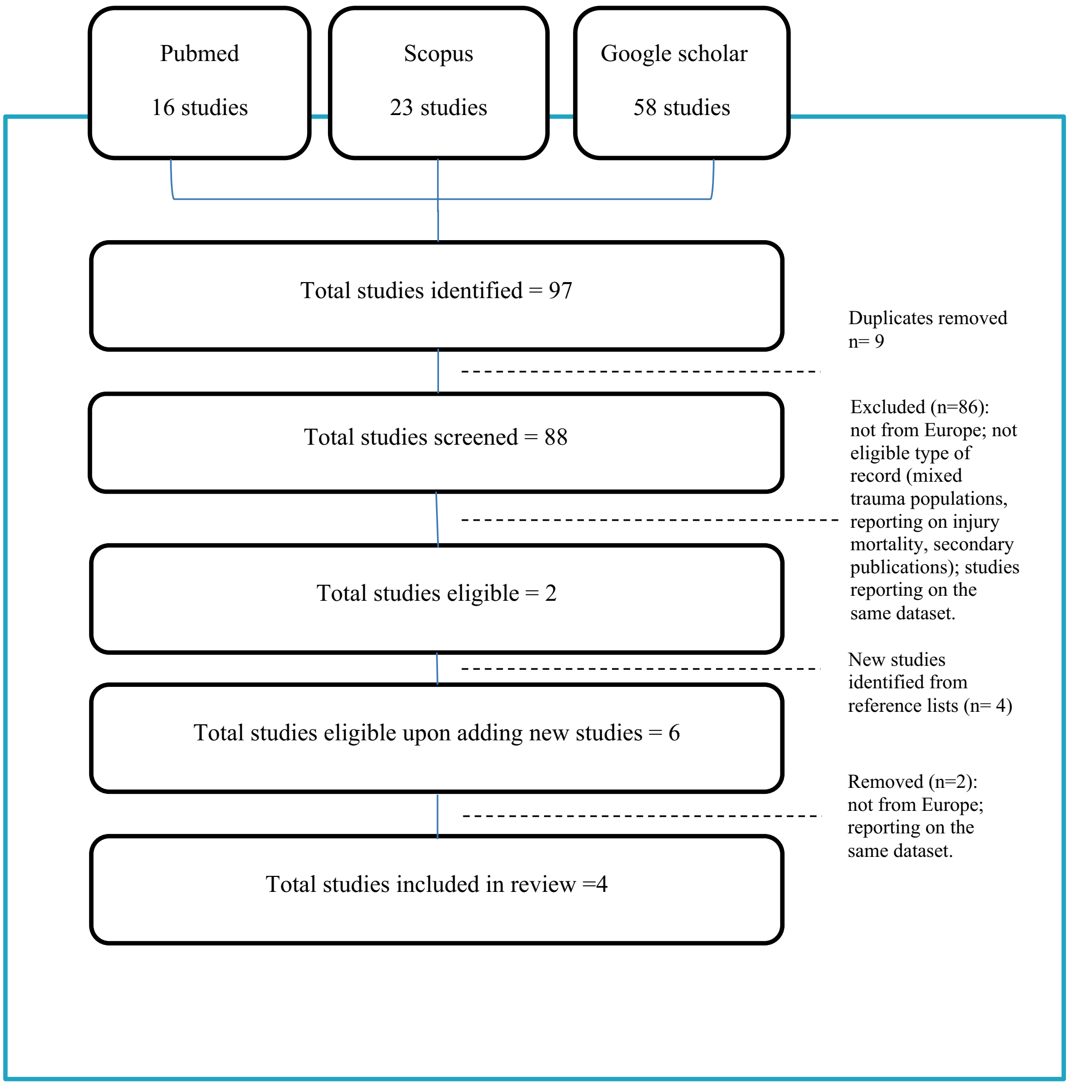

FIGURE 1
PRISMA flow diagram.

study than others (21, 43). Follow up ranged from one-month (20, 24) to a maximum of one-year post-injury (21, 42, 43). Health-related quality of life was used in all the prospective studies as a key concept to measure the "recovery process" of the RTI survivors with mental health captured as one of the multiple dimensions of quality of life. Self-reported symptoms of post-traumatic stress disorder (PTSD), depression and anxiety were also evaluated as indicators of mental health comorbidity after an RTI.

4.2 Prevalence of mental health outcomes after an RTI

Symptoms of PTSD and depression were the most consistently reported mental health outcomes. PTSD symptoms were reported by 35.5% of survivors one-month post-injury, by 39.6% at 6 months and by 19.0–21.1% at one-year post-injury. Likewise, depression was reported by 20.0% one-month post-injury, by 33.0% at 6 months and by 23.3% at one-year post-injury. At one-year post-injury, there was an 88% lower risk of depression and a 72% lower risk of PTSD.

4.3 Factors shown to contribute to poor mental health recovery after an RTI

A diverse range of factors were shown to be associated with mental health morbidity following RTIs, including socioeconomic factors, pre-injury health, injury-related factors and other incident-related circumstances. Many of these factors have already been identified in previous systematic reviews (10, 23). As regards to the socioeconomic factors, age and self-assessed economic status had a strong effect on mental health recovery after an RTI (20, 21, 42, 43). In Papadakaki et al. (21) the risk of depression at one-year post-injury increased by 5% with every additional year of age and in Nhac-Vu et al. (42) age > 24 years was predictive of poor outcome at 1 year. Papadakaki et al. (21) identified a 7.49 times higher risk of survivors being depressed at 6 months post-injury, if divorced or widowed as compared with single. Nhac-Vu et al. (42) identified increased risk of poor outcomes at one-year post-injury among individuals who lived alone, resided in disadvantaged areas, had low educational attainment and occupational instability or lacked health insurance to address their health care needs. As for the impact of pre-injury health, pre-existing chronic disease, psychiatric disease and pain as well as the use of medication before the RTI, increased the risk of enduring psychological impairment after an RTI (20, 21). Injury-related factors linked with poor mental health outcomes were injury severity, suffering and pain severity (20), body region injured (low-limb injuries had poor outcomes at one-year post-injury) (21, 42), initial psychological reaction (those who developed depression immediately after the injury had 4.77 times higher risk of being depressed at 6 months post-injury and 4.81 times higher risk at 12 months post-injury) (21). As for incident-related circumstances, Nhac-Vu et al. (42) and Doohan et al. (24) found that the involvement of a relative in the incident had a major effect on the recovery process, with survivors' well-being being directly affected by their family's well-being. Moreover, vulnerable road users (e.g., pedestrians, cyclists) were shown to be more prone to poor mental health outcomes as compared with other road users. In Papadakaki et al. (21) four-wheel users had 85% decreased risk of developing depression at 12 months post-injury as compared with pedestrians and cyclists.

