A SYSTEMATIC REVIEW OF VISUAL ATTENTION, RIDER RISK-TAKING, AND INJURY MECHANISMS IN ELECTRIC SCOOTER USE

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eSCURB: Electric scooters in urban environments: A study of safety, infrastructure, and mobility dynamics

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ABSTRACT

The rapid increase in electric scooter usage worldwide has introduced recent safety issues to urban areas. This systematic review combines research about rider behavior, gaze behavior, and injury mechanisms. The PRISMA guidelines led to the discovery of 647 articles through database searches in eight major databases. The researchers selected 168 studies for complete evaluation following their screening process. The review examines risky behaviors, including age and gender, helmet use, substance consumption, speeding, distraction, and visibility, to understand their impact on accidents and injuries. The research indicates that young male riders experience the highest rate of crashes while helmet usage remains extremely rare. The combination of alcohol and drugs leads to severe head and facial injuries. The combination of dangerous road conditions with low visibility and faulty scooter designs creates additional injury risks. Most e-scooter riders remain unaware of the specific regulations that govern their use in their area. The review demonstrates that safety regulations, rider training, and scooter design improvements are essential.

Keywords: Human behaviour, E-scooter safety, Visual attention, Micro-mobility, Electric scooter

1. INTRODUCTION

Over the past decade, sustainable, electric-powered micro-mobility solutions have increased globally (Cubell Miralles-Guasch, & Marquet, 2023; Gao & Zhang, 2024;). Electric scooters (e-scooters) have especially come into their own, becoming an essential part of the urban transportation networks around the world (Useche, Gonzalez-Marin, Faus and Alonso, 2022a, b). Cubells, Miralles-Guasch, and Marquet (2023) attribute their rise in popularity, availability, and visibility to the inception of e-scooter sharing services that started in Santa Monica, California in September 2017 (Yang et al., 2020). E-scooters are primarily used for point-to-point travel and are particularly important in enhancing the sustainability of transportation systems (Kopplin, Brand, & Reichenberger, 2021). They help with traffic congestion, emission of greenhouse gases, and accessibility, particularly in areas with poor infrastructure (Zou, Younes, Erdoğan, & Wu, 2020). However, incorporating e-scooters in cities has brought about several problems due to their safety issues. Many cities around the world have encountered adverse effects arising from shared or private e-scooter programs, for instance, minor injuries resulting from falls, crashes, or interactions with other pedestrians or cyclists in the shared path and problems incidence in linking to improperly parked scooters that cause obstruction and clutter on the sidewalks (Traynor et al., 2022).

In safety issues, human behaviour is critical, and riders tend to participate in risky behaviour like forbidden riding and thoughtless parking, which puts them and other road users in danger (Haworth et al., 2024; Kazemzadeh et al., 2023; Ventsislavova et al., 2024). Furthermore, some design features of the e-scooters themselves present safety risks, for instance, the rider has to balance himself on a small deck, use small wheels, and control high speeds (Janikian et al., 2024; Tischler et al., 2023). These problems are significantly worsened by poor urban infrastructure and the absence of proper policies and regulations for using e-scooters and their parking (Niemann et al., 2023; Serra et al., 2021).

Although e-scooters are fun and convenient, their use has met some resistance from residents, drivers, pedestrians, and cyclists. A lot of people feel that e-scooters are annoying, dangerous, and intrusive (Carville, 2018). The sudden appearance of e-scooter services in cities like Santa Monica, San Francisco, Brussels, and Paris has not met with the approval of either the public or the authorities (Notopoulus, 2018). An online survey of 7,000 people in 11 large U.S. cities indicated that approximately 30 percent had a negative perception of e-scooters (Clewlow, 2019). The most significant grievances are riding erratically, not wearing a helmet, and e-scooters being left blocking access to buildings, transit stations, and sidewalks (Carville, 2018; Fang et al., 2018; James et al., 2019; Maiti et al., 2022; Notopoulus, 2018).

Governments debate the appropriateness of the regulations for e-scooters. They are not sure if e-scooters should be regulated like motorized vehicles, bicycles, or pedestrians, and what should be the rules for different public spaces (NACTO, 2019; Notopoulus, 2018). In most areas, e-scooters are not permitted on the sidewalk, but in some places, they are. The odds are better on the road, but an e-scooter rider might get hit by a car (Dhillon et al., 2020). Services like e-scooter sharing have become a topic of discussion for regulation or even ban in cities like New York, Montreal, London, and many others because of these reasons (Bekhit et al., 2020; Sikka et al., 2019; Yang et al., 2020).

In addition, the current paper reveals that many riders are not familiar with the local e-scooter regulations, which is a safety and compliance issue. For instance, in Berlin, many riders were not aware of the rules that govern riding two people, against the traffic flow, areas which are allowed for riding, whether a license is required for the driver, and the use of hand signals (ITF, 2020). This knowledge gap has to be addressed and possibly re-examined by governments when deciding on the rules for using e-scooters because of unplanned service introductions, disturbing behaviours, and increasing safety risks.

In response to the challenges introduced by e-scooters, several authorities have initiated trial programs to assess the viability of these transport schemes. Such evaluations prioritize safety and aim to refine regulations before allowing broader adoption (Kamphuis & Schagen, 2020; Leyendecker et al., 2023). Efforts to address safety concerns have included reducing the maximum speeds of e-scooters to decrease the speed difference between e-scooters and pedestrians and introducing dual braking systems to enhance stability. However, there is still a significant gap in research concerning the effectiveness of these interventions. With the fast pace of innovation in the micro-mobility sector, continuous evaluation and updates are essential to learn from previous experiences and guide future policy and operational strategies to ensure e-scooter usage is safe and responsible. This review incorporates findings from academic research and grey literature, including direct communications from e-scooter providers, technical reports, and government policy documents, to compensate for the scarcity of formalized recent studies. Overall, this paper aims at further exploring the different aspects of e-scooter rider risk taking behaviours in order to provide important information that can be used by policymakers when deciding on where to focus more on safety.

2. METHODOLOGY

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021) were followed for the review. The main systematic search was done on January 13, 2025. It used databases like Google Scholar, Scopus, Web of Science, EBSCO, ProQuest, TRID, APA, and PMS. This search found 647 article records. These were found by looking for a mix of keywords in the titles and abstracts: ("E-scooter" OR "electric scooter") AND ("risk" OR "risky" OR "road" OR "injury" OR "safety" OR "accident" OR "behaviour" OR "behaviour") AND ("eye-tracking" OR "gaze" OR "gaze behaviour" OR "gaze behaviour"). Figure 1 shows the search process. The search procedures followed consistent criteria and keyword combinations across all databases.

