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Is panic over e-bike safety justified? A review of the literature and comparative analysis with conventional bicycles and e-scooters

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ABSTRACT

The increasing popularity of e-bikes has prompted global concerns about their safety. This literature review synthesizes English-language literature on e-bike safety, focusing on publication trends, data sources, major themes, and comparisons with human-powered bicycles and e-scooters. In total, 197 studies published between 2009 and June 2024 were reviewed.

Research activity has expanded rapidly in recent years, with China and the United States emerging as the leading countries. Most studies examined rider demographics, crash involvement, rider behaviors, and comparisons with other traffic modes. The most common data sources were medical records, surveys, and naturalistic designs.

Among studies comparing e-bike safety with bicycles or e-scooters, consistent patterns emerged. E-bike crashes occurred far less frequently than bicycle crashes (often by a magnitude of 10 or more), but when medical attention was required, e-bike riders more often sustained severe injuries. Comparisons between e-bikes and e-scooters were less clear-cut, with mixed findings on both crash incidence and injury severity.

The findings of this review highlight implications for engineering, enforcement, and education. The distinct injury patterns and higher operating speeds associated with e-bikes point to opportunities for engineering improvements, including clearer lane design and safer shared infrastructure for e-bikes. Faster and higher-powered models also introduce enforcement challenges related to speed compliance, lane access, and rider eligibility, underscoring the need for clear and consistent regulations. Finally, targeted education may help address unsafe behavior and support safe integration of e-bikes into multimodal transportation systems.

1. Introduction

Electric bicycles (e-bikes) have rapidly emerged as one of the fastest-growing segments of urban mobility, with global unit sales more than doubling during the COVID-19 pandemic and remaining above 40 million units annually since 2021, alongside a global market that has expanded from under US$10 billion in 2015 to more than US$32 billion in 2024 (Statista, 2025a, 2025b). E-bikes provide many of the benefits of active travel while enabling longer trips, reduced physical exertion, and the potential to displace motorized travel, resulting in substantially lower carbon emissions than cars traveling the same distance (Hasnine et al., 2020; Lee and Sener, 2023; Stilo et al., 2021). E-bikes offer a promising tool to support mode shift, sustainability, and personal mobility, especially among older adults, people with physical limitations, and commuters facing long or hilly routes. However, as e-bike use is accelerating, new questions emerge about whether the devices present distinct safety risks compared with human-powered bicycles. The result is an increasing body of research focused on exploring the unique characteristics of e-bike crashes, injuries, and fatalities.

Despite their mobility and environmental advantages, the rapid growth of e-bike use has been accompanied by increased attention to safety. Several clinical and surveillance studies have found high injury severity among e-bike riders, including increased hospital admissions, head trauma, and serious orthopedic injuries. Studies from the U.S. and European trauma centers indicate that e-bike users are more likely to suffer severe injuries than pedal cyclists (Verstappen et al., 2021; Williams et al., 2024), and studies from China and other Asian countries with the highest e-bike ridership similarly document elevated odds of

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severe injury (Guo et al., 2019; Zhong et al., 2022). However, other research shows that these differences diminish when age, speed, or exposure are taken into account, or that elevated risks only occur in certain roadway, demographic, or behavioral contexts, highlighting the inconsistency of current research (Qian and Shi, 2023; Verbeek et al., 2021).

In addition to evidence about reported injuries and deaths, a number of researchers and safety advocates have put forward hypotheses to explain why e-bikes may be inherently more dangerous than human-powered bicycles. One such hypothesis is that the increased weight of e-bikes and potential for faster riding speeds make the devices more challenging to handle than human-powered bicycles, thus increasing the likelihood that riders will lose control and crash (Schleinitz and Petzoldt, 2023; Siman-Tov et al., 2017). Another argument is that if e-bikes travel at higher speeds than conventional bicycles, crash impacts will be more severe, raising the risk of serious injury and death. Yet another hypothesis is that e-bikes may pose greater risks than human-powered bicycles because e-bike riders will tend to travel farther and thus are exposed for longer periods of time and to a wider range of traffic situations and hazards (Cherry and MacArthur, 2019). Finally, survey evidence also shows that e-bike riders report higher levels of risk-taking and maneuvering behaviors that resemble those of scooter or moped users (Rodon and Ragot-Court, 2019).

Given the mixed findings, it is not yet clear whether e-bike injuries mirror those of human-powered bicycles or reflect a distinct profile, and this distinction has important implications for future education and policy. If injury patterns are comparable to those of bicycles, similar regulatory approaches may be appropriate. However, if e-bikes exhibit a distinct injury profile, policymakers may consider additional measures such as age restrictions, training requirements, or licensing and registration frameworks. Clarifying these distinctions requires synthesizing findings from multiple data sources and international contexts, which currently remain fragmented.

To fill the gap in understand about whether e-bikes present unique safety concerns compared to other modes, this study systematically reviewed the English-language e-bike safety literature. We explored four key questions (1) How safe are e-bikes compared to conventional (human-powered) bicycles and e-scooters? (2) When and where have studies on e-bike safety been published? (3) What data sources have been used? and (4) What topics have researchers studied? Answering the first question is especially critical, as policymakers need robust, mode-specific evidence to craft policies that enhance safety without undermining the mobility and sustainability benefits e-bikes provide. Findings from the remaining questions help identify research gaps and guide future methodological approaches.

The remaining sections of the paper are organized as follows. Section 2 describes the study methods, Section 3 presents findings on the nature of the published literature on e-bike safety (research questions 2, 3, and 4), Section 4 presents findings on the severity of e-bike crashes and how these compare to other modes (research question 1), Section 5 discusses the findings across all four study questions, including limitations to the current body of research, and Section 6 offers policy and research recommendations.

2. Study methods

Our objective was to identify all English-language research published as peer-reviewed journal articles, conference papers, and technical reports that either analyzed primary data on e-bike safety or were standalone, detailed literature reviews about e-bike safety. To identify relevant literature, we searched systematically across multiple databases and used a wide range of keywords. The core search phrases combined a word describing the mode ("electric bicycle," "e-bike," or "pedelec") with a word related to safety ("safety," "crash," "injury," or "fatality"). We also combined these search terms with the names of countries known to have significant bicycle mode share, including Germany, the Netherlands, Israel, China, and Japan. In addition, we manually screened the reference lists of all included studies to identify additional relevant publications.

A key methodological challenge in comparing e-bike safety research across different authors and different countries is that e-bikes can be defined in quite different ways. For instance, China includes scooter-style electric bicycles under the term e-bike, while the USA and most EU countries classify those devices as mopeds (Fishman and Cherry, 2016). Additionally, not all studies clearly define the types of e-bikes they examine, adding further complexity to data analysis. Further challenging definitional clarity are potential differences in how laws, researchers, and research subjects define e-bikes. For example, in the United States, most state e-bike laws legally allow devices that can reach 20 miles per hour (mph) on motor-power only or 28 mph when pedal assisted. However, devices exist in the marketplace that are not street-legal e-bikes but are described as e-bikes by users and retailers. While not technically e-bikes by law, incidents on such devices nevertheless end up labeled as such in crash and injury datasets. For the purposes of this review, we reviewed any publication in which the authors describe the travel mode studied as "e-bikes" or a related term like electric bicycles or pedelecs. Therefore, the results presented here explore e-bikes as broadly conceived globally and do not cover any specific country's legal definition of a street-legal e-bike.

The databases searched were Google Scholar, PubMed, ScienceDirect, Scopus, Transport Research International Documentation (TRID), and Web of Science. These databases were selected to ensure coverage of both the public health and transportation literature, as well to ensure good coverage of both the scholarly literature (e.g., ScienceDirect and PubMed) and the gray literature (e.g., TRID and Google Scholar). Finally, the database searches were supplemented by a review of the bibliographies of the identified studies and citation chaining through Google Scholar and other databases. We continued our search until June 2024, when we reached a saturation point at which no new, relevant studies could be located.