5 Discussion

What clearly comes out of this review is the fact that despite the growing interest in mental health outcomes after an RTI, research is still limited in Europe. The few available studies identified in this review have several methodological limitations (see Table 1) related to their study design (e.g., inconsistent conceptualization of the mental health target and outcomes, short follow up periods limited to 12 months), their participant recruitment techniques (e.g., poor description or non-probabilistic recruitment), and the measurements used (e.g., inconsistent selection of tools and instruments to evaluate the outcomes). More epidemiological studies are needed in Europe with longitudinal study designs and longer follow-up periods to allow for the exploration of these complex trajectories and factors that influence recovery. Non-injury healthy controls could be included for improved research outcomes on psychiatric comorbidity in order to address non-RTI related confounding factors (15, 45).

Another issue clearly identified in this study is the lack of a consistent definition for mental health recovery after an RTI, which is thought to result in the use of heterogeneous instruments and non-consistent epidemiological approaches (see Table 2). In general, recovery after an RTI seems to lack a standardized definition (10), with part of the literature assuming recovery based on improved performance in quality of life measures, mental health status, return to work, disability levels, while another part of the literature employing definitions of recovery, which are guided by regulatory authorities and are based on the status of the compensable injury (23, 46). In this review, we realize that studies employ a narrow clinical definition of recovery, which emphasizes one's psychiatric symptoms and functioning without encompassing psychological aspects such as resilience, coping, self-efficacy and spirituality and without taking into account one's attitudes, feelings, goals, and skills to live within the limitations caused by the injury. We have also noticed that specific mental health conditions have been repeatedly selected as indicators of mental health recovery after an RTI (e.g., PTSD, depression, anxiety, health-related quality of life) and a variety of instruments have been employed to measure the degree of impairment over time (*Trauma Screening Questionnaire, TSQ*; *Impact of Event Scale, IES-R; Center for Epidemiological Studies Depression Scale, CES-D; PTSD Checklist for Civilians, PCL-C; Beck Anxiety Inventory, BAI; Beck Depression Inventory, BDI-I; WHOQoL-bref for HRQoL; SF-36; WHODAS II*). This inconsistency in epidemiological research has been thought to strongly affect comparability of data and potentially hinder the establishment of screening criteria for poor mental health recovery. In light of these limitations, a universal definition of recovery after an RTI, has been seen as critical for improved understanding of risk factors of poor recovery as well as improved identification and treatment of those at risk (22, 47, 48). Considering the variety of definitions and instruments used interchangeably and the mixed results, some studies have endorsed the use of quality-adjusted life year (QALY) (49) and the disability-adjusted life year (DALY) (50) as measures of injury burden that could potentially promote comparability among study outcomes. Berg et al. (51) also proposed the Risk of Permanent Medical Impairment (RPMI) concept (52) and the Function Capacity Index

TABLE 2 Outcome measures and instruments used for mental health recovery after an RTI.

Authors	Mental health outcomes to measure recovery	Instrument used to measure recovery	Study limitations and risk of bias
Nhac-Vu et al. (42)	Post-Traumatic Stress Disorder (PTSD)	Post Traumatic Stress Disorder Checklist Scale (PCLS)	17 items assessing re-experiencing (items 1–5), avoidance (items 6–12) and increased arousal (items 13–17). Responses anchored from "1 = not at all" to "5 = very often." The threshold of 44 was applied to indicate possible PTSD.
	Mental health as a dimension of general health.	World Health Organization Quality of Life Assessment (WHOQOL-BREF)	26 items: 2 items assessing overall satisfaction with life and general sense of personal well-being and 24 items assessing 4 domains: physical health (7 items), psychological health (6 items), social relationships (3 items), and environment (8 items). Responses anchored from 1 to 5, summed, and transformed into a scale from 0 (worst health- related quality of life) to 100 (best health-related quality of life).
(Dooh an et al. (24))	Post-Traumatic Stress Disorder (PTSD)	Trauma Screening Questionnaire (TSQ).	10 items assessing PTSD risk after potentially traumatic experiences. Items covered two of the PTSD criteria: re-experiencing and arousal symptoms. "yes" or "no" responses. Six or more positive answers indicated risk of developing PTSD.
Papadakaki et al. (21, 43)	Post-Traumatic Stress Disorder (PTSD)	Impact of Event Scale (IES-R)	15 items assessing PTSD risk. Two subscales; the "Intrusion Scale" (7 items) and the "Avoidance Scale" (8 items). Responses anchored from "0 = not at all" to "5 = often." Higher scores indicated greater stress symptoms.
	Depression	Center for Epidemiological Studies Depression Scale (CES-D Scale)	20 items assessing depressive symptoms over the previous week. Responses anchored from 0 to 3 (0 = Rarely or none of the time, 3 = Most or all the time). Four items were worded positively and reverse coded. Higher scores indicated greater depressive symptoms.

(FCI) (53) as benchmarks of medical disability to enable comparisons of long-term consequences of injuries among European countries. However, no consensus has been reached yet on the methods that best capture these complex aspects of recovery in the long run.

Despite the above-mentioned methodological challenges, a huge mental health burden has been identified in this review with symptoms of depression, PTSD and anxiety remaining long after the road traffic incident. The recovery trajectory seems to vary widely with a large percentage of survivors in need of extensive time periods for full recovery (5, 13, 18, 58). Given the high incidence of mental health impairment among RTI survivors, is seems essential to ensure that mental health concerns are addressed alongside physical injuries at all levels of health care. Implementing predictive screening at the location of the incident and during initial medical assessments is critical for those at risk of sustaining long-term mental health impairment. Likewise, ensuring access to psychological counseling and trauma-informed care as well as anticipating professional assistance in the process of psychological adjustment to the acquired disabilities, is critical for patients' recovery. Most importantly, mental health assessment and individually tailored interventions need to be integrated into the standard care protocols for RTI patients to ensure an efficient health system's response.

What stands out of this review, is the complex interplay of factors affecting mental health recovery after an RTI. Mental health resilience following RTIs is better understood upon considering a variety of factors related to the individual, the injury and the incident. In our study, the injury type (lower limb injury), initial psychological response to the injury (higher distress immediately after the injury), user type (cyclists, pedestrians), pre-existing physical or mental health problems, socioeconomic fragility and performance in various "Quality of Life" domains (lower scores in various domains including physical health, social functioning, etc), were common factors that influenced the risk of poor mental health recovery after an RTI. Most of these factors are already known from previous research from countries outside Europe (13, 15, 54). This observation implies that there is no silver-bullet solution to prevent poor mental health recovery among RTI survivors.

Interestingly, the current study generates important evidence on the impact of socioeconomic factors on mental health recovery among RTI survivors. It is often the case in research to place emphasis on the physical disability and the functional independence of the individuals and overlooks the capacity of a person to continue functioning. Multiple studies indicate that low-income and low SES households lack access to resources that they need after traumatic events (55). Changes in the employment position or the salary, in-house adaptations, childcare arrangements and the need for paid child-caregiver are often "neglected" parameters after an RTI, which constitute a huge burden for low-income families. Despite this fact, we realized that social, financial, and familial consequences are rarely investigated in the literature on RTIs, most probably due to a lack of investment in this domain and also due to difficulty in accessing such information from public registries. Most importantly, expertise in economic estimation of social capital in this research and policy domain is still low in many EU countries. Assessing all this information, could on one hand offer an opportunity of a holistic assessment of the circumstances caused by the traumatic event on individuals' lives and accurate interpretation of evidence, and on the other hand allow evidence-based decisions on the appropriate therapeutic solutions upon considering the social capital of the individuals (43).