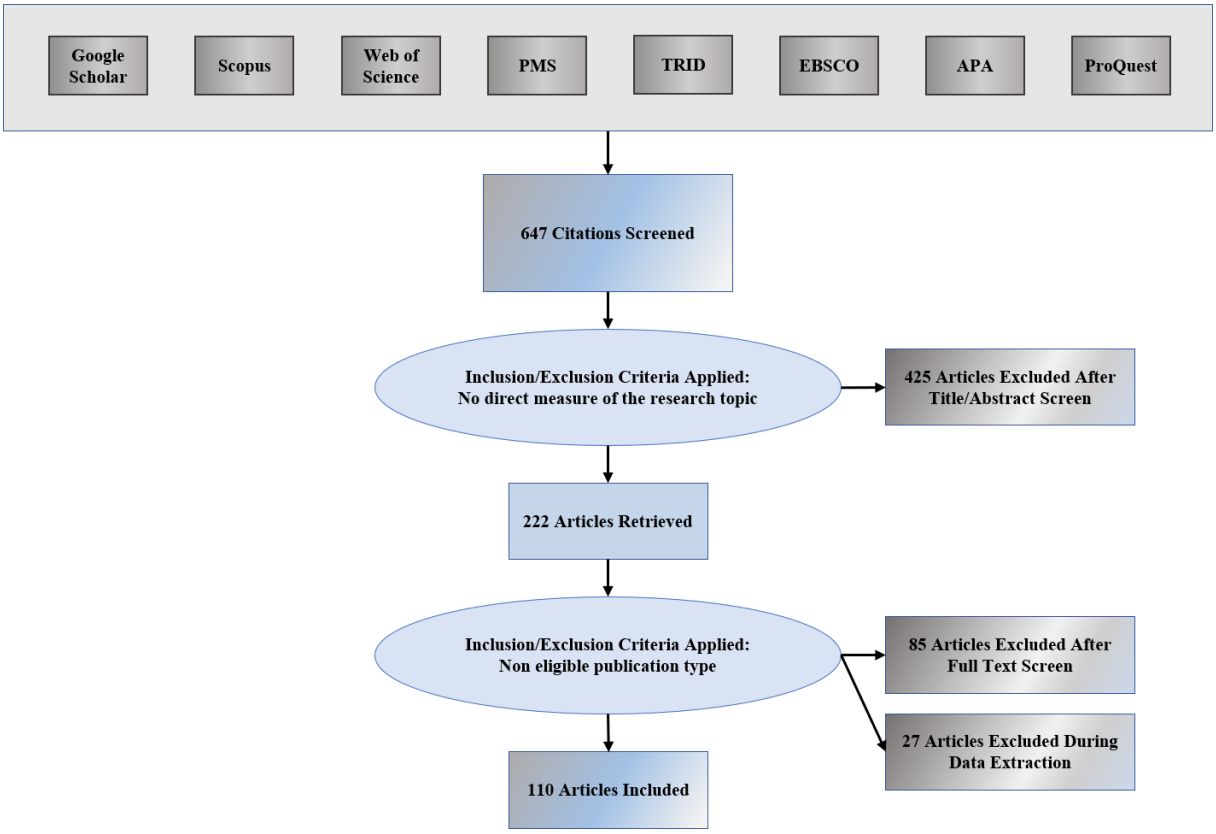

Figure 1. PRISMA flow diagram for systematic review of e-scooter human behaviour

3. RESULTS

Risky behaviour was classified by following factors: sex and age, helmet use, alcohol and/or drug use, age limit, speed, rider's distraction, and rider's visibility.

3.1. Sex and Age Demographics

The analysis of socio-demographic factors in e-scooter usage helps to reveal the potential of users and, therefore, to develop strategies for safety management. According to the literature, gender and age are the determinants of user behaviours. Stereotypes state that male riders are more risk-taking than female riders (Anderson et al. 2021, Dhillon et al. 2020, Kobayashi et al. 2019). The percentage of male riders has always been higher than 50% in all the e-scooter injury studies, which could be because male riders are more likely to engage in risky behaviour (Azimian & Jiao, 2022; ITF, 2020; Sexton et al., 2023). However, the study conducted by the International Transport Forum shows that the injury and crash behaviours of male and female e-scooter riders are the same although they have different tendencies in using the e-scooters (ITF, 2024). Nevertheless, the females were involved in more severe and fatal crashes than the males, and they tended to attribute the accident to losing balance more than the male riders (ITF, 2020). In addition, females highlighted issues with safety, for instance, concern with hitting other people or being hit, falling, and lack of control. Research shows that, compared to their male counterparts, females are more likely to believe that the use of e-scooters is riskier, which could be why they use e-scooters less frequently (Useche et al., 2022). Furthermore, E-scooters are very popular among young adults, which might explain why they use them so much. Research indicates that those between 18 and 44 years old are often involved in crashes (Moftakhar et al., 2020). This might be because they're not experienced with e-scooters and easily get distracted by their phones, doing things like reading texts while riding, just as they do when driving or cycling.

3.2. Helmet Usage

The situation with the high rates of head injuries among e-scooter riders requires a closer examination of the practices regarding the use of helmets. The International Transport Forum (2024) has reported that e-scooter riders are admitted to medical facilities with head and neck injuries more often than bike riders. However, since helmets can significantly reduce the severity of injuries, less than 3% of the e-scooter riders use them (Sexton et al., 2023). The survey results may not always be consistent with the findings; for instance, 20% of the riders in Portland claim to use helmets all the time, while 10% use them sometimes (Portland Bureau of Transportation & Alta Planning & Design, 2020). According to Young (2019), 80% of people in Baltimore have never worn a helmet. Only 2% of Tucson and Salt Lake City riders were observed to be using helmets (Currans et al., 2022).

Although moderate to severe head injuries are common among e-scooter riders, and research has shown that helmet use leads to better safety outcomes for riders of other micromobility devices, helmet usage is relatively low. For instance, in Western Australia, only 43% of those injured while riding an e-scooter wore a helmet (Raubenheimer et al., 2023). In Australia, every e-scooter rider must wear an approved bicycle helmet and not wearing one can attract a fine of at least AUD 143 (Queensland Government, 2023). However, in several regions of the world, helmet use among injured e-scooter riders is still relatively low, even when strict rules and penalties are in place (Haworth et al. 2024, ITF 2024). It is important to understand factors determining whether e-scooter riders wear helmets as this may help to know how to encourage better riding practices. In Canberra, where a helmet is mandatory, people do not always wear one depending on the context, as happens with bicycle helmets (Haworth, Ssi Yan Kai, & Schramm, 2024). Furthermore, a strong relationship exists between non-use of helmets and alcohol consumption (Murros et al. 2023).

3.3. Alcohol and Drug Use

Fifty-seven out of the sixty-two hospital studies reviewed tested or observed alcohol and drug use in e-scooter riders who were injured. These studies found that patients who came into the emergency department (ED) with an injury had consumed alcohol and drugs, according to their report, that of the clinicians and through breath, blood, or urine analysis. It was found that riders who tested positive for alcohol consumption had a five times higher likelihood of having a TBI (Uluk et al., 2022). In craniomaxillofacial (CMF) injuries, 53% to 91% of the injured patients had consumed alcohol, and CMF injury was found to be closely associated with intoxication (OR = 23.1, 95% CI: 7.7, 69.6) (Shiffler et al., 2021). Other works also documented high blood alcohol levels in patients with cranial and maxillofacial injuries (Kobayashi et al., 2019; Shiffler et al., 2021; Suominen et al., 2022). Riding performance worsened with the increasing blood alcohol concentration when the riders were required to navigate an obstacle course (Zube et al., 2022). Furthermore, the injured riders et al. (2019), who were positive for the substances used, with the most common being THC (32%), methamphetamine, or amphetamines (18%). Also, Dhillon et al. (2020) established that 17.2% of the injured riders who were tested used cannabis (13 also used drugs. Among such riders, 60 percent of the riders were tested by Kobayashi (8%), amphetamine (4.6%), opiates (8%), and cocaine (1.1%). Other similar drug tests were also done on injured e-scooter riders in other studies, for instance during a research by Suominen, they found that 71 percent of the riders were drunk. Correspondingly, around 12 and 27 percent of the riders were tested by Shiffler and, Lavoie-Gagne respectively. (Lavoie-Gagne et al., 2021; Shiffler et al., 2021; Suominen et al., 2022). In a survey by Comer et al. (2020), about 50% of the riders and non-riders were not aware that it is against the law to operate e-scooters while intoxicated. An impaired rider may be in violation of the rental agreement or local laws and could receive tickets and fines or be banned from future rentals. Furthermore, those caught riding

with a BAC over the legal limit may also face driver's license suspension, a measure that requires police training and active enforcement (Oksanen et al., 2020).

As for the measures aimed at preventing injuries among young riders and riders who have consumed alcohol and decided to ride at night they can be implemented with the help of a nighttime riding ban (Moftakhar et al., 2020; Oksanen et al., 2020; Suominen et al., 2022). For example, e-scooters were banned from use between 9 pm and 4 am in Atlanta in August 2019 after four fatalities (GHSA, 2020; Nisson and Chu, 2020). This restriction resulted in a decrease in the percentage of nighttime injuries treated at a major trauma center in Atlanta, from 32% to 22%, but the difference was not statistically significant (Anderson et al., 2021).

3.4. Underage Riding

Many cities set age limits for riding e-scooters, yet injuries among children remain common, as shown in the research. Underage riding refers to using an e-scooter below the legal age set by local laws, usually 18 years old, although some places allow younger riders. For example, in Copenhagen, children from 12 to 16 years old can ride e-scooters if they are with a parent (Blomberg et al., 2019). It's hard to accurately judge a rider's age just by looking, but hospital records can provide more reliable information. Studies show that between 3.3% and 14% of injured riders were not old enough to legally ride. Trivedi et al. (2019a) found that 4.7% of riders were younger than 13 years, and another study by Trivedi et al. (2019b) noted that 5.5% of those needing surgery were children. In the U.S., about 19% of emergency room visits for e-scooter injuries were by riders 14 years old or younger (Tark, 2022).