The title and abstract of each publication identified in the search was evaluated for relevancy, and 278 pieces of literature were selected for a second-level review to determine their relevance to the research project. After looking at the full text of each of these articles, we found 197 relevant studies for analysis. The 81 other studies did not match the study inclusion criteria because they were not primarily focused on safety. Instead, these articles focused on topics such as e-bike user characteristics, travel mode substitution, the environmental benefits of e-bike use, and the physical energy expended to ride e-bikes vs. human-powered bikes.

For each study determined to be relevant to the study, we read and coded with key details that included the type of publication, time and place of publication, and themes related to the research questions. Finally, for studies comparing the safety outcomes of e-bikes with other modes, we reviewed the study findings on safety outcomes. To facilitate comparisons by mode across the studies, we calculated the ratios of e-bike crashes, injuries, and fatalities to incidents for conventional bicycle and/or e-scooter riders.

3. Characteristics of the publications reviewed

This section describes key characteristics of the 197 research studies analyzed, according to publication type, publication date, and the country from which the data is collected.

3.1. Publication type

The great majority of the publications analyzed were published in academic journals or as scholarly conference papers (87%). The other 13% of studies were published as reports, strategic plans, or, in one case, a student thesis.

3.2. Publication trends over time

Fig. 1 shows the publication year for the 197 studies included in the study. Only a scattering of studies were published annually until 2014, when there was a notable uptick to nine publications. Publication numbers jumped again in 2017 to 18 and have stayed consistently high since. The noticeable increase in publications in recent years presumably reflects the growing sales and use of e-bikes. Readers should note that the 21 studies reported for 2024 reflect only those published through June 2024, when we stopped our search. (The final total for 2024 will certainly be considerably higher.).

3.3. Geographic distribution

Fig. 2 shows the geographic distribution of e-bike safety studies, which we define as the country from which the study data was collected. China is without question the leader in e-bike safety research published in English, an unsurprising finding given the country's unusually early and fast growth in e-bike use. Chinese data is the subject of more than twice as many publications as the second-best represented data source, the United States (65 vs 31 studies). Within Europe, the Netherlands, Germany, and Switzerland were particularly frequent sources of e-bike safety research.

3.4. Data sources

Fig. 3 shows the distribution of data sources used in e-bike studies. The most common data sources were hospital patient records (49 studies) and surveys of either e-bike riders or the general public (48 studies). Other fairly common data sources were observational and naturalistic data (33 studies) and crash records (27 studies). In addition, 13 studies were review papers, and 8 used qualitative methods such as interviews or focus groups with e-bike users. Another 19 studies used a variety of other data sources such as simulations, Twitter posts, and video recordings.

3.5. Research topics

When initially designing the study questions and methodology, we drew up a wide-ranging set of questions related to e-bike safety that would generate findings useful to policymakers or researchers. The questions address both the state of e-bike safety literature and findings about safety outcomes, such as crash and injury prevalence, crash outcomes, causes of crashes, and strategies for preventing crashes. Fig. 4 presents the full set of topics for which we hypothesized we might find multiple publications.

As shown in Fig. 5, some but not all the topics listed above have been the subject of many different studies. By far the most common topic explored was the demographics of e-bike riders involved in crashes and injuries, with age and gender most often the focus (Fyhri et al., 2019; Papoutsi et al., 2014).

In addition, almost 40% of the studies (74) examined the number of safety incidents involving e-bikes on three safety outcomes: injuries, crashes, and/or deaths. By far the most common focus was injuries (50 studies), more than twice as many as the number studying crashes (22 studies). The crash-focused studies primarily examined crash characteristics, such as type (single vs. multi-vehicle), location, the modes of other travelers involved, and contributing factors such as rider behavior, environmental and geometric design factors. Rider deaths were the subject of only 5 studies. Many of the safety studies (56) compare safety for e-bikes to safety for bicycles or other modes of transportation. A detailed analysis of the comparative studies is provided in Section 4.

Yet another topic with a comparatively large number of studies is the question of whether certain e-bike rider behaviors are associated with safety issues (72 studies). These studies evaluate e-bike rider behavior such as red light running (Ma et al., 2019; Schleinitz et al., 2019), speeding (Korn et al., 2023; Langford et al., 2015), helmet use (Fernandez et al., 2024; Xu et al., 2024b), risky riding behavior and traffic violations (Huang et al., 2023; Zhong et al., 2022), riding under influence of alcohol (Fernandez et al., 2024; Niemann et al., 2023). However, although there are many studies about rider behavior, there are too few studies about any single type of behavior to provide the critical mass of research needed to predict with confidence that certain e-bike rider behaviors are particularly likely to cause crashes and injuries.

Over a quarter of the studies examined infrastructure factors (52), including street lighting or crash hotspots (Dozza et al., 2016; Guo et al., 2019; Lu et al., 2015; Zhou et al., 2024). Researchers also examined

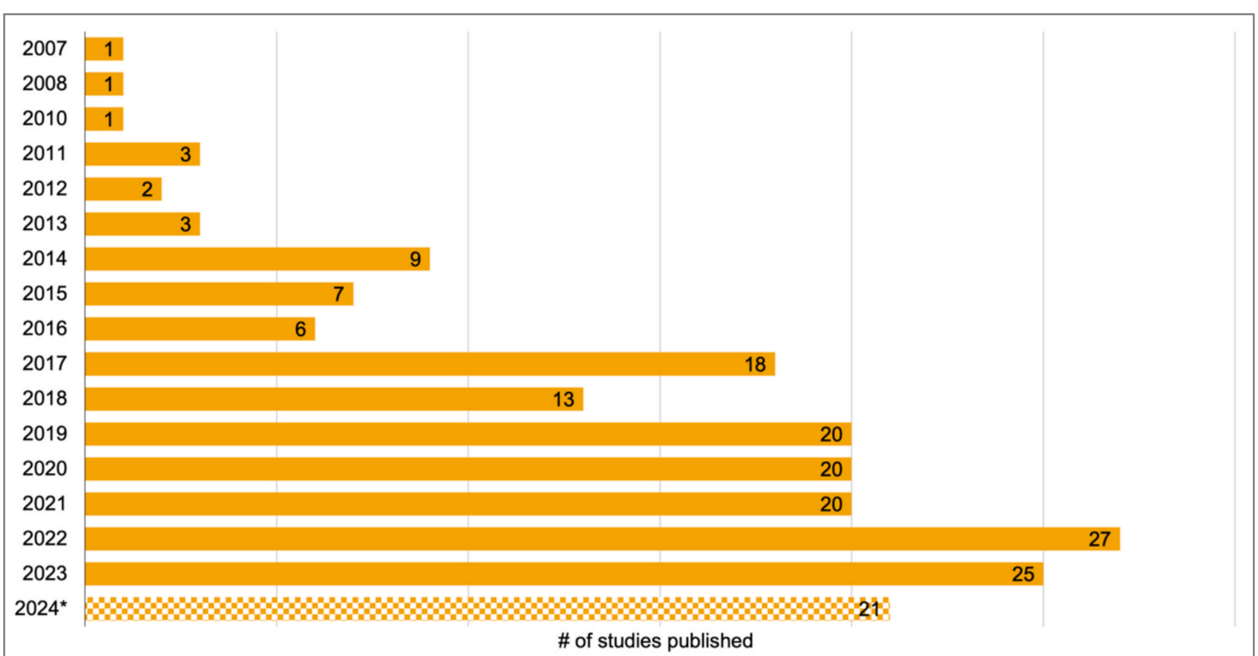

Fig. 1. Number of E-bike safety papers published annually. *Data for January 2024 through June 2024, when the literature search ended.