5.1 Study limitations

A number of limitations have been identified and need to be acknowledged. The current review included only three databases and this implies that there may be other studies not captured in this review. We only included studies written in English language and we may have missed findings reported in other languages. Citation snowballing, although useful in detecting "hard-to-find" studies, it should be used with caution due to being susceptible to selection biases. The study employed "mental health" as an umbrella term to capture the state of participants' well-being. It is possible that there are studies focusing on specific mental health conditions or outcomes that may fall within the scope of the study but not identified in this review. Critical appraisal of identified studies did not explicitly inform the synthesis stage, and therefore did not influence the review outcomes. This implies that the review findings may be biased due to including studies with low quality and internal validity. Likewise, the small sample of identified studies and their diverse methodological characteristics made it inappropriate to undertake a meta-analysis or infer that the findings can be generalized to other EU countries. More longitudinal studies are thus warranted in the future to facilitate interpretation of the complex mental health recovery trajectories after injury and improve our understanding of how subgroups adjust following an RTI. Lastly, given the methodological limitations and the research gaps revealed in this review, based on insights from articles focusing on Europe, a higher level of inclusion could be considered as useful and more impactful in future systematic reviews on the mental health recovery of RTI survivors.

6 Conclusion

Efforts to fully understand the mental health outcomes of patients sustaining RTIs, remain inconsistent in Europe. There are few challenges to be mentioned. First, injury data collection and analysis are still problematic in Europe. Many countries still lack the data and the systems for collecting accurate and comprehensive information on the burden of RTIs and mental health outcomes, and this makes it difficult to understand the true impact of injuries on populations and guide public health interventions. Second, even the few countries in Europe that have more advanced injury registries and robust data management systems (e.g., Norway, the Netherlands, Belgium) are still struggling with data linkage challenges, inconsistent injury coding systems, missing data due to non-mandatory recording, privacy and security concerns. The complex mechanism of injuries cannot be understood if access to valid data is not granted, and countries in Europe still lack a comprehensive picture of morbidity due to injuries and their predisposing factors. The EU-IDB (European Injury Database), operated under the European Association for Injury Prevention and Safety Promotion (EuroSafe) and the European Burden of Disease Network of the WHO Regional Office for Europe are leading initiatives in Europe, currently acting as a technical platform for integrating and strengthening capacity in the assessment of injury burden across Europe. Apart from this, it is critical for Europe to invest more efforts on systematic collection of data on risk exposures, better diagnostic tools and prediction models of mental health morbidity to accurately predict mental health outcomes. This can be achieved through equipping hospitals with standardized assessment tools, clinical evaluation protocols and trained mental health professionals to early address risk factors and facilitate a successful mental health recovery after an RTI. In fact, a modern comprehensive trauma system should start with injury recognition, continue with triage to a trauma center, multidisciplinary inpatient care, and outpatient follow-up of long-term physical and psychosocial sequelae (56). To manage this stepwise process, it is critical for health care systems to run gap analyses and develop action plans. Most importantly, it is critical for systems to select performance measures, establish collaborative relationships and operational processes as well as adopt a core set of trauma-related skills to optimize medical and nursing post-injury care. The American College of Surgeons (ACS) released new guidelines in 2023 to assist trauma centers in efficiently addressing mental health issues among patients who have experienced a traumatic injury. Investment on interprofessional education and joint curricula, is also critical as it will allow a holistic understanding of patient care, emphasizing the importance of addressing not only the physical but also the psychological and social aspects of recovery. Addressing patients' needs holistically upon hospital discharge, will strengthen personalized care and will support patients in building resilience and coping strategies. Most importantly, managing service integration between health (medical, psychological) and social services (rehabilitation, community support) will improve patients' access to information and will ensure continuity of care, which is essential for recovery. In fact, collaboration with social services can provide patients with access to resources like counseling, financial support, and community programs while offering a support network, education and support groups, which are vital for mental health recovery. What is even most important is securing a strong political commitment to prioritize injury prevention efforts among other topics in the political agenda. This requires synergies, joint policy-making, aligned goals among different sectors and high public acceptability. To make it feasible, it is necessary to ensure financial and technical resources, a legal mandate and "a champion" at higher political levels to drive implementation.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Effect of emergency medical service response time on fatality risk of freeway crashes: Bayesian random parameters spatial logistic approach

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Introduction: Emergency medical service (EMS) serves as a pivotal role in linking injured road users to hospitals via offering first aid measures and transportation. This paper aims to investigate the effect of emergency medical service (EMS) response time on the fatality risk of freeway crashes.

Methods: Crash injury severity data from Kaiyang Freeway, China in 2014 and 2015 are employed for the empirical investigation. A Bayesian random parameters spatial logistic model is developed for analyzing crash severity.

Results: Bayesian inference of the random parameters spatial logistic model demonstrates the importance of reducing EMS response time on minimizing the fatality risk of freeway crashes. Fatality odds would increase by 2.6% for 1 min increase in EMS response time. Additionally, vehicle type, crash type, time of day, horizontal curvature, vertical grade, and precipitation are also found to have significant effects on the fatality probability of freeway crashes.

Conclusion: It is crucial to reduce EMS response time to decrease the fatality likelihood of freeway crashes. Some countermeasures have been proposed to shorten EMS response time.

KEYWORDS

emergency medical service, response time, fatality risk, freeway crash, random parameters spatial logistic model

1 Introduction

Given the huge emotional and economic burden imposed by roadway crashes on the society, identifying contributing factors to crash occurrence and injury severity and quantifying their effects have long been a research focus in the research field of traffic safety (1). Most of existing studies (2–5) explored contributing factors to crash occurrence (pre-crash factors) and those to injury severity during the crash event from human, vehicle, and environmental factors. On the other hand, post-crash factors, such as those pertaining to emergency medical services (EMS), have been relatively less investigated, due to data availability and reliability.

After the crash occurrence, EMS serves as a pivotal role in linking injured road users to hospitals via offering first aid measures and transportation (6). EMS response time, herein

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defined as the time that elapses from the notification of a traffic crash until EMS personnel arrives at the crash scene (7), is an important indicator of the time for patients to be treated and the performance of dispatching EMS resources (8). Many safety researchers (9–11) acknowledge the significant impact of EMS response time on the fatality likelihood of traffic crashes, especially in cases of victims sustaining severe injury. This opinion is reasonable, because a proportion of crash deaths would be evitable, from the clinical perspective, if timely medical treatments were provided to the severely injured victims, particularly those with brain/heart trauma (12) or in need of haemorrhage controls or open airways (13, 14).