3.5. Inexperienced Riding and E-Scooter-Related Injuries

Although many cities have age restrictions for the use of e-scooters, children are still injured, as depicted in the research. Underage riding is defined as the use of an e-scooter before the legal age limit set by the law of the specific city or country, which is 18 years in most countries, but some countries allow children to ride them. For instance, in Copenhagen, children between the ages of 12 and 16 years can ride e-scooters if they are accompanied by a parent or legal guardian (Blomberg et al., 2019). Estimating a person's age based solely on appearance is challenging; however, hospital records provide more reliable and precise data. Research indicates that between 3.3% and 14% of the injured riders were not of the correct age to use the road. The study by Trivedi et al. (2019a) established that 4.7% of the riders were below 13 years and another study by Trivedi et al. (2019b) established that 5.5% of the patients who required surgery were children. About 19% of the emergency room visits for e-scooter-related injuries in the U.S. were made by riders 14 years of age or younger (Tark, 2022). The unexpected speed of e-scooters often surprises new riders, which causes accidents, and 33% of the injured riders claimed they were newbies to the road (Cicchino et al., 2021a; Stormann et al., 2020). Inexperience is the cause of 32% of the orthopedic injuries that are related to e-scooters

(Kayaalp et al., 2023). Lime has conducted some studies and found that 36% of incidents take place within the first five rides of a user (Lime, 2023), and in Austin, TX, 63% of the accidents involved riders who have made fewer than 10 trips (Sexton et al., 2023). However, some research shows that there is no statistical significance in the severity or type of injury between the novice and experienced riders (Williams et al., 2022), but other studies show that the more experienced riders may have more serious injuries due to higher risk-taking tendencies (Cicchino et al., 2021b).

Most research today focuses on the initial period after the introduction of an e-scooter, and the riders are usually inexperienced (Sexton et al., 2023). To prevent injuries, the interventions could be more specific to training than to separating e-scooter traffic. For example, a pre-ride safety tutorial may also be helpful for new and regular riders to improve their skills and safety knowledge (Lime, 2023). Research shows that mandatory training before the first ride significantly decreases the risk of injury (Brunner et al., 2020). Also, making everyone take a driving test could mean that everyone knows the traffic rules, as found by a study that pointed out that most accidents are caused by solo riders (Brauner et al., 2022). Thus, restricting speed or access in high-traffic areas during the first rides could also contribute to the safety of new riders.

To make e-scooters safer for new riders, well-known companies like Beam (Beam, 2023 a), Bird (Bird, 2023), and Lime (Lime, 2023) have a feature called a 'Beginner Mode'. This mode either restricts the top speed of the e-scooter or decreases the sensitivity of the acceleration to ensure that new riders do not accelerate suddenly. However, the effectiveness of 'Beginner Mode' for particular groups of users, such as new users, females, and senior citizens who are likely to be more cautious when riding, has not been well established. This feature is still optional, which has generated debate about whether it should be mandatory. The effects of making "Beginner Mode" a compulsory setting for using e-scooters and their integration into the city's transportation system require further investigation.

3.6. Speeding

Speeding is a safety threat that is likely to increase the risk of e-scooter use in urban areas. Studies clearly show that faster riding increases the frequency and severity of accidents. For instance, 50% of e-scooter injuries in the UK were associated with speeding, and 70% required surgery (Flaherty et al., 2022). At lower speeds, the force in accidents is lower, reducing the chances and severity of injuries, including head injuries (Cicchino et al., 2021b). A study on e-scooter-related bone injuries revealed that riding at a speed of more than 15 km/h resulted in injuries that required surgical repair (Kayaalp et al., 2023). Various studies have backed the necessity of enforcing speed limits (Field & Jon, 2021; Ma et al., 2021a, 2021b). The speed regulation is possible for e-scooter companies by fixing the maximum speed. Moreover, it is

feasible to tell riders who exceed the speed limits by their registration data, but this raises legal issues about using personal information for traffic control.

Table 1. Review of Human Factors of E-scooter Rider Safety

Sex and Age Demographics						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Azimian & Jiao, 2022	United States	Accident data from the Patch platform	Real-world analysis of crash data	Zero-inflated Poisson (ZIP) and Zero-inflated Negative Binomial (ZINB) models	To identify factors contributing to e-scooter injury accidents in Austin	Significant factors include the ratio of young males, median household income, public transport usage, land use entropy, and presence of sidewalks. Higher complexity in land use and more points of interest correlated with increased accidents.
Sexton et al., 2023	United States	Accident data, surveys, observational studies, and media reports	Real-world analysis of crash and medical databases	-	To understand safety in e-scooter usage, focusing on perceived safety, rider characteristics, injury trends, and crash characteristics	E-scooter injuries are increasing, with a focus on head injuries and the importance of infrastructure and rider education to improve safety
Helmet Usage						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Currans et al., 2022	United States	Data types include observations, online surveys, and accident data	Real-world observations and analysis of crash/medical databases	Logistic regression analysis	To examine the use and safety of e-scooters and their impact on transportation modes	E-scooters can replace short automobile trips but may also substitute for walking and public transit. Low helmet use and high injury rates were noted
Haworth et al. 2024,	Australia	Online survey data	Real-world study	Logistic regression and descriptive statistics	To understand factors associated with non-use of mandatory e-scooter helmets and whether non-use is consistent or situationally influenced	Most non-use of helmets is situational; factors include risky behaviours, lack of knowledge, and lack of support for the law

Alcohol and Drug Use						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Anderson et al., 2021	United States	Medical records from emergency department visits	Just analysis of crash/medical database(s)	Watson-Wheeler test for comparing time of arrival distributions	To assess the effects of Atlanta's nighttime ban on e-scooter rentals on injuries	Nighttime rental ban reduced the proportion of e-scooter injuries during the ban hours from 32% to 22%, but this was not statistically significant
Kobayashi et al., 2019	United States	Multi-institutional retrospective case series data from trauma registries	Real-world analysis of crash/medical database(s)	Pearson $\chi 2$ test, t-test, Mann–Whitney test, Spearman's rank correlation, multivariate analysis	To examine the incidence of injury, injury patterns, prevalence of helmet use, and drug and alcohol use in e-scooter trauma	Significant increase in e-scooter-related trauma, high rates of alcohol and drug use, low helmet use, and common injuries included extremity and facial fractures
Nisson and Chu, 2020	Puerto Rico	The study utilized accident data and reports related to electric scooter injuries	Real-world analysis of crash and medical databases.	The specific statistical methods are not detailed in the provided context.	To assess the public health implications and safety concerns associated with electric scooter use.	The findings indicate a significant rise in injuries related to electric scooters.
Zube et al., 2022	Germany	Real driving test study	Real-world	Statistical tests with p-values for significance	To assess the effects of alcohol on e-scooter driving performance	Significant deterioration in driving performance at BACs as low as 0.21 g/kg; increased risk for e-scooter drivers under the influence of alcohol
Oksanen et al., 2020	Finland	Medical records of patients with craniofacial fractures or dental injuries	Just analysis of medical database(s)	Descriptive statistics with absolute numbers and percentages	To identify the occurrence and characteristics of craniofacial fractures and dental injuries	Majority of injuries occurred at night, on weekends, with high alcohol intoxication;
Underage Riding						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Blomberg et al., 2019	Denmark	The data used were from emergency medical services (EMS) records	Real-world data analysis from medical databases	Descriptive analyses and non-parametric statistics were used for comparative analyses	The aim of the study was to describe injuries related to manual and electric scooter use from January 2016 to July 2019	The study found that manual scooter riders were mostly children with minor injuries, while electric scooter riders were young adults often injured under the influence of alcohol or drugs.

Inexperienced Riding and E-Scooter-Related Injuries						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Brunner et al., 2020	Germany	Data from field trials and real driving test study	Real-world	The study utilized a 9D-Kalman filter for data processing	To assess the dynamics and behaviour of e-scooter riders, particularly regarding stability while performing hand signals.	Novice riders can maintain stability while signalling; significant training effects were observed.
Cicchino et al., 2021a	United States	Data from medical records and structured interviews with injured riders	Real-world study based on emergency department visits	Logistic regression and relative risk calculations	To compare injury characteristics and circumstances between e-scooter riders and cyclists	E-scooter riders had higher injury rates per mile travelled, different injury types, and demographics compared to cyclists
Stormann et al., 2020	Germany	Data from emergency department presentations and clinical records	Real-world analysis of crash data from emergency departments.	Chi-square test and Fisher's exact test for categorical variables; descriptive statistics.	To identify injury patterns following E-scooter accidents and evaluate the need for treatment.	56.6% of patients had serious injuries; upper extremities were most affected; low helmet usage; significant burden on emergency departments.
Brauner et al., 2022	Germany	Media and police reports	Real-world analysis of crash data	Sentiment analysis, network analysis, and clustering (Louvain algorithm)	To identify relevant causes and implications associated with e-scooter crashes in Germany	Key issues include driving under the influence of alcohol, riding in pairs, and common crash causes.
Speed						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Flaherty et al., 2022	United Kingdom	Retrospective case analysis of E-scooter foot and ankle injuries	Real-world analysis of crash/medical data	Descriptive analysis, Fisher's exact test, Odds ratios	To assess the injury pattern and severity of foot and ankle trauma associated with E-scooter use	Significant foot and ankle injuries were observed, with 45% requiring surgery; higher speeds correlated with more severe injuries
Cicchino et al., 2021b	United States	Data from medical records and structured interviews with injured riders.	Real-world study based on emergency department visits.	Logistic regression and relative risk calculations.	Compare injuries and circumstances between e-scooter riders and cyclists.	E-scooter riders had higher injury rates per mile travelled, different injury types, and demographics compared to cyclists.