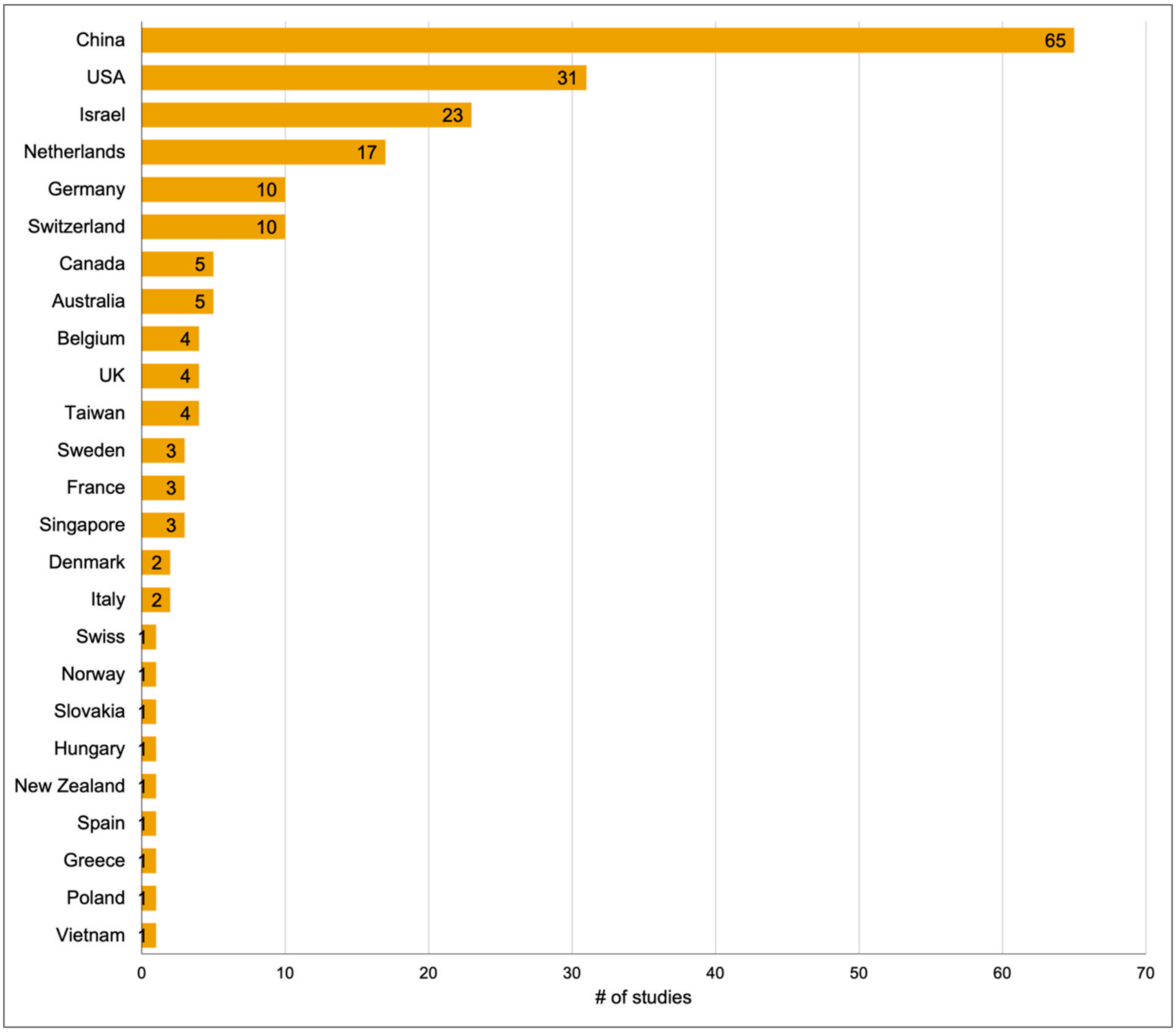

Fig. 2. Countries where E-bike safety studies have been published. *Notes*: Some studies drew data from more than one country. Table excludes the 13 review papers.

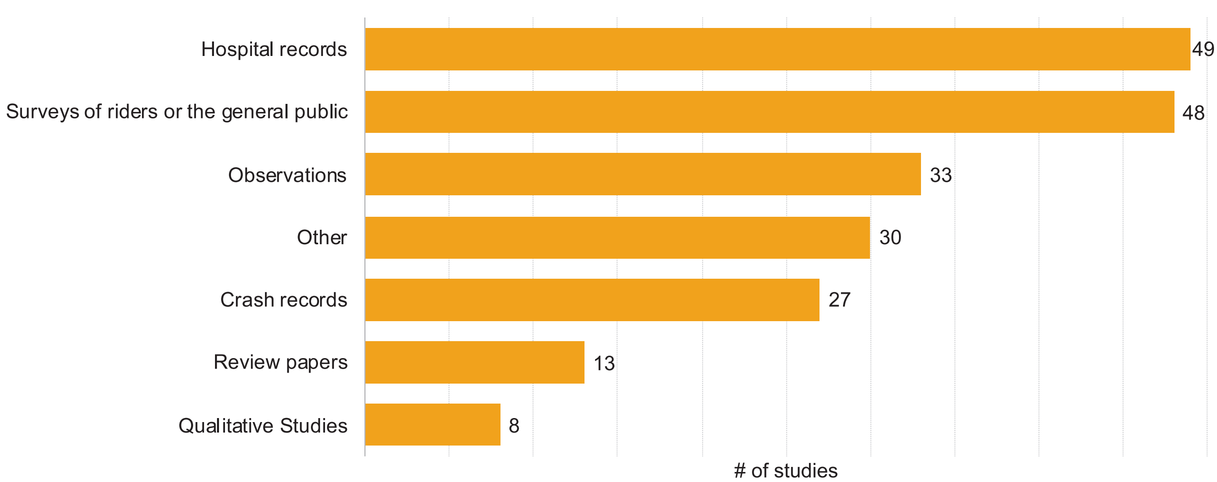

Fig. 3. Data sources used in E-bike safety studies. *Note*: Some studies drew from more than one source of data.

rider attitudes and safety perceptions (Johnson and Rose, 2015) and perceived barriers and motivations for e-bike use (MacArthur et al., 2017).

Only a few studies have empirically evaluated the safety impacts of specific e-bike regulations, but policy reviews describe a range of regulatory approaches used across jurisdictions. Regulations vary widely