Despite of sparseness, there is a small quantity of studies that have investigated the effect of EMS response time on the injury severity of traffic crashes, using discrete outcome models. For example, based on a binary probit regression analysis of a dataset with over 1,400 traffic crashes in Spain, Sánchez-Mangas et al. (11) concluded that a 10-min reduction of EMS response time is expected to result in the fatality likelihood decreasing by 33%. Using a dataset from the Fatality Analysis Reporting System (FARS) in the U.S., Ma et al. (15) investigated the smooth relationship between crash fatality probability and EMS response time and found that 17 min is the gold time for crash rescues. Lee et al. (6) developed a random effects ordered probit model for analyzing crash injury severity, and incorporated crash-reporting time, response time, and transport time into the analysis. Their results indicate that longer response time and transport time are linked to more severe injury outcomes. Hosseinzadeh and Kluger (16) also adopted a random effects ordered probit model for uncovering the association between crash injury severity and EMS response time and on-scene time, as well as crash-related factors. They found that shorter response time and longer on-scene time is helpful to decrease the severity level of entire-body injuries. Zeng et al. (17) proposed a spatial generalized ordered probit model for the analysis of freeway crash severity, where EMS response time is included as an explanatory variable. The results also suggested that is lower crash severity is associated with a shorter EMS response time. Although the above studies have all demonstrated the significant impact of EMS response time on crash injury severity, a distinct difference lies in them: the former two studies categorized crash severity into two levels (i.e., fatal and non-fatal) and assumed that EMS response time has a considerable effect on fatality likelihood, and the latter three studies categorized crash severity into more than two levels (e.g., KABCO has five severity levels) and implied that EMS response time may have significant effects on the likelihoods of other severity levels, such as no injury. Obviously, the former assumption is more reasonable and consistent to the findings from clinic medicine. To accurately quantify the effect of EMS response time on the fatality likelihood of freeway crashes, in this research, the injury severity will be divided into fatal and non-fatal, as in Sánchez-Mangas et al. (11) and Ma et al. (15). Our research focuses on freeway crashes, as they are more likely to result in human deaths than traffic crashes on other types of roadways, such as urban roads. Besides, the unique built environment (e.g., far from hospitals) and roadway conditions (e.g., the existence of emergency lane and no intersection) may make the EMS response time for freeway crashes different from that for crashes on other roadways.

Analytic method is also important to analyze crash injury severity. Given the binary categorization, statistically, binary logit or probit models have been most frequently used. In the recent decade, accounting for the unobserved heterogeneity and spatial correlation is prevalent when modeling crash severity (18, 19). Random parameters (20), latent class/finite mixture (21), and Markov switching approaches (22) are typical methods capable of capturing the unobserved heterogeneity. Among them, random parameters approaches are most widely used. To accommodate spatial correlation, various spatial structures, including spatial lag (23, 24), spatial error (23), intrinsic conditional autoregressive (CAR) (25, 26), and Leroux CAR (17), have been incorporated into the formulation of discrete outcome models. Zeng et al. (17) found that the Leroux CAR is superior to other alternatives. In this research, we propose a random parameters spatial logistic model with Leroux CAR for analyzing freeway crash severity, which can simultaneously capture the unobserved heterogeneity and spatial correlation in it.

The rest of the article is organized into four sections. The freeway crash-severity data used for the empirical analysis are introduced in Section 2. We specify the formulation of the random parameters spatial logistic model in Section 3. The Bayesian estimation results of the proposed model are summarized and interpreted in Section 4. In the last section, we draw conclusions from the research and offer guidance for future research.

2 Data

Crash data of 2 years in 2014 and 2015 were collected from Kaiyang Freeway in Guangdong, China, which were acquired from the Highway Maintenance and Administration Management System maintained by Guangdong Transportation Group. Excluding the crash records with incomplete information, 1,414 crash records were used for the empirical analysis. In the original crash records, injury severity is categorized into four levels: no injury, slight injury, severe injury, and fatality. As mentioned earlier, the paper focuses on quantifying the effect of EMS response time on the fatality likelihood of freeway crashes versus that of non-fatality. Thus, the injury severity in the analysis was contracted into two levels: non-fatality (combining no injury, slight injury, and severe injury) and fatality. Among the observations, 1,378 crashes' severity levels are of non-fatality and 36 crashes' are of fatality.

In the crash records, in addition to injury severity, some information pertaining to EMS, involved vehicle(s) and accident configuration is also documented, including: EMS response time, vehicle type (passenger car, coach, truck, and others) and license number (which is used to distinguish if a vehicle is local or not), crash time (morning, afternoon, evening, and before dawn), crash date (weekday and weekend), crash type (single-vehicle crash, rear-end crash, and angle crash), and crash location (which is expressed as kilometers marker of the freeway). As the key factor under investigation, the distribution of EMS response time in the dataset is shown in Figure 1.

We obtain the geometry design materials on Kaiyang Freeway from Guangdong Province Communication Planning and Design Institute Co., Ltd. Four roadway attributes, including horizontal curvature, vertical grade, and if the crash site is near a ramp or on a bridge, are extracted from the materials and matched with each crash according to their location information. To capture the spatial effects in the crashes, the freeway is segmented into 154 sections based on the criterion of homogeneity in horizontal curvature and vertical grade, which is line with the roadway segmentation methods used in the past studies (17, 27).

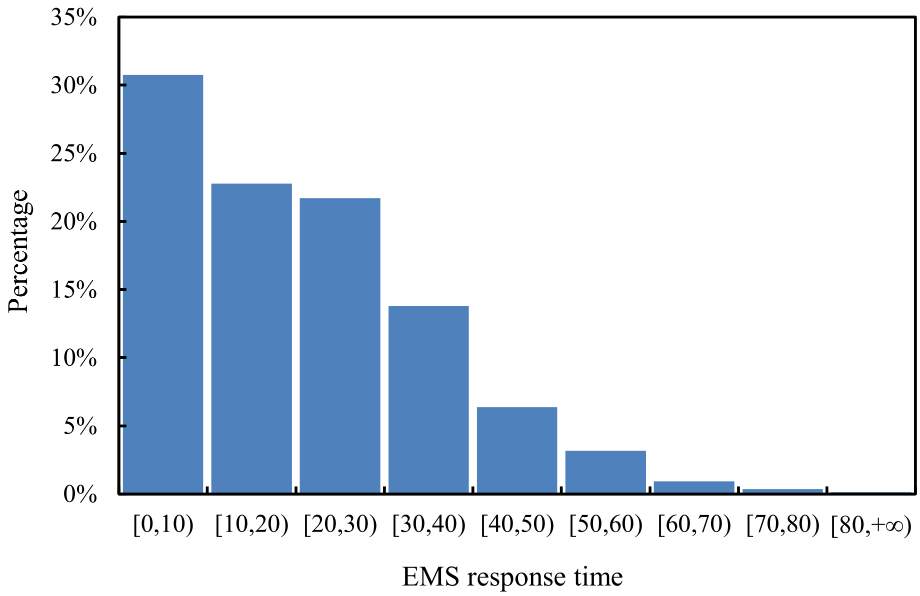

FIGURE 1
The distribution of EMS response time.