Kayaalp et al., 2023	Turkey	The data used were from electronic hospital records and follow-up surveys	The study was based on real-world data from medical records and follow-up surveys	Pearson's Chi-square test, Fisher's exact test, and Mann–Whitney U-test were used for analysis.	The study aimed to analyse orthopaedic injuries associated with e-scooter use, factors related to these injuries, and the impact on patients' lives.	The study found a high rate of operative treatment (39%), significant regres among patients (74%), and identified e-scooter accidents as a leading cause of hip fractures in young adults.
Field & Jon, 2021	Australia	Data from policy documents, media contents, and council meeting minutes	Real-world study	Grounded theory approach for qualitative analysis	To explore e-scooter governance and its implications for urban planning	E-scooter governance is a contested area requiring ongoing negotiation between public and private interests.
Ma et al., 2021a	United States	Data from naturalistic riding experiments, mobile sensing data, and GPS-tracked trips.	Real-world data collection through naturalistic riding experiments	Descriptive analysis and data mining techniques were employed.	To evaluate the riding risk of E-Scooters and understand their interactions with different riding environments.	E-Scooter riders experience higher frequencies of vibration events on sidewalks compared to vehicle lanes, indicating increased safety challenges.
Ma et al., 2021b	United States	Data types: Origin-destination (OD) data, news reports, and accident data.	Real-world analysis using news reports and accident data.	Descriptive analysis and cross-tabulation analysis.	To investigate E-Scooter operations and safety, focusing on usage patterns and safety issues.	E-Scooter crashes are unevenly distributed, with significant safety concerns related to riding conditions and user demographics.

3.7. Rider Distraction

Rider distraction has been a focus of five studies (Arellano & Fang, 2019; Austin Public Health, 2019; Gioldasis et al., 2021; Huemer et al., 2020; Tark, 2022). These studies collected data from various locations, including San Jose, California; Paris, France; Braunschweig, Germany; and across the U.S. using the NEISS database. Common distractions for riders included listening to music or podcasts, taking selfies, talking, streaming videos, using navigation tools, interacting on social media, and eating, drinking, or smoking while riding. Approximately 26% of injured riders reported holding something while riding (Tark, 2022). About 5% of e-scooter injuries in the U.S. were linked to listening to music or using a phone (Tark, 2022). The most detailed study showed that using headphones or earphones was noted among 11.5% of riders, talking accounted for 2.8%, and eating, drinking, or smoking was 1.2% in a sample of both shared and private e-scooter

riders in Braunschweig, Germany (Huemer et al., 2022). In Paris, riders reported being distracted by music (65%), GPS (67%), texting (32%), phone calls (33%), and taking photos (21%) (Gioldasis et al., 2021).

3.8. Infrastructure-Related Challenges

People are currently discussing the issue of safe routes for e-scooters and varying local regulations for their use. There is also a concern for the safety of pedestrians with e-scooters since the latter are allowed on the sidewalks. Issues such as e-scooters moving at a higher speed than pedestrians can result in anger, incidents, and injuries, particularly on narrow tracks with several objects (Ma et al., 2021; Uluk et al., 2022). To avoid confrontation, some cities have prohibited e-scooters from using the roads. But this has resulted in some near misses with cars, which makes the riders uncomfortable (Sucha et al., 2023; Pourfalatoun et al., 2023). The research indicates that while riding on the roads, e-scooter accidents result in moderate to critical or even fatal injuries to the e-scooter riders if the accident involves a car (Cicchino et al., 2021; Neuroth et al., 2022).

Studies have usually indicated that e-scooters should be used on bike lanes since they operate at the same rate as bicycles (Toofany et al., 2021). Surveys from cities in different countries and regions reveal that riders prefer bike lanes to sidewalks or roads (Cicchino et al., 2021; Tian et al., 2022; Lanza et al., 2022). Nevertheless, some riders have indicated they have been uncomfortable in the bike lanes (Lyons et al., 2020). Suggestions for enhancing integrated infrastructure include widening bike lanes and using physical barriers to separate bike lanes from the sidewalks. It is also advised that bike lanes should be cleared and in good condition and not have objects on the ground (Blazanin et al., 2022; Laa & Leth, 2020; Pérez-Zuriaga et al., 2023). This is because regulating e-scooters to use these paths only as a means of transport is not always straightforward. Some recommendations have been made to enhance these paths to make them more e-scooter friendly (Anke et al., 2023), but that does not always mean the riders will use them. Instead, the rider tends to assess the path and determine if it is convenient and comfortable to use rather than looking at the safety or the regulations.

For instance, if e-scooters are restricted in terms of speed, then riders might prefer to use the sidewalk rather than the road (Cicchino et al., 2023). This is because bad road surfaces constitute a significant safety threat, and many riders claim that they have been involved in an accident due to poor paths (Cicchino et al., 2021; Lavoie-Gagne et al., 2021). Also, the process of managing the parking of e-scooters is essential, especially in crowded places, to avoid the congestion and dangers that come with e-scooters being placed anywhere (Hardt & Bogenberger, 2019; James et al., 2019; Sikka et al., 2019; Wallius et al., 2021; Zou et al., 2020).

Several cities are increasing the amount of space for e-scooter safety and comfort. In these locations, e-scooter riders are more likely to ride on bike lanes than to use the sidewalks.

Nevertheless, there is currently limited understanding of the efficacy of such measures in decreasing the interactions between e-scooters and other road users, as well as the frequency and severity of injuries. A study of e-scooter riders and cyclists suggests the possibility of shared use, and support for e-scooters in cycling facilities (Anke, Ringhand, & Petzoldt, 2024). However, the need for future longitudinal research was acknowledged to observe how riders interact as e-scooters appear more in bike lanes. Additional studies are required to establish if including e-scooters in bike lanes can stop them from using sidewalks and busy roads, resulting in fewer confrontations.

Table 2. Review on Rider Distraction and Infrastructure-related Challenges

Rider Distraction						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Arellano & Fang, 2019	United States	Observation data collected through direct observation of e-scooter riders	Real-world observations	t-tests and ANOVA for statistical analysis	To study e-scooter riding behaviour, focusing on speed, helmet use, and distractions, and to compare it with other modes of transport	E-scooter riders travel faster on streets than on sidewalks, with low helmet use and minimal distraction from cell phones
Gioldasis et al., 2021	France	Data type: Face-to-face Road survey	Real-world	Approaches: Logit models, mixed logit models, and structural equation modelling	To explore risk-taking behaviours among e-scooter users in Paris, focusing on factors like alcohol and drug use, and smartphone usage while riding	Young and male riders are more likely to engage in risky behaviours; longer trip durations are associated with increased risk-taking
Huemer et al., 2020	Germany	Observational data collected through direct observation of cyclists	Real-world observational study	Logistic regression models were used for analysis	To estimate the frequency of secondary tasks while cycling and examine influencing factors	22.7% of cyclists engaged in secondary tasks; most common was wearing headphones (13.1%). Younger cyclists and females were more likely to engage in secondary tasks
Huemer et al., 2022	Germany	Data type: Observational study	Real-world observational study	Logistic regression models, chi-squared tests, hierarchical clustering analysis	Estimate the frequency of secondary tasks, safety equipment use, and rule violations among bicycle and e-scooter riders	13.4% engaged in secondary tasks; 17.8% wore helmets; 90.8% did not commit traffic rule violations; significant correlations between secondary tasks and risky behaviours