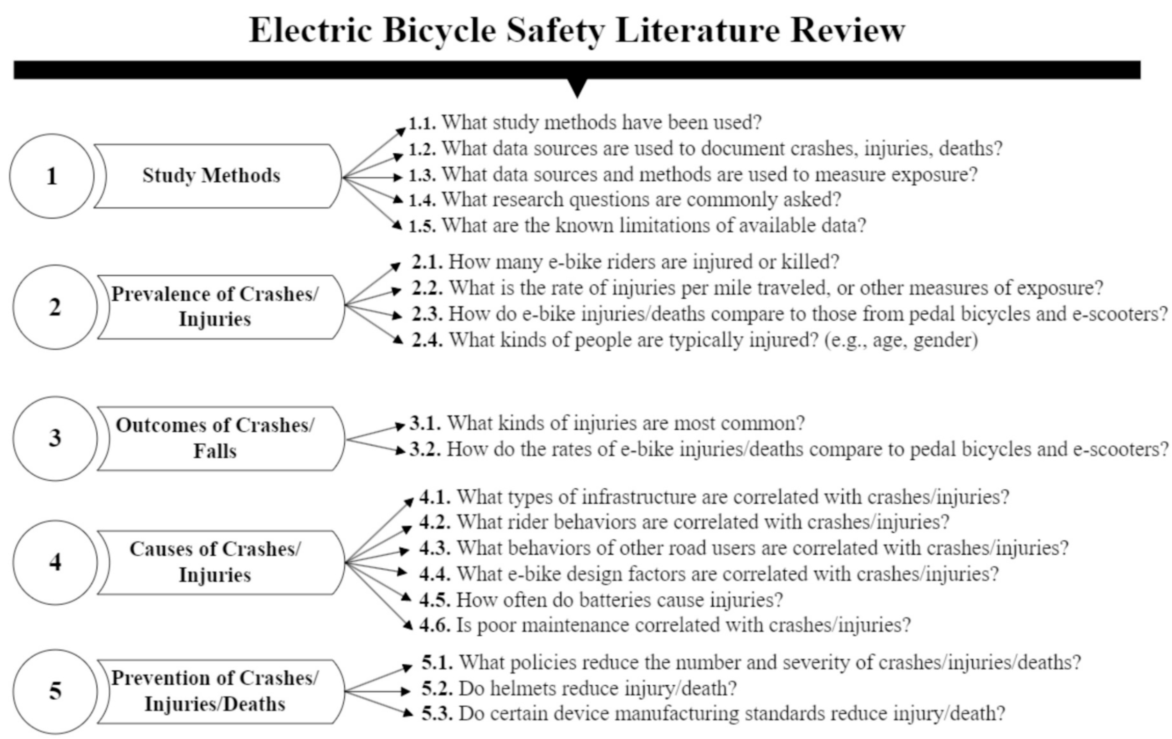

Fig. 4. Framework of research questions for E-bike safety: methods, prevalence, outcomes, causes, and prevention.

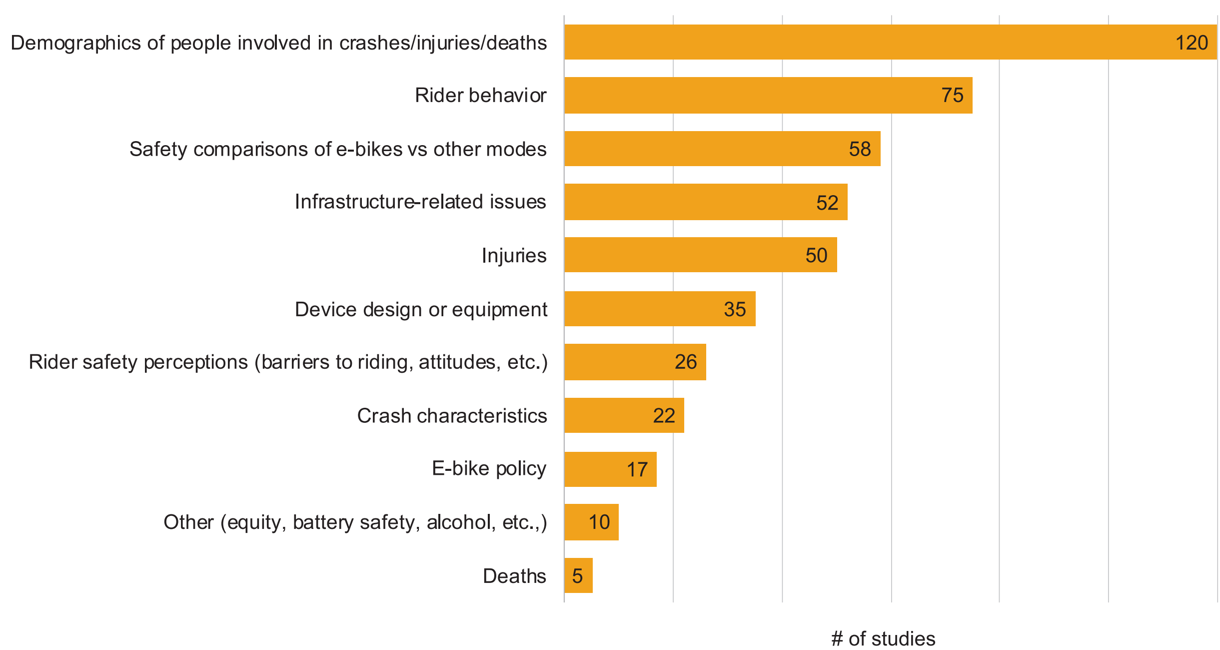

Fig. 5. Topics addressed in E-bike safety research. *Note:* Most studies addressed multiple topics.

across countries and even by states or regions within a single countries, including differences in speed limits, helmet mandates, minimum age requirements, and the adoption of class-based systems intended to align device capabilities with appropriate use limitations (Dill and Rose, 2012; Macarthur and Kobel, 2014). A cross-country review of regulations in 30 countries similarly found substantial global inconsistency in speed limits, power thresholds, helmet requirements, and lane-access rules, with almost no jurisdictions evaluating the safety implications of these policies (Akter et al., 2021). However, the real-world safety impact of these measures remains largely undetermined.

One notable example is China, where a more comprehensive regulatory framework has been implemented. National standards limit e-bike speeds, weights, and motor power, while some cities have introduced registration requirements, restrictions on non-compliant models, and enforcement campaigns. In Hangzhou, the Electric Bicycle Management Regulations require helmet use, license-plate registration, equipment compliance checks, and stronger enforcement of illegal modifications and improper lane use. Following implementation of these interventions, helmet use increased significantly and illegal riding behaviors such as red-light running decreased (Xu et al., 2024a).

However, another study indicated unintended consequences, such as increased numbers of unregistered vehicles when bans are too strict (Ruan et al., 2014). The limited evidence available suggests that while regulatory frameworks continue to evolve in response to faster and higher-powered e-bikes, the real-world safety impacts remain mostly unevaluated.

4. Comparing the safety of e-bikes with comparable modes

The final study question, investigating the safety performance of e-bikes as compared to conventional (human-powered) bicycles and e-scooters, is of the most direct interest for policymakers setting e-bike safety policy. We compared e-bikes to these two modes because all three devices are frequently used in urban settings and share physical and operational similarities in terms of approximate travel speed, location where ridden, and device size.

We analyzed the findings from those studies that (1) directly compared safety outcomes for e-bikes with outcomes for conventional bicycles or e-scooters and (2) reported incident frequency or severity. Out of 56 studies that addressed safety comparisons between e-bikes and other modes, only 26 provided quantitative data on injuries or crashes that allowed for direct statistical comparison.

The data sources varied across the 26 studies, but the great majority (80%) relied on medical records from hospital emergency departments and trauma centers. Three studies from China and Germany used police crash reports, and two studies used patient surveys. Notably, all five of the publications analyzing incidents in the United States used the same data set, emergency department hospital records from the National Electronic Injury Surveillance System (NEISS). Most studies included relatively small samples of e-bike cases, typically under 100, though larger datasets were used in some studies from China, Israel, Germany, and the United States.

The specific outcomes that we compare by mode are the *number* of riders involved in crashes, injured, or killed; *rates* of hospitalization, severe injuries, and mortality among riders involved in an incident; and the number and severity of head and traumatic brain injuries (TBI). These outcomes were chosen because they represent clinically meaningful, standardized indicators across studies. To facilitate comparisons across studies, for each metric we calculated the ratios for e-bike riders compared to conventional bike and/or e-scooter riders.