We collect the real-time weather data along the freeway from the Meteorological Information Management System. The system is administrated by the Guangdong Climate Centre, an official meteorological organization. The data on wind speed, precipitation, visibility, temperature, and humidity are observed and recorded in each hour by three weather stations: Enping Weather Station, Kaiping Weather Station, and Yangjiang Weather Station. We match each crash under investigation with the hourly meteorological information from the nearest weather station through the crash time and location.

Table 1 displays the definitions and descriptive statistics of crash injury severity and its potential influence factors for the empirical analysis. We conduct Pearson correlation test and multi-collinearity diagnoses for the factors in SPSS software and find that there is no significant correlation or multi-collinearity among them.

3 Methods

We propose a random parameters spatial logistic model for investigating the crash injury severity with binary outcomes (fatality and non-fatality). To justify the superiority of the proposed model, we compare it with traditional logistic model and spatial logistic model. In the section, the formulations of these models are clearly specified in the order of model complexity (Section 3.1); and then the implementation processes of Bayesian estimation and performance assessment criterion for the models are introduced (Section 3.2).

3.1 Model formulation

3.1.1 Logistic model

Logistic model (i.e., binary logit model) is one of the most extensively used methods for the analysis of crash injury severity divided into two levels (1). As suggested in Table 1, denote fatal crash = 1 and non-fatal crash = 0. For any crash i, a latent variable U_i is set. It is assumed that there is a linear association between U_i and the covariates. If U_i is positive, the injury severity of crash i is fatal; otherwise, it is non-fatal. The model equation is shown in Equations 1 and 2:

$$U_i = \beta_0 + \sum_{j=1}^{J} \beta_j x_{i,j} + \varepsilon_i, \tag{1}$$

$$Y_i = \begin{cases} 1, & if\ U_i > 0 \\ 0, & if\ U_i \le 0 \end{cases}, \quad i = 1, 2, \cdots, N \tag{2}$$

where $x_{i,j}$ is the observed value of the jth $(j = 1,2,\cdots,J)$ covariate, x_j, in crash i, and β_j is the coefficient corresponding to x_j. β_0 is a constant term. J and N are the numbers of covariates and crashes in the dataset. ε_i is a residual term and is assumed to have a logistic distribution. Its cumulative distribution function is expressed as Equation 3:

$$F(\varepsilon) = \frac{1}{1 + \exp(-\varepsilon)}, \tag{3}$$

According to the model formulation, the probabilities of crash i resulting in fatality and non-fatality (represented by $p_{i,1}$ and $p_{i,0}$ respectively), can be calculated as Equations 4 and 5:

$$p_{i,1} = \frac{\exp\left(\beta_0 + \sum_{j=1}^{J} \beta_j x_{i,j}\right)}{1 + \exp\left(\beta_0 + \sum_{j=1}^{J} \beta_j x_{i,j}\right)}, \tag{4}$$

$$p_{i,0} = \frac{1}{1 + \exp\left(\beta_0 + \sum_{j=1}^{J} \beta_j x_{i,j}\right)}, \tag{5}$$

TABLE 1 Definitions and descriptive statistics of crash injury severity and influence factors.

Variables	Description	Mean	S.D.	Min.	Max.
Crash injury severity	Fatality = 1; non-fatality = 0	0.025	0.155	0	1
EMS response time	The duration from the crash notification to the arrival of EMS personnel at crash scene (minute)	19.56	16.61	1	260
Weekend	Crash happens on a weekend = 1; otherwise = 0	0.347	0.476	0	1
Vehicle characteristics					
Car*	Only passenger cars are involved =1; otherwise = 0	0.579	0.494	0	1
Coach	At least a coach is involved =1; otherwise = 0	0.064	0.245	0	1
Truck	At least a truck is involved = 1; otherwise = 0	0.313	0.464	0	1
Other_vehicle	At least a other vehicles (e.g., towed vehicles) is involved = 1; otherwise = 0	0. 098	0.298	0	1
Non_local_vehicle	At least an involved vehicle is not registered in Guangdong Province (non-local vehicle) = 1; otherwise (local vehicle) = 0	0.280	0.433	0	1
Time of day					
Before_dawn*	Crash happens within the period [00:00, 06:00) = 1; otherwise = 0	0.223	0.416	0	1
Morning	Crash happens within the period [06:00, 12:00) = 1; otherwise = 0	0.370	0.483	0	1
Afternoon	Crash happens within the period [12:00, 18:00) = 1; otherwise = 0	0.223	0.418	0	1
Evening	Crash happens within the period [18:00, 24:00) = 1; otherwise = 0	0.184	0.388	0	1
Crash type					
Single-vehicle crash*	Only one vehicle is involved in the crash = 1; otherwise = 0	0.455	0.498	0	1
Rear-end crash	A rear end collision = 1; otherwise = 0	0.381	0.486	0	1
Angle crash	An angle collision = 1; otherwise = 0	0.163	0.245	0	1
Roadway attributes					
Curvature	The horizontal curvature of crash location (0.1 km-1)	1.838	1.233	0	4.35
Grade	The vertical grade of crash location (%)	0.709	0.588	0	2.91
Bridge	Crash happens on a bridge =1; otherwise = 0	0.536	0.499	0	1
Ramp	Crash happens near a ramp = 1; otherwise = 0	0.244	0.430	0	1
Dynamic weather conditions					
Wind speed	Average wind speed during the hour of crash occurrence (m/s)	2.860	1.889	0	16.7
Precipitation	Accumulated precipitation during the hour of crash occurrence (mm)	0.760	3.425	0	54.8
Temperature	Average air temperature during the hour of crash occurrence (°C)	23.68	6.057	4.8	36.8
Humidity	Average humidity during the hour of crash occurrence (%)	81.31	15.48	21	100
Visibility	Average visibility during the hour of crash occurrence (km)	17.77	18.41	0.1	80

*The reference category.

Accordingly, the odds of fatality crash are calculated as Equation 6:

$$p_{i,1} / p_{i,0} = \exp\left(\beta_0 + \sum_{j=1}^{J} \beta_j x_{i,j} \right), \quad (6)$$

To quantify the effect of a certain factor on crash injury severity, its odds ratio is usually computed and reported (28). For any covariate x_j, its odds ratio is defined as Equation 7:

$$OR_j = \frac{\left(p_{i,1} / p_{i,0} | x_{i,1}, \cdots, x_{i,j}+1, \cdots, x_{i,J} \right)}{\left(p_{i,1} / p_{i,0} | x_{i,1}, \cdots, x_{i,j}, \cdots, x_{i,J} \right)} = \exp\left(\beta_j\right). \quad (7)$$