Infrastructure Related Challenges						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Hardt & Bogenberger, 2019	Germany	Field test data, travel diaries, pre-post surveys	real-life field test	Descriptive statistics, longitudinal survey analysis	To investigate the potential of e-scooters and user acceptance in urban environments	Majority of daily trips suitable for e-scooters; charging infrastructure sufficient; subjective safety and weather conditions are limiting factors
Sucha et al., 2023	Australia, Belgium, the Czech Republic, Norway, and Sweden.	Data were collected through an online survey.	Real-world data was collected through an online survey.	Ordinal logistic regression and linear regression were used for statistical analysis.	To describe the effects of e-scooters on pedestrians, focusing on interactions, perceived safety, and conflicts.	E-scooter riders often use sidewalks, perceived safety varies by country, and many pedestrians find e-scooter interactions annoying.
Pourfalatoun et al., 2023	United States	Online survey data collected from participants	Real-world study based on survey responses	Binary logistic regression, chi-squared tests, Cochran's Q tests, and McNemar tests	To compare perceptions of safety, trip behaviours, risk propensity, and technology adoption between e-scooter users and non-users	Users showed higher risk propensity, felt safer riding e-scooters, and had more positive perceptions of e-scooter sanitation compared to non-users
Neuroth et al., 2022	United States	The study utilized data from the emergency department visit data related to e-scooter injuries	The study is an analysis of a medical database (NEISS) regarding real-world e-scooter injuries.	The study employed weighted tabular analyses and Rao-Scott adjusted chi-square tests	To characterize e-scooter injuries, particularly those involving motor vehicles, using national injury surveillance data.	Approximately 18.6% of e-scooter injuries involved motor vehicles, with a higher proportion of males and younger individuals among those injured. Injuries involving motor vehicles were more severe.
Wallius et al., 2021	various urban locations globally	media coverage and promotional materials related to e-scooters	real-world analysis through media and promotional materials.	Qualitative analysis.	To explore the relationship between play and mobility in urban settings, through the lens of e-scooters	The findings highlight the tensions between playful and practical aspects of e-scooter usage, including issues of safety, data privacy, and urban sustainability.
Zou et al., 2020	United States	GPS-tracked trips data from e-scooter share program	Real-world analysis of e-scooter trip data	Descriptive statistics and correlation analysis	To analyse e-scooter travel patterns and behaviour	E-scooter trips are concentrated in specific areas and times, with significant usage in leisure contexts.
Tian et al., 2022	US and other countries	Data were collected through an online survey	Real-world data collected from e-scooter riders.	Negative Binomial regression and Poisson robust variance regressions	The aim was to identify characteristics and risk factors for e-scooter-related crashes and injuries.	Males and frequent users had higher crash risks; riding on bike lanes reduced injury risks.

Lanza et al., 2022	United States	Observation data collected through systematic direct observation	Real-world study	Binomial logistic regression and chi-square tests of independence	To observe travel behaviours of different non-vehicle travellers on various types of transportation infrastructure	Significant differences in travel behaviours; many travellers crossed into other infrastructure and used not recommended infrastructure, with variations by travel mode
Blazanin et al., 2022	United States	online survey of Austin area residents	Real-world data collected from an online survey	Employed a Generalized Heterogeneous Data Model (GHDM) for analysis	The aim was to analyze factors affecting first-use and use frequency of ESS and BSS, focusing on psycho-social constructs and demographics.	The study found that safety concerns significantly impact the first-use and frequency of both ESS and BSS, with distinct pathways for each mode.
Laa & Leth, 2020	Austria	Online survey and field observations	Real-world study.	Descriptive statistics and observational analysis.	To assess the socio-economic profiles and usage patterns of e-scooter users in Vienna.	E-scooter users are predominantly young, male, and highly educated; e-scooters mainly replace walking and public transport trips.
Pérez-Zuriaga et al., 2023	Spain	Simulation data from PC-Crash software.	Simulator (PC-Crash).	the study focused on simulation results rather than statistical analysis	To analyse the kinematics and injury risk of micromobility users in car-to-micromobility user side-impact crashes	E-scooter riders experience higher HIC15 values than cyclists in side-impact crashes, indicating greater injury risk. Recommended speed limit at intersections is below 40 km/h
Anke et al., 2023	Ger many	Online experiment data	Real-world scenarios presented in video clips	Two-way ANOVAs for analysis	To investigate ingroup-outgroup phenomena between cyclists and e-scooter riders	Cyclists and e-scooter riders judged in group rule violations more harshly than outgroup violations, indicating ingroup discrimination

3.9. Policy-Related Challenges

It has been established that enforcing rules helps reduce traffic violations among e-scooter riders, as stated by Useche et al. (2022a,2022b). However, in some countries, the legal status of e-scooters is not well-defined, which raises questions about their use (Serra et al., 2021). Based on the city, e-scooters may be controlled like pedestrians, bicycles, or motorized vehicles. The present discussion on the legal framework for e-scooters, including where they can be allowed, speed limits, helmet requirements, and time and space restrictions on their use suggests the need for more detailed studies.

All the experts agreed that e-scooters should at least be made to obey the same rules as bicycles. However, it is difficult to extend the findings from bicycle research to e-scooters because e-scooters are used differently, and they pose a higher risk of injury, are less stable, and

faster than bicycles, with a high center of gravity, slow reaction times, and poor braking performance (Dozza et al., 2022; Harbrecht et al., 2022). Some safety measures that were suggested include Encouraging people to wear helmets, educating riders, not consuming alcohol while riding, ensuring that the e-scooter has a good lighting system, and obeying traffic rules (Barker et al., 2022; Pepper et al., 2022). The literature has a wide range of support for streamlining e-scooter regulations to increase adherence (Crowe & Elkbuli, 2021). The role of social media in shaping people's behaviour is also evident, particularly when companies like Bird post pictures of people riding without helmets, which can be interpreted as a way of justifying this behaviour (Allem & Majmundar, 2019). Surveys have revealed that riders and non-riders of the e-scooters are likely to be unaware of the rules that apply to them, which can result in an accident (James et al., 2019). A recent study in Australia indicates that informing the public about the e-scooter rules may not alter risky behaviours. Instead, efforts should be made to shift the perception of risk, which may be more successful (Phipps & Hamilton, 2024). Therefore, there is a need to have more specific educational campaigns for the enforcement of helmet laws and the effects of head injuries (Haworth et al., 2024). Displaying safety messages via apps, along with training camps and mandatory licenses or insurance, are suggested measures to improve e-scooter safety.

Table 3. Review of Policy-related Challenges

Policy-Related Challenges						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Useche et al., 2022	Spain	The data were collected through online surveys and qualitative interviews	Real-world data was collected from external raters' perceptions	Statistical analyses included paired t-tests and multi-group structural equation modelling (MGSEM)	To compare the external-rated behaviour of cyclists and e-scooter riders and understand perceived differences in their behaviours	E-scooter riders were perceived as having riskier behaviours than cyclists, with significant differences in violations and errors
Comer et al. (2020)	United States	Data from a cross-sectional survey	Real-world data collected from survey participants	Descriptive statistical analysis and Chi-square tests	To determine self-reported incidences of health and safety hazards among e-scooter riders, knowledge of e-scooter laws, and attitudes	44% of respondents believe e-scooters pose a health and safety threat.;15% of riders reported crashing or falling off; Only 2.5% wear helmets.
Serra et al., 2021	Portugal	Data from various studies, including accident data and observational studies.	Real-world analysis of crash and medical databases.	-	To review head protection in electric micromobility and provide recommendations for safety measures.	High rates of head injuries among e-scooter usage.

Dozza et al., 2022	Sweden	Data from field trials	Real-world	Linear regression and modelling techniques.	To compare the kinematics and controls of bicycles and e-scooters in field trials.	Bicycles had shorter braking distances and higher deceleration than e-scooters.
Salas-Niño, 2022	United States	Data from the CDESRII study, which included medical records and interviews with injured riders.	Real-world analysis of crash and medical databases.	Descriptive analysis.	To analyse the effectiveness of Austin's e-scooter safety regulations using epidemiological components.	Current regulations inadequately address safety concerns; only 16.6% of identified risk factors are covered.
Crowe & Elkbuli, 2021	United States	National Electronic Injury Surveillance System (NEISS) data.	Analysis of crash/medical database(s)	Analysis of hospital admission data	To highlight the need for regulation and safety measures for e-scooter use.	Significant increase in e-scooter injuries, particularly head injuries; low helmet use; need for regulation.
Allem & Majmundar, 2019	United States	Data from social media (Instagram posts)	Real-world (analysis of social media posts)	-	To determine how much 'Bird' emphasized safety in its Instagram posts.	Rare emphasis on protective gear
James et al., 2019	United States	Online survey and observational study.	Real-world study	Descriptive statistics	To investigate e-scooter parking and perceptions of safety among riders and non-riders	16% of e-scooters were parked improperly; 6% blocked pedestrian right-of-way. Riders felt safer around e-scooters compared to non-riders
Phipps & Hamilton, 2024	Australia	Online survey data from 262 Australian undergraduate students.	Real-world data collected through an online survey.	Path modelling using the lavaan package in R.	To investigate willingness to engage in dangerous e-scooter behaviours using an integrated model of behaviour.	Subjective norm predicted willingness for all behaviours; attitude and perceived behavioural control predicted two behaviours; males showed higher willingness to engage in risky behaviours.