Tables 1 and 2 summarize the findings that compare the injury rates and severity of e-bikes with conventional bicycles and e-scooters. In cases where a study reported several different versions of one of these metrics (i.e., different injury severity levels), we selected the most serious case to include in the study analysis. Additionally, we reported the level of statistical significance when provided; if no statistical testing was conducted or reported, this is indicated as NA (not available) in the tables. Importantly, almost all numbers presented in the tables are raw, unadjusted values, extracted from each study's reported medical records or crash data. The one exception is that the U.S. studies all report on estimated total numbers of national incidents, rather than reporting the actual numbers of incidents recorded in NEISS records. No figures in the tables have been adjusted for demographic factors, exposure, or injury context. In the few cases where authors did conduct multivariate analysis to adjust for such factors, these findings are noted in the text.

4.1. Comparing the safety of e-bikes to conventional bicycles

4.1.1. Numbers of crashes and patients

Among the 18 studies comparing e-bikes with conventional bicycles in terms of injuries and crashes, 16 reported fewer e-bike incidents than conventional bicycle incidents (Table 1). The ratio ranges from less than 0.1 to 8.9. The ratio is particularly low in the five U.S. studies, all of which used the same emergency department medical records (NEISS). For example, DiMaggio et al. and Goodman et al. both reported ratios below 0.1 (DiMaggio et al., 2020; Goodman et al., 2023). In contrast, the only two studies to find more e-bike than conventional bike injuries or crashes (i.e., a ratio over 1) analyzed e-bike riders in China. Hu et al., (2014) reported a ratio of 2.7, and Qian and Shi (2023) reported a ratio of 8.9 more e-bike crashes than conventional bicycle crashes (Hu et al., 2014; Qian and Shi, 2023). The comparatively high rate of e-bike crashes in the Chinese studies is likely explained at least in part by the fact that China classifies a wider range of vehicles as e-bikes, including mopeds.

It is important to note that none of the studies reported crash or injury *rates* (e.g., the percentage of riders on each device that crashed or

Table 1
Studies comparing the safety of E-bike with conventional bicycles.

Study	Country	Data[a]	Crashes/injuries		Hospitalization		Severe injuries		Mortality		Head/face/neck injuries		Traumatic Brain Injuries (TBI)	
			# EB cases	Ratio	EB %	Ratio, sig[b]	EB %	Ratio, sig[b]	EB %	Ratio, sig[b]	EB %	Ratio, sig[b]	EB%	Ratio, sig[b]
Verstappen et al. (2021)	Netherlands	PS	78	0.9	21%	1.5, S	–	–	–	–	4%	0.60, NS	27%	1.4, NS
Verbeek et al. (2021)	Netherlands	MR	379	0.8	27%	1.2, S	–	–	–	–	33%	1.1, NS	15%	0.9, NS
Van der Zaag et al. (2022)	Netherlands	MR	73	0.3	57%	1.7, S	–	–	–	–	47%	1.4, S	–	–
Berk et al. (2022)	China	MR	27	0.5	48%	2.0, S	–	–	–	–	22%	1.0, NS	–	–
Spörri et al. (2021)	China	MR	67	<0.1	–	–	19%	1.1, NA	2%	1.3, NA	66%	1.0, NA	3%	0.8, NA
Baschera et al. (2019)	China	MR	73	0.2	–	–	–	–	6%	4.6, NA	–	–	69%	1.2, S
Qian and Shi (2023)	China	CR	873	8.9	5%	0.6, NA	–	–	1%	1.3, NA	–	–	–	–
Hu et al (2014)	China	MR	146	2.5	–	–	33%	1.9, S	–	–	–	–	–	–
Rauer et al. (2024)	China	MR	19	<0.1	–	–	26%	0.9, NS	–	–	–	–	–	–
Zmora et al. (2019)	Israel	MR	46	0.5	–	–	34%	1.8, S	–	–			13%	4.3, S
Siman-Tov et al. (2018)	Israel	MR	1733	0.2	16%	1.5, S	13%	1.2, S	–	–	45%	1.1, S	–	–
Otte and Facius (2019)	Germany	CR	64	<0.1	–	–	2%[d]	0.4, NA	–	–	44%	1.3, NA	–	–
Gehlert et al. (2018)	Germany	PS	2495	<0.1	–	–	28%	1.6, NA	1%	3.5, NA	–	–	–	–
Schleinitz and Petzoldt (2023)	Germany	CR	5688	<0.1	–	–	–	–	–	–	–	–	–	–
Fernandez et al. (2024)	USA	MR	53,200[c]	<0.1	–	–	–	–	–	–	32%	1.1, S	–	–
Goodman et al. (2023)	USA	MR	3945[c]	<0.1	12%	2.4, S	–	–	–	–	35%	1.1, NA	4%	1.4, NA
Williams et al. (2024)	USA	MR	57,578[c]	<0.1	21%	2.0, S	–	–	–	–	60%	1.2, S	10%	1.1, S
DiMaggio et al. (2020)	USA	MR	3075[c]	<0.1	–	–	–	–	–	–	–	–	<1%	0.2, NA

[a] PS = patient survey, MR = medical records, and CR = crash records.
[b] Statistical significance of the ratio. S = statistically significant, NS = not statistically significant, and NA = statistical significance not reported.
[c] These values represent nationally weighted estimates derived from the database, rather than the actual patient counts recorded.

Table 2
Studies comparing the safety of e-bikes with e-scooters.

Study	Country	Data[a]	Crashes/injuries		Hospitalization		Severe injuries		Mortality		Head/face/neck injuries		Traumatic Brain Injuries (TBI)	
			# EB cases	Ratio	EB %	Ratio, sig[b]	EB %	Ratio, sig[b]	EB%	Ratio, sig[b]	EB %	Ratio, sig[b]	EB%	Ratio, sig[b]
DiMaggio et al. (2020)	USA	MR	3075[c]	<0.1	–	–	–	–	–	–	–	–	<1%	0.2, NA
Tark (2023)	USA	MR	53,200[c]	0.3	21%	2.9, NA	–	–	<0.1%	0.9, NA	–	–	–	–
Fernandez et al. (2024)	USA	MR	53,200[c]	0.3	13%	1.1, S	–	–	–	–	32%	1.0, NS	–	–
Arbel et al. (2022)	Israel	MR	82	0.3	35%	1.5, S	–	–	–	–	–	–	5%	0.8, NS
Savitsky et al. (2021)	Israel	MR	3996	5.4	84%	5.4, NA	–	–	–	–	–	–		
Simon-Tov et al (2017)	Israel	MR	663	10.5	–	–	3%	0.9, NS	–	–	45%	1.2, NS	8%	1.7, NS
Hashavia et al (2024)	Israel	MR	466	0.7	–	–	24%	1.4, S	–	–	18%	1.1, NS	–	–
Lin et al (2020)	Israel	MR	321	5.7	–	–	–	–	–	–	85%	5.7, NA	–	–
King et al. (2020)	Singapore	MR	33	0.4	–	–	43%	1.5, S	–	–	–	–	–	–

[a] PS = patient survey, MR = medical records, and CR = crash records.
[b] Statistical significance of the ratio. S = statistically significant, NS = not statistically significant, and NA = statistical significance not reported.
[c] These values represent nationally weighted estimates derived from the database, rather than the actual patient counts recorded.

were injured), a limitation discussed below. As a result, the evidence from the 18 studies says nothing about whether e-bike riders are more or less likely than other riders to be in a crash or injured.

4.1.2. Rates of severe injuries, hospitalization, and mortality

Even though most of the studies comparing emergency room visits for e-bikes and conventional bicycles found fewer *numbers* of emergency department visits for e-bike riders, those e-bike riders who did get injured were more likely than conventional bicycle riders to suffer the worst outcomes: severe injuries, hospitalization, or death. These differences were almost all either statistically significant or had not been tested for significance. (In only 1 study out of 15 looking at these topics was the difference found to be not statistically significant.).