3.1.2 Spatial logistic model

Some unobserved/unobservable factors may have similar effects on the injury severities of crashes in close proximity, resulting in spatial correlation/dependency across them (17). To account for the spatial dependency, a spatial logistic model is developed, by adding a random error term with CAR prior into the formulation of U_i. Different from the intrinsic CAR prior adopted in the previous studies (25, 26), the Leroux CAR prior which is able to flexibly capture the strength of spatial correlation (29), is specified in the spatial logistic model. Specifically, for crash i occurring in freeway section m can be calculated by Equations 8 and 9:

$$U_i = \beta_0 + \sum_{j=1}^{J} \beta_j x_{i,j} + \varepsilon_i + \varphi_m, \quad (8)$$

$$\varphi_m \sim N\left(\frac{\rho \sum_{n \neq m} \omega_{m,n} \varphi_n}{1 - \rho + \rho \sum_{n \neq m} \omega_{m,n}}, \frac{\delta^2}{1 - \rho + \rho \sum_{n \neq m} \omega_{m,n}} \right),$$
$$m = 1, 2, \cdots, M \quad (9)$$

where φ_m and φ_n represent the spatial effects of crashes in freeway sections m and n. $\omega_{m,n}$ represents the degree of the proximity between sections m and n. The first order adjacency-based rule which is widely used in spatial modeling, is employed to define the proximity degrees: if freeway sections m and n share a common end, $\omega_{m,n} = 1$; otherwise, $\omega_{m,n} = 0$. $\rho\left(0 \le \rho \le 1\right)$ is an estimable parameter which measures the strength of spatial correlation. A higher value of ρ indicates stronger spatial correlation. $\rho = 0$ implies that no spatial correlation exists among the injury severities of observed crashes. $\rho = 1$ (equivalent to the intrinsic CAR prior) suggests that the injury severities of adjacent crashes are fully correlated. δ is a hyper-parameter related to the variance of spatial correlation.

3.1.3 Random parameters spatial logistic model

There may be unobserved heterogeneities in the effects of certain factors on crash injury severity (18). To simultaneously account for unobserved heterogeneity and spatial correlation, a random parameters spatial logistic model is proposed. Specifically, the coefficient $\beta_j\left(j = 0,1,2,\cdots,J\right)$ in Equation 8 is switched to random parameters $\beta_{i,j}\left(i = 1,2,\cdots,N; j = 0,1,2,\cdots,J\right)$ which can vary across crashes. Although there are a number of applicable forms of random parameters, the commonest one is adopted in the study as shown in Equation 10:

$$\beta_{i,j} = \bar{\beta}_j + \mu_{i,j}, \tag{10}$$

in which $\bar{\beta}_j$ is the mean of $\beta_{i,j}$. $\mu_{i,j}$ is a normally distributed random term as shown in Equation 11:

$$\mu_{i,j} \sim N\left(0,\sigma_j^2\right), \tag{11}$$

where σ_j denotes the standard deviation of $\mu_{i,j}$.

3.2 Model estimation and performance assessment criterion

3.2.1 Model estimation

Given the complex structure of CAR prior, the above models are estimated by Bayesian inference method. It necessitates specifying a prior distribution for each parameter or hyper-parameter, which reveals the researchers' prior knowledge on it. In the case of no available prior knowledge, as in the previous studies (17, 25, 26), non-informative distributions are adopted. Specifically, a diffused normal distribution, $N\left(0,10^4\right)$, is set as the prior of β_j and $\bar{\beta}_j\left(j = 0,1,2,\cdots,J\right)$; a uniform distribution, $U\left(0,1\right)$, is set as the prior of ρ; and a uniform distribution, $U\left(0.01,10\right)$, is set as the prior of δ and $\sigma_j\left(j = 0,1,2,\cdots,J\right)$.

The Bayesian estimation is implemented in the WinBUGS software (30), in which Gibbs sampling algorithms and Markov chain Monte Carlo (MCMC) simulation techniques are embedded to infer the posterior distributions of parameters. For each model, a chain of MCMC simulation is run, and 100,000 simulation iterations are set, with the first 50,000 iterations acting as burn-in. To judge if the MCMC simulations are converged, we visually inspect the history plots for the parameters (such as that for EMS response time in the random parameters model as shown in Figure 2) and monitor whether the ratio between the Monte Carlo simulation error for each parameter and its posterior standard deviation is less than 5%. In the random parameters spatial logistic model, if the posterior variance is not statistically significant at the 95% Bayesian credibility level, it is transformed to a fixed parameter.

3.2.2 Performance assessment criterion

The deviance information criterion (DIC), which is the most popular criterion for assessing Bayesian models, is used for comparing the comprehensive performance of the above crash severity models. As a Bayesian generalization of Akaike's information criterion, the DIC provides a hybrid measure of model fitting and complexity. According to Spiegelhalter et al. (31), its calculation equation is expressed as Equation 12:

$$DIC = \bar{D} + pD, \tag{12}$$

where $\bar{D}$ and pD are the posterior mean deviance and the effective number of parameters respectively, which are used to measure the model fitting and complexity accordingly. Generally, a lower DIC value means a better overall performance. As suggested by Lunn et al. (30), we can conclude that a model with a lower DIC is considerably superior if the DIC difference with another one is greater than 10.

4 Modeling results

The results of Bayesian estimation and performance assessment for the three models are summarized in Table 2. Only the covariates whose parameters are significant at least at the 90% credibility level are included in the table. We can find that the $\bar{D}$ value of the spatial logistic model is lower than that of the logistic model with the difference over 20. It indicates that the spatial logistic model performs substantially better than the logistic model in fitting the association between crash severity and EMS response time as well as other factors. Although the lower pD value of the logistic model implies that it is more parsimonious, the 16 points of DIC lower for the spatial logistic model suggest its superior overall performance. These findings are in line with the previous studies (17, 23, 25, 26): accounting for spatial correlation among adjacent crashes by CAR prior can effectively reduce model misspecification and improve model estimation. The reasonableness of the spatial logistic model with Leroux CAR prior can also be demonstrated by the Bayesian estimates of δ and ρ, which are both significant at the 95% credibility level. Additionally, the posterior mean of ρ is 0.62. It implies that the spatial correlation in the crash severity is medium, that cannot be figured out by the intrinsic CAR prior applied in Xu et al. (26) and Meng et al. (25).

The random parameters spatial logistic model yields the lowest values of $\bar{D}$ and DIC. We may conclude that accounting for the unobserved heterogeneities in the effects of certain covariates by allowing their parameters to vary across observations can further improve model fitting performance, given the consideration of spatial correlation. Similar results can be found in the research conducted by Zeng et al. (32). In the random parameters spatial logistic model, the posterior mean of ρ is a little higher than the counterpart in the spatial logistic model. That is, the strength of spatial correlation is slightly increased due to the accommodation of random parameters. Besides, the posterior mean of δ is significantly lower in the random parameters model. This is reasonable, as a proportion of the structure

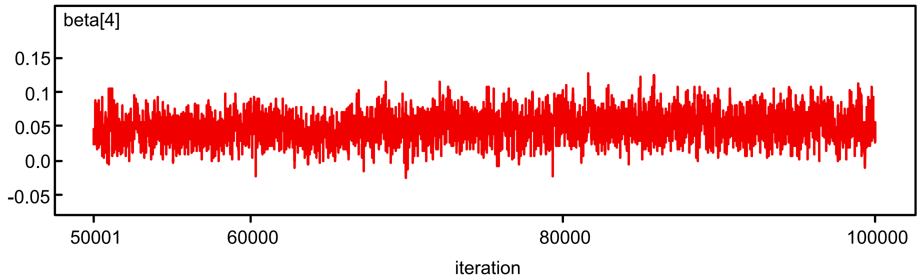

FIGURE 2
History plot of the parameter for EMS response time in the random parameters model.