3.10. E-scooter reliability

The third theme is the reliability of e-scooters and their possible link with injuries. The Consumer Product Safety Commission (2021) made 48 specific examinations and determined numerous problems: Brake failure in 18 cases, fire hazard in 12, power off without warning in 5, control panel problems in 5, several causes in 5, and 8 cases with an unknown cause that led to e-scooter accidents (Tark, 2022). Moreover, seven researchers established that failures were the reason for 3%-16% of e-scooter injuries (Cicchino et al., 2021; Lavoie-Gagne et al., 2021). In particular, mechanical failures, including poor-quality brakes, throttles, handlebars, and steering

systems, were the cause of 16% of the cases reported by Cicchino et al. (2021). Austin Public Health (2019) reported that 19% of riders they interviewed believed their e-scooters had malfunctioned during use. A Consumer Reports survey showed that 8% of the participants reported that their e-scooters were not in good condition or were broken. Moreover, brake failures were reported to be the most common cause of accidents in previous studies (Seabrook, 2021; Uluk et al., 2022).

3.11. Patterns of Injury

a) Severity

Research suggests that injuries from e-scooter accidents are generally less severe than those from other transportation modes (Beck et al., 2020; Demir et al., 2023; Harbrecht et al., 2022; Toofany et al., 2021). However, the mortality rate associated with e-scooters is still a significant global concern, highlighting the potential for fatal outcomes despite the prevalence of minor injuries (Aulino et al., 2022; Dhillon et al., 2020; Traynor et al., 2022).

b) Motor Vehicle Collisions

Vehicle collisions are a common cause of injury among e-scooter riders, as detailed in 26 studies. These incidents, which may occur when e-scooters are hit by or collide with motor vehicles on roads or at intersections, tend to be more severe due to the significant energy transfer to the less protected rider (Dhillon et al., 2020). Factors such as higher traffic volumes (Kim et al., 2021) and the severity of injuries (Dhillon et al., 2020) contribute to the high frequency of vehicle involvement in reported injuries. Apart from these findings, other hospital injury studies indicate that incidents of e-scooters avoiding a vehicle or collisions involving striking or being struck by a vehicle range from 1.6% to 16.1% of cases.

c) Injuries and Deaths of Pedestrians and Bicyclists in Connection With E-Scooters

The use of e-scooters has been associated with injuries and fatalities of pedestrians and bicyclists. A fatal accident, for instance, involved an e-scooter hitting a pedestrian crossing the road (Tark, 2022). Further, an older woman suffered from a spinal fracture when she was hit by an e-scooter (Sikka et al., 2019). More so, the pedestrians injured by e-scooters were above 60 years 44.1%, which may be attributed to the age factor. There were instances of e-scooter riders colliding with pedestrians and vice versa, according to the Portland Bureau of Transportation (2018). This paper shows that pedestrians feel less safe when the e-scooter comes up from behind at a high speed than when it comes from the front (Che et al., 2020). One of the pedestrian accidents involved an intoxicated driver (Blomberg et al., 2019). Bicyclists have also suffered from modulo accidents or avoidance of e-scooters (Cicchino et al., 2021).

d) Anatomical Places of Injury

The injuries from e-scooter accidents involve several body parts, and forty-six studies provided information on the specific parts. The most frequent injuries were to the head, face, and neck the frequency of which ranged between 15% and 62.7% (Lavoie-Gagne et al., 2021; Harbrecht et al., 2022), followed by the upper extremity injuries, including the wrist and forearm which were seen to range between 16.7% and 72.5% (Bodansky et al., 2022). Lower limb injuries, which include the ankle, shin, and knee, were also noted, with thigh and pelvic region injuries being rarer (Uluk et al., 2022). Abdominal, thoracic, chest and spinal injuries were among the least reported (Moftakhar et al., 2020). Several studies reported multiple injuries in different parts of the body (Cohen et al., 2021; Dela Cruz et al., 2022).

The type of specialists and the level of detail in classifying the affected areas determined the frequencies of the reported injuries. Many studies were directed toward certain types of injuries, such as head, neck, and craniomaxillofacial injuries; one study showed that 86.2% of craniofacial injuries that occurred during e-scooter falls were to the upper and midface areas because the riders protected their chin, leaving these areas uncovered (Trivedi et al., 2019). Different kinds of trauma, such as surgical, orthopaedic trauma, and radiological, were seen to be associated with varying types of injuries in other studies (Dhillon et al., 2020).

e) Types of Injuries

Thirty-nine works have reviewed various kinds of traumas experienced by the e-scooter riders. These injury types are also usually associated with the part of the body where the injury occurred, according to the findings of numerous research studies (e.g., Harbrecht et al., 2022). For example, fractures are more frequent than other injuries, with rates reported to be between 11.6% (Blomberg et al., 2019) and 73.6% of all injuries (Dela Cruz et al., 2022) with a separate subgroup of more severe open fractures observed at 12.9% (Dela Cruz et al., 2022).

The percentages of the reported types of injuries are quite divergent and may be attributed to the medical facility where the injured rider is seen, including orthopedic surgery units or trauma centers (Dela Cruz et al., 2022; Trivedi et al., 2019b). Hospitals documented fractures more often than primary care clinics (29.3% versus 9.4%) (Bekhit et al., 2020), and the injuries also had dislocations in addition to fractures. The majority of the soft tissue injuries observed included lacerations, abrasions, punctures, contusions, sprains, and strains, which were more frequent in primary care settings than in hospitals (52.7% and 24.4%, respectively; Bekhit et al., 2020). For instance, abrasions and contusions ranged between 10.2% and 33.7% of the injuries, while lacerations ranged between 14% and 72.6%. Head injuries are categorized explicitly as concussions, traumatic brain injuries (TBI), or severe head injuries such as brain hemorrhage and fractures of the skull according to the different specialists employed in the study (Dhillon et al., 2020; Suominen et al., 2022).

3.12. *E-Scooter Crash Trends and Fatalities*

The rates of e-scooter crashes in the U.S. from 2017 to 2021, were generally on the rise before the COVID-19 pandemic, with incidents increasing from 1 in 2017, 5 in 2018, 25 in 2019, decreasing slightly to 14 in 2020, and then rising again to 23 in 2021 (Tark, 2022). Most of the deaths were due to being run over by a vehicle (49 cases), followed by tip-overs (9 cases), unspecified trips (4 cases), charging fires (2 cases), collisions with a pedestrian (2 cases), being hit by a commuter train (1 case), and operating while intoxicated (1 case) (Tark, 2022). Moreover, 55 out of 62 fatalities were males, and only 7 were females. Moreover, six papers included information on fatalities among their patients (both crash data and post-crash analysis) (Dhillon et al., 2020; Ioannides et al., 2022; Kim et al., 2021; Shiffler et al., 2021). International data up to 2020 also reported another 21 deaths in countries other than the United States (ITF, 2020).

Table 4. Review on Pattern Injury

Severity						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Beck et al., 2020	New Zealand	The data used were from electronic medical records of emergency department visits related to injuries.	Real-world analysis of crash and medical databases	$\chi 2$ test and Fisher's exact test for analysis	Describe the impact of the e-scooter sharing service on emergency department presentations and injury patterns	The introduction of e-scooters resulted in 56 related ED presentations, with most injuries being minor. On average, one ED bed was occupied for nearly three hours daily by e-scooter patients
Demir et al., 2023	Turkey	Accident data from clinical records.	Real-world analysis of crash/medical database(s).	Descriptive statistics, Mann–Whitney U-test, Kruskall–Wallis test, Pearson's Chi-square, and Fisher's exact test.	Analyse the characteristics of e-scooter-related injuries and accidents among young people.	Majority of victims were university students, most injuries were minor, predominantly soft-tissue injuries.
Trivedi et al. (2019a)	United States	Medical records from a Level I trauma center; retrospective case series	Real-world analysis of crash/medical database(s)	Descriptive statistics; median and interquartile range	Evaluate the incidence and types of craniofacial trauma associated with e-scooter	52 patients (57.7%) had craniofacial injuries; high prevalence of severe injuries; no helmet use reported.
Trivedi et al. (2019b)	United States	The data used were from a retrospective cohort medical record review and public observations of scooter riders.	Real-world data from emergency department	Descriptive statistics, including proportions, means, and standard deviations.	Characterize injuries associated with standing e-scooter use and common use practices.	The study found that 249 patients presented with injuries, with common injuries being fractures (31.7%) and head injuries (40.2%). Helmet use was low (4.4%).