Among the eight studies reporting hospitalization rates, in all but one study e-bike riders had higher hospitalization rates and the differences were statistically significant. The ratios ranged from 1.2 to 2.40. For instance, a study of patients at a Swiss trauma center found that 48% of e-bike riders required hospitalization, compared to 24% of conventional bicycle riders, a statistically significant difference ($p = 0.025$) (Berk et al., 2022). Similarly, DiMaggio et al. (2020), analyzing U.S. NEISS data from 2009 to 2017, reported that even after adjusting for demographical factors such as age, gender, and injury mechanism, e-bike riders were almost three times more likely to require hospitalization (OR = 2.8, 95% CI: 1.3–6.1). The one study that found a lower hospitalization rate for e-bike riders is a study of Chinese riders by Qian and Shi (2023), and the results were not statistically significant. The authors found that 4.6% of e-bike riders required hospitalization, compared to 7.1% of conventional bicycle riders. Notably, this was the only study examining hospitalization that relied on police crash reports instead of medical records.

Seven studies reported injury severity using standardized scales, and all but one found that e-bike riders had higher rates of injuries of at least moderate severity—typically defined as an Injury Severity Score (ISS) >9. Three of these studies reported statistically significant differences, with observed risk ratios ranging from 1.2 to 1.9. For instance, Zmora et al., (2019) analyzed pediatric traffic injury hospitalizations in Israel and found that 34% of e-bike riders had an Injury Severity Score (ISS) >9, compared to 19% of conventional bike riders. In their multivariable model, regular bike riders had 61% lower odds of sustaining severe injury than e-bike riders (OR = 0.39, 95% CI: 0.17–0.91), even after adjusting for age and sex. The only study reporting lower injury severity in e-bike riders than conventional bicycle riders was Rauer et al. (2024), which found an ISS >15 ratio of 0.87 for e-bike riders as compared to conventional bike riders. However, their analysis included only 19 e-bike cases out of 1068 trauma patients treated between 2009 and 2019, and it focused exclusively on a very specific injury, cranio-cervical injuries. These factors make it particularly difficult to predict whether the results would be generalizable to the Chinese population (or to other countries).

A similar pattern was observed among the four studies reporting mortality rate: all found a higher mortality rate for e-bike riders than conventional bike riders, with ratios ranging from 1.3 to 4.6, though none of the studies reported on whether the differences are statistically significant. It is important to note that three of the four studies look at data from China, where the "e-bike" label encompasses a wider range of devices, including mopeds, which are faster and more powerful. The fourth study, conducted by Gehlert et al. (2018) in Germany using police-reported crash data from 2012 to 2015, analyzed 2495 pedelec crashes and 887,800 conventional bicycle crashes and found higher fatality rates among pedelec crashes compared with conventional bicycle crashes (1.4% vs. 0.4%). In addition, Schleinitz and Petzoldt (2023) also reported higher mortality and injury severity among e-bike riders. However, because the study used a different analytical approach, its results are not presented in Table 1. Using police-reported data from more than 95,000 injury crashes across three German states between 2013 and 2021, the authors found that, after adjusting for age, sex, and crash year, e-bike riders had 1.25 times higher odds of sustaining serious or fatal injuries compared with conventional bicyclists (OR = 1.25, 95% CI: 1.17–1.33).

4.1.3. Rates of head, face, neck, and traumatic brain injuries

Lastly, we examined the severity of head, face, neck (HFN), and traumatic brain injuries (TBI). These measures were selected given their potential for life-altering consequences, especially traumatic brain injuries. We looked separately at HFN and TBI studies because while TBI injuries are by definition very serious, injuries to the head, face, and neck range from minor scrapes to serious concussions).

Ten studies reported on head, face, and neck (HFN) injuries, with nine of them reporting higher rates among e-bike riders. Among the four studies with statistically significant results, ratios ranged from 1.1 to 1.4. The only study reporting an HFN injury ratio below 1.0 was a prospective study of emergency department patients aged 16 and older in the Netherlands, which included 78 e-bike cases. Verstappen et al (2021) found that facial injury rates were slightly lower among e-bike riders (4%) compared to conventional bicycle riders (6%), although the difference was not statistically significant (As noted below, the same study also found that e-bike riders were more likely to suffer TBIs) .

A less pronounced trend was observed when comparing TBIs between e-bike and conventional bicycle riders. Eight studies reported TBI-related ratios, and five of them showed higher rates for e-bike riders. Three of the five studies reported statistically significant differences, with ratios ranging from 1.1 to 4.3. For instance, Siman-Tov et al. (2018), using five years of national trauma registry data in Israel, reported a ratio of 1.1: 45% of patients who had been riding e-bikes sustained head, face, or neck injuries, compared to 41% of conventional bike riders (P = 0.003). Even after adjusting for age, sex, ethnicity, and collision type, e-bike riders had higher odds of these injuries, with an adjusted OR of 1.16 (95% CI: 1.00–1.25). By contrast, a study by Spörri et al. (2021), which analyzed trauma registry data from Switzerland between 2009 and 2018, found a slightly lower rate of severe TBI among e-bike riders (3.0%) compared to conventional cyclists (3.6%). However, this statistic reflects only the most critical injuries. The same study also found that moderate TBIs were more than twice as common among e-bike riders (10.4%) than among conventional cyclists (3.9%). Finally, one outlier study reported a TBI ratio of 4.34 (Zmora et al., 2019). However, this study was based on only 46 e-bike injuries, drawn from a single pediatric trauma center in Israel. Therefore, despite the statistical significance, the findings may not be generalizable to broader or adult populations.

4.2. Comparing the safety of e-bikes and e-scooters

Nine studies compared the safety of e-bikes to e-scooters, all using medical records from the United States, Israel, and Singapore. In contrast to conventional bicycles, data on the relative safety performance of e-bikes compared to e-scooters is more mixed.

4.2.1. Numbers of crashes and patients

The three U.S.-based studies using NEISS data consistently reported lower numbers of patient visit for e-bike riders compared to e-scooter users. For example, Tark (2023), looking at patient records from 2017 to 2022, estimated a ratio of 0.31—more than three times as many e-scooter patients as e-bike patients. However, the five studies from Israel show mixed results: although two studies found ratios under 1, the other three found ratios ranging from 5.4 to 10.5. For instance, Siman-Tov et al. (2017) used Israel's National Trauma Registry data from 2013 to 2015 to analyze patients injured by either e-bikes or e-scooters, and they found that e-bike riders accounted for more than 90% of the 795 hospitalized cases, a 10.5 ratio. Similarly, Lin et al. (2020) analyzed data from 2014 to 2019 on hospitalized Israeli patients with dental and maxillofacial injuries, finding that 85% of the 3686 cases were related to e-bikes, or a ratio of 5.7.

4.2.2. Rates of hospitalization, severe injuries, and mortality

All four studies that reported hospitalization rates found that e-bike riders had higher hospitalization rates than e-scooter riders, with the ratios ranging from 1.1 to 5.4. Two studies did not report on statistical significance for the differences, but the other two studies found significant differences. For example, Savitsky et al. (2021), who analyzed national trauma registry data in Israel, reported that among 4733 hospitalized e-device riders, 84% were e-bike riders (a 5.4 ratio).