TABLE 2 Results of Bayesian parameter estimation and performance assessment for the models.[a]

	Logistic model	Spatial logistic model	Random parameters spatial logistic model
Constant	−5.99 (1.87)[b],**	−6.67 (1.98)**	−7.10 (2.09)**
EMS response time	0.021(0.009)**	0.024 (0.010)**	0.026 (0.010)**
Truck	0.41 (0.12)**	0.44 (0.13)**	0.51 (0.15)**
S.D. of Truck	—	—	1.23 (0.16)**
Other vehicle	0.64 (0.20)**	0.68 (0.23)**	0.71 (0.22)**
Non_local vehicle	0.87 (0.31)**	0.99 (0.34)**	0.86 (0.32)**
Curvature	−0.17 (0.06)**	−0.14 (0.05)**	−0.12 (0.04)**
Grade	0.79 (0.24)**	0.91 (0.29)**	1.09 (0.31)**
Afternoon	−2.53 (0.97)**	−2.57 (0.98)**	−2.67 (1.01)**
Rear-end crash	1.44 (0.56)**	1.53 (0.56)**	1.47 (0.54)**
Angle crash	1.76 (0.62)**	1.85 (0.62)**	1.91 (0.67)**
Precipitation	—	0.92 (0.62)*	0.95 (0.65)*
ρ	—	0.62 (0.27)**	0.68 (0.26)**
δ	—	0.74 (0.17)**	0.56 (0.22)**
$\bar{D}$	285	259	236
pD	18	28	35
DIC	303	287	271

[a]Weekend, Coach, Morning, Evening, Bridge, and Ramp, are excluded, because their effects on crash injury severity are not significant at the 90% credibility level in the models.
[b]Bayesian posterior mean of the parameter (Bayesian posterior standard deviation of the parameter).
*Statistically significant at the 90% credible level.
**Statistically significant at the 95% credible level.

spatial effects may be derived from the unobserved heterogeneity which has been captured by the random parameter.

5 Discussion

The effects of EMS response time and other significant variables on the fatality probability of freeway crashes are interpreted based on the parameter estimation in the random parameters spatial logistic model, since it outperforms the other two models.

5.1 Effect of EMS response time

According to the Bayesian modeling estimation results summarized in Table 2, the parameter for *EMS response time* is statistically significant with a positive coefficient at the 95% credibility level, which indicates that a longer *EMS response time* is expected to increase the probability of fatality crash. The odds ratio for *EMS response time* is estimated to be 1.026 (=exp.(0.026)), i.e., the odds of resulting in fatality crash would be increased by 2.6% for per one-minute increase of *EMS response time*. The findings are generally consistent with those in most of the previous studies (6, 11, 17) and experiences from clinic medicine and transportation engineering: rapid response of EMS personnel is able to prevent the death of certain traffic crash victims suffered from severe trauma injuries, but are different from those in some others. For example, Ma et al. (15) found that the effect of EMS response time on fatality risk is non-monotonic, such that EMS response time may be negatively associated with the odds of fatality in some cases. These phenomena are originated from the urgency level of a crash and EMS dispatch priority (15, 33–35). Nevertheless, we did not find such phenomena from the current study. It is possible because freeway crashes in China usually have the high priority for EMS dispatch, given their more severe outcomes than those on other types of roadways (17). Besides, the average marginal effect of 10-min EMS response time on fatality crash is estimated to be 0.0023[1]. That is, 0.23 less fatality crash per every 100 crashes is expected for a 10-min reduction in EMS response time. The marginal effect is significantly lower than that (=0.024) estimated by Sánchez-Mangas et al. (11), which may be attributed to lower fatality rate of our crash data and the differences in EMS level between China and Spain.

To make the EMS personnel and vehicles arrive at crash scenes as soon as possible, the following countermeasures may be effective (1): Installing sufficient EMS facilities near freeways. Once a freeway crash is reported or detected, the emergency management agencies usually dispatch rescue personnel and vehicles from the nearest EMS facility to the crash scene. More EMS facilities can reduce the expected distance between them and crash locations (2).; Optimizing the traveling path to crash scenes (as shown in Figure 3), according to the real-time traffic data collected by various detection techniques and transmitted by 5G communication technology. There may be several alternative traveling paths from a EMS facility to the crash scene. The

1 Please refer to Afghari et al. (41) for the detailed calculation method of marginal effect.

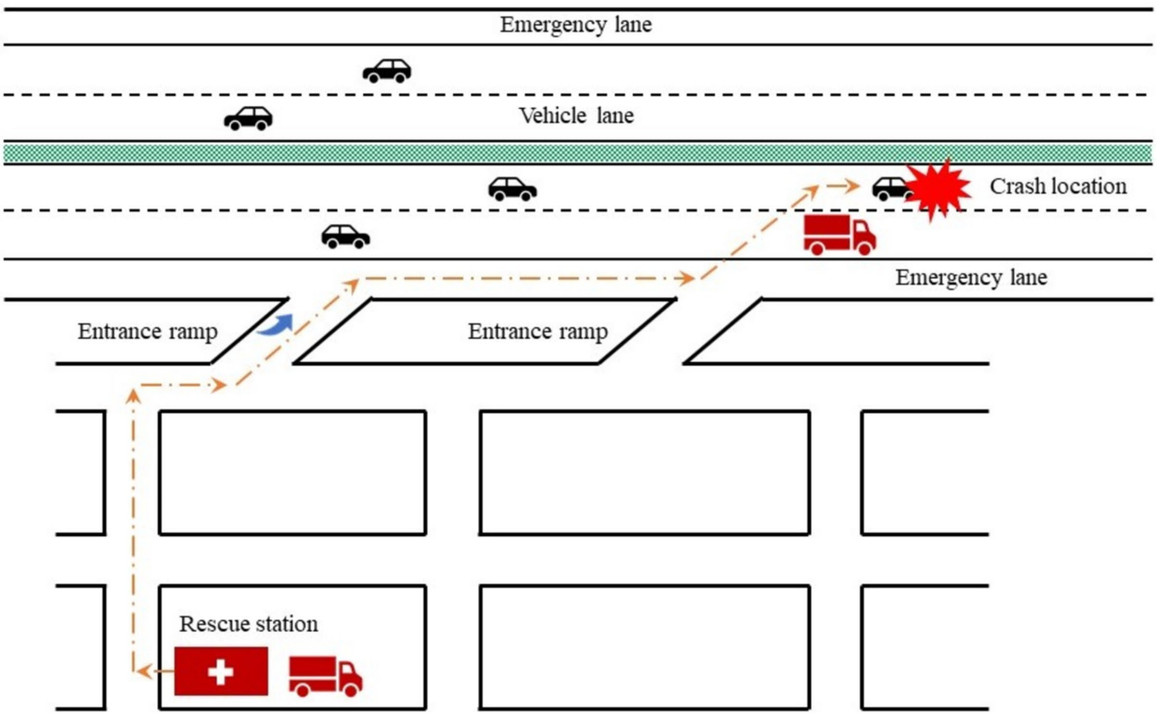

FIGURE 3
Traveling path of a rescue vehicle.

travel time of each path is depended on the traffic conditions which is usually influenced by the traffic crash. If the traffic conditions on each path is detected, transmitted, and predicted in real-time, we can find the one with shortest travel time (3). Strict enforcement against illegal occupancy of emergency lanes on freeways. The occurrence of traffic crash may bring about traffic congestion. A rescue vehicle can travel on emergency lanes to avoid the adverse impacts of traffic congestion on its travel speed. However, emergency lanes may also be illegally occupied by other vehicles. Thus, strict enforcement against the illegal occupancy is also helpful to reduce the arrival time of EMS vehicles.