Murros et al. 2023	Finland	Retrospective study data from a tertiary trauma center, including patient records	Real-world analysis of crash/medical database(s)	Firth logistic regression analysis, univariate and multivariate analyses	Compare clinically relevant variables, incidence, and severity between bicycle and e-scooter-related facial fractures	E-scooter patients were younger, more likely under the influence of alcohol, and sustained more severe craniofacial fractures compared to bicycle patients	
Moftakhar et al., 2021	Austria (Vienna)	Data from medical records, including demographics, injury patterns, types of injury, and treatment	Real-world analysis of crash/medical database(s)	Statistical analysis using SPSS 26.0 software, independent sample t-test, and Chi-square test	Report on the incidence and severity of e-scooter-associated injuries and identify protective measures to decrease morbidity	175 patients sustained e-scooter injuries; 40.6% had major injuries, primarily to the head and upper extremities. Injuries peaked during nighttime, and older patients had higher injury severity scores	
Traynor et al., 2021	United States	The study utilized data from the National Electronic Injury Surveillance System (NEISS), which records emergency department encounters related to consumer product-related injuries	The research was conducted through an analysis of a medical database, specifically the NEISS.	The authors used interrupted time series (ITS) analysis, chi-square tests, multivariable logistic regression, and autoregressive parameters to model the data.	Determine whether the introduction of e-scooter sharing systems increased serious scooter-related injuries across the United States	The study found that there was a significant increase in serious motorized scooter injuries coinciding with the introduction of e-scooter shares in the U.S., with hospitals near e-scooter shares experiencing a notable rise in hospitalizations due to scooter-related injuries	
Toofany et al., 2021	Canada	Databases used: Medline, Embase, SafetyLit, Transport Research International Documentation (TRID).	Real-world analysis of crash and medical databases	Narrative synthesis and descriptive statistics were used for analysis	Evaluate injury patterns and circumstances associated with electric scooter collisions.	Head, upper extremities, and lower extremities were most vulnerable to injuries, with low helmet use among riders. Most injuries were minor, and falls were the leading cause.	
Aulino et al., 2022	Italy	Case report data from an electric scooter accident.	Real-world case analysis.	Descriptive analysis of case report	Data repository associated with the manuscript	Analyse cranio-encephalic trauma from an e-scooter accident	The case highlighted severe craniofacial injuries and emphasized the need for compulsory helmet use to reduce

Motor Vehicle Collisions						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Dhillon et al., 2020	United States	The data used were trauma registry data from 9 urban trauma centres, focusing on patient demographics, diagnoses, interventions, and outcomes related to e-scooter injuries	Real-world data analysis from medical databases related to e-scooter injuries	Data were summarized using percentages for categorical variables and means with standard deviations for continuous variables.	Characterize hospital admissions and outcomes related to electric scooter injuries among Southern California trauma centres and to understand regional variations in injury incidence	The study found that 87 patients were treated for scooter-related injuries, primarily involving head and face injuries, with 20.7% requiring ICU admission and 17.2% needing surgical intervention. Helmet use was low (18.4%)
Kim et al., 2021	South Korea	The Emergency Department-based Injury In-Depth Surveillance (EDIIS) database, which includes accident data	An analysis of crash/medical database(s)	Descriptive and correlation analysis	Describe the characteristics of PMD-related injuries presented to emergency departments and to determine differences in injury types and body locations based on the type of PMD.	The study found that most PMD-related injuries occurred in men aged 19-59, primarily due to traffic accidents, with the head being the most commonly injured body part. Only 6 patients wore helmets.
Injuries and Deaths of Pedestrians and Bicyclists in Connection With E-Scooters						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Tark, 2022	United States	Data from the National Electronic Injury Surveillance System and Consumer Product Safety Risk Management System	Analysis of crash/medical databases	Statistical significance tests (p-values) and raking ratio estimation for handling nonresponse	To summarize injuries, deaths, and hazards associated with micromobility products from 2017 to 2021	Significant increase in ED visits for micromobility products; 129 fatalities reported from 2017 to 2021, with e-scooters being the most involved
Sikka et al., 2019	United States	Accident data from emergency department visits	Real-world analysis of crash/medical database	Primarily descriptive analysis	To highlight the safety risks and incidence of injuries for pedestrians associated with e-scooters	The study found that pedestrians, particularly vulnerable groups, face significant injury risks from electric scooters, including severe injuries and financial burdens

Che et al., 2020	Singapore	Data from virtual reality experiments assessing user attitudes	Simulator (virtual reality)	Wilcoxon signed rank test and Wilcoxon rank sum test	To determine user attitudes toward ES operating speed during pedestrian-ES interactions on shared footpaths	Lower speeds (10 km/h) perceived as safer in overtaking; 15 km/h rated safer in face-to-face interactions; ES riders felt 10 km/h was too slow

Anatomical Places of Injury						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Lavoie-Gagne et al., 2021	United States	Data from the institutional electronic medical record database, including clinical encounters with e-scooter injuries	Just analysis of crash/medical database(s)	Multivariable logistic regression models and nomograms for risk stratification	To characterize e-scooter injuries and provide risk stratification tools for modifiable risk factors associated with injury morbidity.	40.7% of patients required hospital admission; 14.7% sustained major trauma. Modifiable risk factors included age, substance use, and lack of helmet use
Dhillon et al. (2020)	United States	The data used were trauma registry data from 9 urban trauma centres, focusing on patient demographics, diagnoses, interventions, and outcomes related to e-scooter injuries	Real-world data analysis from medical databases	Data were summarized using percentages for categorical variables and means with standard deviations for continuous variables.	The aim was to characterize hospital admissions and outcomes related to electric scooter injuries among Southern California trauma centres and to understand regional variations in injury incidence	The study found that 87 patients were treated for scooter-related injuries, primarily involving head and face injuries, with 20.7% requiring ICU admission and 17.2% needing surgical intervention. Helmet use was low (18.4%)
Bodansky et al., 2022	United Kingdom	Data from electronic patient records, rental e-scooter usage statistics, and weather data	Real-world analysis of crash/medical database(s)	Unpaired t-test and Pearson coefficient for correlation	To evaluate the incidence and severity of musculoskeletal e-scooter injuries in Liverpool	Injury rates for e-scooters were comparable to bicycles; 26.1 injuries per million km for e-scooters and 24.1 for bicycles
Uluk et al., 2021	Germany	Prospective observational data from emergency departments, including patient-related and incident-related data, questionnaires.	Real-world study	Descriptive analyses, Student's t-test, Chi-square test, Fisher's exact test, McNemar tests, Mann-Whitney U test.	To investigate trauma mechanisms, injury patterns, and risk factors associated with E-scooter incidents.	Most injuries were multifocal, with lower limbs (42%) and head injuries (40%) being most affected. Alcohol consumption was linked to traumatic brain injuries.

Cohen et al., 2021	United States	National Electronic Injury Surveillance System (NEISS) data, focusing on e-scooter injuries.	Just analysis of crash/medical database(s)	Wilcoxon rank-sum test, Chi-squared test, Fisher's exact tests	To describe the epidemiology of admitted paediatric e-scooter injuries and compare them with existing literature on adults.	Increased incidence of fractures and polytrauma in children compared to adults; significant growth in ED admissions from 2017 to 2018; low helmet use among injured children.

Types of Injuries						
Authors/ Published year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Harbrecht et al., 2022	Germany	The data used were observational data on E-scooter-related accidents treated at the trauma centre	The study involved real-world data	Descriptive statistics and chi-square tests were used for data analysis.	To document and analyse the injury patterns of E-scooter-related accidents over one year	The study found that most injuries were to the upper and lower extremities and craniofacial areas, with no fatalities reported.
Bekhit et al., 2020	New Zealand	Accident Compensation Corporation (ACC) claims data	Just analysis of crash/medical database(s)	Retrospective review and descriptive statistic	To describe the number and types of injuries from e-scooter use and determine the financial burden of injuries	770 e-scooter injuries identified; 246 hospital presentations; total cost of injuries was $1,273,058 NZD
Suominen et al., 2022	Finland	The data used were retrospective cohort data from patient charts, focusing on accident data related to e-scooter injuries	Real-world data analysis of crash and medical databases	Descriptive analyses	Identify modifiable risk factors for electric scooter-related traumatic brain injuries, hypothesizing low helmet usage and high alcohol intoxication rates.	The study found high rates of alcohol intoxication (71%) and low helmet usage (3.8%) among patients. Most accidents occurred late at night, with a significant increase in the incidence of injuries over the study period.
Dela Cruz et al., 2022	United Kingdom	Retrospective review of orthopaedic referrals related to e-scooter use	Real-world data from medical records and orthopaedic referrals	Descriptive analyses were performed, reporting absolute numbers and percentages	Identify patterns and severity of orthopaedic injuries related to e-scooter use.	The study found 105 injuries in 83 patients, predominantly fractures, with a high incidence of upper limb injuries and low helmet use among riders.