In terms of injury severity and mortality, results are mixed, and often there are very small differences in the rates for e-bikes and e-scooters. Among the three studies reporting Injury Severity Score (ISS) comparisons, two found more e-bike cases (ratios of 1.4 and 1.5), while the other study found a ratio close to 1. Hashavia et al. (2024) found that 24% of e-bike riders sustained severe injuries (ISS > 15) compared to 18% of e-scooter riders, a ratio of 1.4. Even after adjusting for confounders such as sex, age, and injury mechanism, the study found that e-bike riders were significantly more likely to experience severe injuries, with an adjusted odds ratio (aOR) of 1.4 (95% CI: 1.0–1.9). In contrast, Siman-Tov et al. (2018) found that the proportion of critical injuries (ISS 25–75) was slightly higher for e-scooter riders (3.2%) compared to e-bike riders (2.9%), but the difference was not statistically significant. Tark (2023) was the only study reporting mortality. That study of U.S. data from 2017 to 2022 found 104 deaths among e-bike riders compared to 111 among e-scooter riders, a ratio of 0.96.

4.2.3. Rates of head, neck, face, and traumatic brain injuries

No particularly clear trend emerges from the six studies on HNF and TBI injuries. Three of the four studies on HNF injuries found ratios close to one, and the (very small magnitude) differences were not statistically significant. The only outlier is the Israeli study by Lin et al (2020), which found a ratio of 5.7, although the authors did not report whether the difference was statistically significant. As for the three studies reporting TBIs, two found more e-scooter deaths, while the other found more e-bike deaths. Also, in two studies the differences were not statistically significant, and significance was not reported for the third. For example, DiMaggio et al. (2020) looked at NEISS data from the US and reported that concussions occurred in 3% of e-scooter cases versus less than 1% for e-bike. In contrast, Siman-Tov et al. (2017), using trauma registry data in Israel, found a ratio if 1.7: 8% of e-bike riders compared to 5% of e-scooter riders (5%) had TBI injuries.

5. Discussion

The global literature review presented here reviewed trends in the types of publications on e-bike safety and synthesized findings from studies comparing the relative safety risks of riding e-bicycles as compared to human-powered pedal bicycles and e-scooters. The review advances understanding of e-bike safety in several key ways. First, it expands on prior reviews with a substantially larger and more recent body of literature (197 studies, through mid-2024. Additionally, this study differs from earlier efforts in terms of a more comprehensive scope: we looked at literature spanning multiple countries and examined a wider array of incident types (crashes, injuries, and fatalities). Third, this review offers a novel quantitative comparison of incident rates and injury severity outcomes for e-bikes relative to other modes, providing a more nuanced understanding of the relative safety profiles of these transport options.

5.1. Overview of the nature of e-bike safety research

The first section of the analysis presents an overview of the nature of the English-language scholarship on e-bike safety. Paralleling the increase in e-bike sales, the number of publications per year has gradually increased since 2007, with a substantial increase starting in 2017. In 2022 and 2023, the last full years of data included in the review, there were 27 and 25 studies. With respect to geography, about a third of the studies come from China and close to half analyze data from the United States, Israel, the Netherlands, Germany, and Switzerland. Several factors likely explain the high volume of research from China. China traditionally has high bicycle use and was also the earliest country to adopt e-bikes in large numbers (Zhang et al., 2014). In addition, China labels a wider range of device types as e-bikes than do other countries. Therefore, the e-bike category encompasses fast, high-powered devices that other countries would label differently, perhaps as mopeds or scooters (Gu et al., 2021). This point is critical to keep in mind when comparing e-bike safety statistics in China with other countries.

We also reviewed the collection of studies to identify what topics the authors address. Almost two-thirds of publications analyzed the demographics of e-bike riders who were in crashes, injured, and/or died. With such a wide body of research coming from multiple countries, the literature provides a fairly clear picture of demographics worldwide, if not necessarily for most individual countries. The demographics of e-bike riders in crashes is related to the demographics of all e-bike riders, and the kinds of people who ride e-bikes in a specific county will depend at least in part on that country's cultural norms about riding e-bikes, policies (e.g., any age minimums or helmet requirements) and built environment characteristics.

The literature leaves major gaps on almost all the topics that are needed to identify what policies will improve e-bike safety. Although there are dozens of safety studies on themes such as e-bike rider behaviors, infrastructure design, and device characteristics, there are too few studies on any *specific* topic to provide a clear understanding of how that policy choice would impact safety outcomes. For example, although there were 72 studies looking at rider behaviors, these looked at a wide range of different behaviors, from red-light running to helmet use to “risky behaviors.” As a result, there are only a handful of studies investigating any specific behavior. Also, there were very few studies that looked directly at the safety implications of different policies on how and where e-bikes can be ridden.

The e-bike safety literature relies on a wide range of data sources. Although the most common were hospital patient records and surveys of either e-bike riders or the general public, researchers have also used many other data sources, including observations and video recordings, crash records, social media posts, interviews, and simulations. While much additional knowledge can be mined from expanded use of these techniques, there is opportunity to expand to new sources of data. For example, the studies on injuries and deaths rely primarily on hospital records, and while these will capture the most serious injuries, they miss the great majority of injuries, which will be treated in outpatient settings or even at home. Another limitation of the data on medical outcomes is that there is rarely information on the type of e-bike device ridden or the circumstances that surrounded the incident, such as behaviors of the cyclist and other road users, or the street infrastructure and design and where the incident occurred. Additionally, current datasets typically do not differentiate between private and shared micromobility users, even though prior research indicates these groups may have distinct behaviors and risk profiles. This distinction is especially important in dense urban settings, where shared and private users interact differently with infrastructure and regulations. For example, Roig-Costa et al. (2024) found significant behavioral and demographic differences between users of shared bikes and private e-scooters in Barcelona, suggesting that regulatory context and access type can influence mode choice and potentially crash risk. The fact that hospital and crash datasets have not incorporated this distinction represents a critical gap in micromobility safety research.

5.2. The relative safety performance of e-bikes versus other devices

The second goal of the literature review was to determine the relative safety of e-bikes compared to the comparable modes of conventional bicycles and e-scooters. These findings can help policymakers identify whether it is appropriate to allow e-bikes to be ridden the same way as other active travel modes vs. regulating e-bikes similarly to mopeds or even motor vehicles.

We synthesized findings from the 26 studies we found that compared the safety of e-bikes to either human-powered bicycles or e-scooters and also reported the crash frequency and/or severity of medical outcomes. This synthesis shows very clearly that there have been far fewer e-bike than human-powered bike incidents, and the difference is often large, with ten times or more as many human-powered bicycle injuries. The comparison of e-bikes and e-scooters, however, finds mixed results: some studies found more e-bike incidents and others more e-scooter incidents.

Our review of the literature reveals that most studies found more severe outcomes for e-bike riders compared to other modes once a crash occurs. Across medical, trauma, and emergency department datasets, injured e-bike riders seen at these facilities were more frequently hospitalized than pedal cyclists treated at the same facilities. Additionally, patients involved in e-bike incidents were more likely to sustain head, facial, and traumatic brain injuries compared with pedal cyclists. Nearly all studies examining injury severity reported higher proportions of severe injuries and hospitalizations among e-bike riders, and more than half of the studies assessing traumatic brain injuries documented a greater proportion of cases among e-bike users relative to conventional bicyclists. These conclusions are based on the direction of observed differences across studies, and the reported differences were not necessarily statistically significant. Collectively, these findings suggest meaningful differences in injury mechanisms and crash forces between e-bikes and human-powered bicycles, although the underlying crash risk per unit of exposure remains unknown.