5.2 Effects of other factors

Truck is the only covariate that has a heterogeneous effect on crash injury severity. The estimated mean and standard deviation of the random parameter for *truck* are 0.51 and 1.23 respectively, which indicate that about 66% of truck involved crashes are more likely to result in fatality. It is reasonable, because trucks usually possess larger mass and higher structural rigidity which impose greater harm on the occupants in other vehicles involved in the same collision, i.e., higher crash aggressivity defined in Huang et al. (36). Meanwhile, the rest 34% of truck involved crashes are less likely to result in fatality. In this research, a proportion of *truck's* effect on crash severity may be derived from truck drivers' driving behavior which is not observed in the crash data. Considerable variability in truck drivers' behavior when occurring a crash may explain the heterogeneous effect.

Other_vehicle is found to have a significant and homogeneous effect on crash severity. According to the Bayesian estimates, the fatality odds of crashes involving other type vehicles (e.g., towed vehicles) are 2.03 [=exp(0.71)] times of that of crashes involving passenger cars only, with all other factors equal. Similar to trucks, other type vehicles also possess higher crash aggressivity than passenger cars, thus more likely to resulting in fatalities.

It is interesting to find that *non_local* vehicle has a significantly positive effect on crash severity. That is, involving non-local vehicles (i.e., those not registered in the province where the crash happened) would increase the crash fatality risk. Specifically, the fatality odds are expected to increase by 136% [=exp(0.86)−1], if there is one or more non-local vehicle involved in a crash. We can find similar results in the research conducted by Zeng et al. (17). They argued that the drivers of non-local vehicles are usually less familiar with the roadway environment, and thus may not have enough time to take proper actions before crashes.

Regarding roadway geometric attributes, *curvature* and *grade* are significantly associated with crash injury severity. The negative sign of the parameter for *curvature* suggests that crashes on freeway sections with smaller horizontal curve radius are less likely to result in fatalities. The crash fatality odds would decrease by 11% [=1−exp(−0.12)] for a 0.1 km^{-1} increase in horizontal curvature. It is possible, because drivers tend to reduce speed and become more cautious to avoid vehicles out of control when driving on small radius curves (37, 38). The estimated mean of the parameter for *grade* is 1.09. It indicates that the odds of crash fatality would increase by 197% [=exp(1.09)−1] for a 1% increase in vertical grade. High grade would reduce sight distance (2, 5). Thereby, less time is retained for drivers to appropriately respond to upcoming crashes.

For the time of day, the parameter for *afternoon* on crash injury severity is negative at the 95% credibility level. It is anticipated, as the vision of drivers is usually clearer in afternoon than before dawn (the reference case), and thus more time is available for them to take defensive actions when encountered with emergency. In addition, because of the light traffic and human circadian rhythmicity respectively, we may observe more frequent speeding and fatigue/drowsy driving before dawn, which probably result in severe traffic accidents (4).

With regard to crash type, the estimation results suggest that rear-end crashes and angle crashes are more prone to lead to fatalities than single-vehicle crashes (the reference type). Particularly, the fatality odds of rear-end crashes and angle crashes are 4.35 and 6.75 times of that of single-vehicle crashes, respectively. The results are generally in line with the findings of Zeng et al. (17), and may be attributed to that more casualties usually exist in multiple-vehicle crashes (covering rear-end crashes, angle crashes, and others) than in single-vehicle crashes.

Precipitation is the weather-related variable with a significant effect on crash injury severity. According to its estimated parameter, heavier precipitation is associated with higher probability of fatality crash. The results are consistent with the previous research (39, 40) and engineering intuitions: because of rainfall, roadway surfaces would become slippery and their skidding resistance would be reduced. Accordingly, vehicles would collide at higher speeds which were prone to bring about severer injury severity outcomes. Additionally, during the processes of precipitation, drivers' vision might be impaired which results in reduced reaction time available to drivers.

6 Conclusion

This research empirically investigated the effect of EMS response time and the fatality risk of freeway crashes, using a two-years crash injury severity dataset from Kaiyang Freeway, China. A Bayesian random parameters spatial logistic model was advocated for the empirical investigation. The advocated model simultaneously accounted for the spatial correlation across adjacent crashes and unobserved heterogeneities in effects of the observed factors.

The values of DIC indicated that the overall performance of the random parameters spatial logistic model is substantially better than the logistic model and spatial logistic model. The parameter estimation results in the random parameters spatial model revealed that EMS response time has a significantly positive effect on crash injury severity. One minute increase in EMS response time would increase the crash fatality odds by 2.6%. Three countermeasures were suggested to reduce the EMS response time. They are: (1) establishment of EMS facilities near freeways at the optimized location; (2) optimization of path to the crash location based on real-time traffic data; and (3) strict enforcement against illegal occupancy of emergency lanes.

In addition, the estimation results show that truck has a heterogeneous effect on crash injury severity. Fatalities are more likely to occur in crashes involving other vehicles, non-local vehicles, on freeway sections with smaller horizontal curvature and greater vertical grade, in weather conditions with more precipitation, and before dawn. The fatality risk of rear-end crashes and angle crashes is higher than that of single-vehicle crashes.

While the significant effect of EMS response time on crash fatality risk and the superiority of the advocated Bayesian random parameters spatial logit model were demonstrated, there are some limitations to the current research. For instance, only the crash data from one freeway are used in the model development, and the attributes related to drivers are not included. It will be necessary to further validate the safety effect of EMS response time if comprehensive crash injury severity data are available in the future.

Data availability statement

The data are available from the corresponding authors upon reasonable request. Requests to access these datasets should be directed to Qiang Zeng, zengqiang@scut.edu.cn.

Author contributions

PH: Validation, Resources, Project administration, Investigation, Writing – original draft. SO: Resources, Formal analysis, Conceptualization, Writing – original draft. HY: Writing – review & editing, Conceptualization, Funding acquisition. XW: Writing – review & editing, Software, Project administration, Methodology, Data curation. JL: Writing – review & editing. QZ: Writing – review & editing, Supervision, Software, Methodology.

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Conflict of interest

PH, SO, and HY were employed by Guangzhou Expressway Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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