E-Scooter Crash Trends and Fatalities						
Authors/ Year	Location	Data base(s)	Methodology	Statistical/ML approach	Study aim	Findings
Ioannides et al., 2022	United States	The data used were clinical notes	Real-world analysis of medical databases	Natural language processing (NLP) techniques	Describe e-scooter injuries and estimate the rate of injury per e-scooter trip.	The study found 1,354 e-scooter injuries, with an estimated injury rate of 115 injuries per million e-scooter trips.
Shiffler et al., 2021	United States	Clinical Data Warehouse	Just analysis of crash/medical database(s).	Logistic regression analysis.	To identify risk factors for craniomaxillofacial injuries in standing electric scooter accidents	Craniomaxillofacial trauma occurred in 23% of cases; intoxication was a significant risk factor, with 52.6% of those injured being intoxicated.

3.13. Gaze Behaviour

The safe operation of micromobility systems requires understanding how riders perceive their environment visually. Mobile eye-tracking technology has gained increased usage in scientific studies to study gaze patterns and attention behaviours among cyclists and, more recently, among e-scooter users. The following subsection presents findings from recent studies about visual attention and its connection to hazard perception, mental workload, and infrastructure context. Field-based research reveals that e-scooter riders have unique eye movements that differ from both pedestrian and cycling activities. Mobile eye tracker data shows e-scooter users focus their gaze 39–43% on the road ahead and 35–38% on other road users because they need to scan for potential conflicts at higher speeds (Pashkevich et al., 2022). Research shows dedicated cycle lanes promote consistent gaze patterns and fewer head movements, improving safety outcomes (Kegalle et al., 2025). Research on cycling provides important parallel findings. Systematic reviews demonstrate that intersections require a high visual workload because they cause gaze variability to increase and fixation durations to lengthen due to more complex decision-making (Kchour et al., 2025, Ma et al., 2024). The research analyzes cognitive processing levels, perceived stress, attention shifts, as well as fixation duration, and scan paths (Kchour et al., 2025, Ma et al., 2024). The way people group together determines their patterns of eye movements. During group bicycle rides, cyclists focus primarily on group members instead of traffic elements or signs. Hence, their fixations on traffic signs become shorter, making their steering movements more variable (Li et al., 2025). The same behaviour patterns could potentially exist among e-scooter users who ride in informal groups.

Simulation research confirms that gaze patterns remain constant throughout different environmental contexts. The study verified that fixations at crossings remained stable at 4.3% during real-world and simulated cycling tests, thus demonstrating that these zones receive insufficient attention despite their dangerous nature (Acerra et al., 2023). The visual actions of

drivers become significant when they perform turns at intersections. Research shows that wing mirror checks before turning across cycle lanes are completely absent in 83% of drivers, creating serious safety hazards for cyclists and e-scooter users (Abbasi et al., 2025). ADAS systems that integrate these findings could help develop safer interactions between drivers and vulnerable road users. Natural observations of e-scooter users in pedestrian-rich areas reveal how their visual attention patterns interact with their ability to avoid conflicts. The observation of e-scooterists shows how they modify their visual perspective and speed to maintain safe co-movement in public spaces (Lloyd, 2023). Research demonstrates two essential findings about e-scooter operations: (1) E-scooter riders need to dedicate extensive attention to their environment when using mixed-use areas; (2) The design of infrastructure determines both visual attention patterns and how people experience workload levels micromobility systems.

4. DISCUSSION AND CONCLUSION

The research provides a systematic review of recent studies about e-scooter safety issues in urban areas. The available research data remains fragmented particularly regarding rider conduct and various elements that influence total e-scooter safety. The emergence of e-scooters, primarily marketed as a recreational activity rather than a practical mode of transit, has been sudden, catching society unprepared and prompting inquiries into e-scooter safe use. This paper offers a comprehensive understanding of safety factors related to e-scooter use, including e-scooter rider behaviour and broader factors such as device-related features, policies, and road infrastructure. This review addresses shortcomings in prior studies by providing a broader global scope of e-scooter safety concerns. This approach expands the discussion on each reviewed theme and ensures a more comprehensive understanding of e scooter safety and related issues.

This study underscores the significance of conducting in-depth investigations of e-scooter interaction and incident data to gain a better understanding of safety risks associated with e-scooters and to develop targeted interventions. Such data should encompass accident scenarios, injury patterns, socio-demographic factors related to incidents, and how e-scooters interact with pedestrians and other devices. The study also highlights specific areas of research focus, pinpointing safety concerns that warrant further investigation, including helmet use, substance use, speeding, inexperienced riding, and underage riding. The study strongly emphasised that the shaping of safety culture is influenced by rider education programs and policy enforcement. Authorities should ensure that definitions and classifications of micro-mobility in regulatory frameworks support effective enforcement and address safety needs, with particular attention to speed and mass as key factors in crash severity. Proactively maintaining and adapting existing road infrastructure to safely accommodate e-scooters contributes significantly to safer rides. While efforts have been undertaken by stakeholders to address the interconnected risk factors through industry-leading technology, the persistent safety challenges within this domain underscore the necessity for further investigation. Effective interventions could benefit from being customised to account for time, location, and user specific factors rather than using a one-size-fits-all approach.

Research now focuses on visual attention and gaze behaviour as additional factors which affect rider safety in addition to behavioural and infrastructural risks. Research using eye-tracking technology shows that e-scooter users tend to focus their attention on the straight path in front of them while they pay less attention to surrounding dangers particularly at crossroads and busy visual areas. The combination of group riding with high-traffic areas and ambiguous infrastructure layouts creates additional cognitive demands that result in missed cues and delayed hazard response. The research demonstrates that designing rider training programs and infrastructure should focus on reducing the mental load to enable better attention

allocation. Future research that incorporates eye-tracking methods will deliver essential information about rider perception and decision-making which will create scientific foundations for specific safety solutions.

4.1. Research Gaps and Future Directions

The review offers an extensive analysis of e-scooter safety issues while there need to be some further explorations. The existing literature lacks systematic investigations which analyze how rider behaviour interacts with infrastructure quality and policy regulation together as a single scenario. The majority of current research investigates individual safety factors independently which exclude to understand their combined impact on safety results. The research about gaze behaviour and visual attention has recently gained attention but the existing studies in this field remain limited in their scope and scale. The existing research includes some studies which use small sample groups and simulated testing environments. Future research needs to implement eye-tracking technology with behavioural and physiological monitoring for extended periods in real-world settings to better understand how attention patterns change in urban environments.

The research needs to focus more on studying diverse users. The factors of age, gender, prior experience, and riding frequency strongly affect risk perception and safety performance, yet researchers frequently ignore these elements. Knowledge about individual user characteristics would enable developers to create safety interventions and adaptive infrastructure solutions. The current research lacks regional data, particularly from places where e-scooter usage is on the rise. Studies that compare cities and countries with different regulations and infrastructure designs would reveal optimal practices which could direct policy regulations. Research has not fully investigated how environmental factors such as night-time visibility weather conditions and surface types affect both rider safety and gaze patterns. Future research needs to study these variables to develop safer and more inclusive micro-mobility systems. The current research lacks regional data particularly from places where e-scooter usage is on the rise. Studies that compare cities and countries with different regulations and infrastructure designs would reveal optimal practices which could direct policy regulations. Research has not fully investigated how environmental factors such as night-time visibility and weather conditions and surface types affect both rider safety and gaze patterns. Future research needs to study these variables to develop safer and more inclusive micro-mobility systems.

4.2. Limitations

The research study used the PRISMA framework to perform database searches in Google Scholar, Scopus, Web of Science, EBSCO, ProQuest, TRID, APA, and PMS. The researchers spent many hours selecting precise keywords that matched the research objectives by giving priority

to e-scooter rider safety. The authors typically specify their keywords, yet researchers may have failed to identify relevant papers that use different terminology.

The research studies organized their safety concerns into two main categories, which included risky rider behaviour and external risks that surpassed rider control. The research studies discovered that, three primary safety issues related to e-scooter design problems and lack of policy frameworks, and inadequate road infrastructure. Our analysis resulted in six distinct clusters that addressed e-scooter rider safety concerns.

The search for peer-reviewed papers that examine e-scooter rider gaze behaviour produced only a few relevant studies despite our efforts to include strong and relevant research. The limited research on e-scooter riders requires us to draw insights from cyclist studies although these findings may not perfectly translate to e-scooters. The findings present challenges for comparison because different research methods including eye-tracking tools and route types and data handling procedures create inconsistencies between the results.

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