The literature does not provide evidence to explain why e-bike incidents lead to more severe outcomes, but causal factors may include the performance characteristics of e-bikes, rider behavior, and the environments where they are ridden. Compared with conventional bicycles, e-bikes can reach higher speeds with less physical effort, increasing both exposure to traffic environments and the likelihood of more severe injury outcomes when crashes occur (Li et al., 2026). Additionally, their greater mass and higher operating speeds contribute to more severe impacts, particularly involving the head and torso, during collisions, as was shown in prior research (Schepers et al., 2014). Furthermore, rider behavior is also important: some studies have reported frequent rule violations and low helmet use among e-bike riders, including running red lights and using a mobile phone, all of which have been linked to increased crash involvement and injury severity (Yuan et al., 2017). Other studies, however, have reported similar traffic violation rates between e-bike and conventional bicycle riders, while still finding higher operating speeds among e-bike users, which may lead to more severe injuries (Langford et al., 2015).

Beyond individual factors, infrastructure design may introduce an additional layer of risk. It is possible that facilities originally designed for conventional bicycles may not adequately accommodate e-bikes’ higher speeds and faster acceleration, leading to increased conflict potential, particularly in mixed-use environments. Evidence from naturalistic studies supports this concern. For example, Vlakveld et al. (2021) found that conflict risks were higher when speed-pedelec riders used bicycle facilities than when they rode on roadways, even in a country like the Netherlands where these vehicles are typically restricted from standard bicycle paths.

Literature comparing e-bikes and e-scooters is more mixed and does not suggest a clear-cut finding that e-bike incidents are either more or less likely to lead to the most medically serious outcomes. One potential reason for this ambiguity is the relatively smaller number of studies directly comparing e-bikes and e-scooters, as opposed to the more extensive body of work comparing e-bikes and pedal bicycles.

5.3. The significant limitations of the available data on e-bike safety

While the increasing amount of literature on e-bike safety in recent years has provided new insights, there are numerous important unanswered questions and limitations in the broader literature and, thus, in our findings. Key limitations fall into four themes:

1. *Absence of exposure-based measures:* A critical limitation underlying all comparisons of incidence frequency is the complete absence of exposure-based measures, whether that be incidents per rider, per trip, or per distance traveled. Researchers generally report fewer absolute numbers of e-bike crashes compared with conventional bicycles, but the degree to which this is due to fewer people riding e-bikes than human-powered bicycles is unknown. Relatedly, researchers have also generally found increasing numbers of e-bike incidents over time, but without data on incident rates, we cannot determine whether this increase is simply proportional to the growth in e-bike use or if riding e-bikes is becoming either more dangerous (or safer) over time. The lack of data on incident rates is presumably a downstream consequence of the lack of information on e-bike usage that is necessary to calculate incident rates. Future research measuring e-bike usage would enable researchers to calculate

incident rates, thus resolving one of the most significant gaps that prevent informed policymaking.

2. *Systematic underreporting of incidents:* Most incidents are likely never documented in any official capacity. For example, most available injury and fatality data comes from emergency departments or trauma centers and therefore captures only the more severe injuries. Non-emergency injuries treated in clinics, physicians' offices, or other non-emergency settings are excluded, leaving out a substantial portion of the injury spectrum. Similarly, police and crash reports typically document only incidents that occur on public roads, omitting crashes on private property, trails, or parking lots. Further, police likely report only those crashes that led to serious injury or death. This underreporting of micromobility incidents is well documented in the United States and abroad. For instance, Schleinitz et al. (2017) noted similar data gaps in Germany, and Shinar et al. (2018) found that many bicycle crashes go unreported to police, a pattern likely applicable to e-bikes as well.
3. *Limited ability to explain causal mechanism*: While the literature collectively points to some differences in safety performance between e-bikes, human-powered bicycles, and e-scooters~~,~~ it tells us very little about *why* such differences exist. The available research reveals little about how much those differences reflect inherent danger of the mode versus different user characteristics, types of trips made, or the environment where the devices are ridden. For example, there is much popular speculation about e-bikes being more dangerous because it is easier ability to reach high speeds, but the actual speeds of injured riders are rarely, if ever, reported. We also do not know the degree to which e-bike riders ride in more dangerous circumstances, such as in heavier traffic or on higher-speed roadways.
4. *Inconsistent definitions of e-bikes*: Finally, and perhaps most importantly, the results presented here depict the safety performance of *e-bikes as broadly conceived globally* but do not offer insights into the safety of *devices legally defined as e-bikes in any specific country*. Research included here comes from different countries that have varying regulations defining what an e-bike is. Furthermore, even research from a single county may include a wide range of devices that fall outside the characteristics of a legal e-bike. For example, in the United States, most states define street-legal e-bikes as having specific maximum assisted speeds and maximum motor power limits. However, Agrawal and Fang (2025) found most e-bike incident reporting processes in the U.S. make no attempt to document whether the device met the legal definitions of an e-bike, and many reported "e-bike" incidents actually involve devices with much higher assistant speeds and/or motor power than legally allowed for e-bikes. Indeed, these devices sometimes have power and speed profiles similar to those for a moped or electric motorcycle. We suspect that the same mislabeling of over-powered devices as legal e-bikes occurs other countries as well, given that the studies reviewed do not describe processes in the data collection or processing that would check for such errors.

6. Conclusion and future research

In this paper, we sought to explore the state of knowledge on e-bike safety from the rapidly increasing volume of e-bike safety literature globally. Overall, studies report consistent evidence that when they are injured, riders of e-bikes (as broadly defined globally) tend to sustain more severe injuries than conventional bicycle riders, including higher rates of hospitalization, severe trauma, and head injuries. These findings are important to consider in the ongoing debate about whether e-bikes should be regulated more like motorized vehicles (e.g. motorcycles, mopeds) or conventional bicycles. However, literature has yet to provide insights on many topics and characteristics of interest critical to setting effective safety policy. Perhaps most notably, the lack of good data on device usage (e.g. number of riders, number of trips, distance traveled) makes it impossible to calculate exposure-based crash or injury rates. Further, literature is sparse exploring the safety outcomes associated with the types of policies that decisionmakers are considering, including different regulations on who may ride e-bikes (e.g., age minimums), the regulations on how e-bikes are ridden, and different street infrastructure designs.

To improve both policymaking and scientific understanding, future research should prioritize three areas. First, there is a need for more accurate data collection on crashes and injuries, including detailed information about the types of e-bikes involved in an incident. This would be especially helpful in places like the United States, which has multiple-classes of street-legal e-bikes as well as non-street-legal e-bikes in circulation. Accurate device classification will require attention from the organizations that collect the data researchers use, such as hospitals and law enforcement agencies. Second, future important research topics are to investigate e-bike crash kinematics, and how motor power, device weight, and maximum assisted speed influence crash frequency, type, and severity. Finally, multivariate analyses should investigate the extent to which e-bike rider demographics, rider behavior, motorist behavior, e-bike device characteristics, and infrastructure design directly affect incident severity and frequency.

The findings of this review also highlight implications for engineering, enforcement, and education. The distinct injury patterns associated with e-bikes suggest that some jurisdictions may need to reassess whether existing bicycle-oriented infrastructure and rules sufficiently accommodate these devices. The fact that e-bike riders likely travel at higher speeds and cover longer distances than conventional bicyclists raise questions about potential conflicts with other road users. This may include reconsidering where e-bikes are permitted to ride, such as sidewalks, shared paths, or mixed-traffic lanes. Finally, targeted education for both new and less experienced riders may help support safer integration of e-bikes into multimodal transportation systems.

Author contributions

The authors confirm contribution to the paper as follows. Ghanbari: study conception, data collection (lead), analysis (lead), manuscript preparation. Agrawal: study conception, data collection, analysis, manuscript preparation. Fang: study conception, analysis, manuscript preparation. All authors reviewed the results and approved the final version of the manuscript.

CRediT authorship contribution statement

Amir Ghanbari: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Asha Weinstein Agrawal:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Formal analysis, Data curation, Conceptualization. **Kevin Fang:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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