Politecnico di Torino

Corso di Laurea
A.a. 2025/2026
Sessione di Laurea Marzo 2026

Perceived Safety in Urban Electric Micromobility: A Scoping Review of Road Safety Evidence for E-Scooters and E-Bikes

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Abstract

This thesis presents a scoping review of the literature on road safety in micromobility, with a specific focus on e-scooters and e-bikes and on how perceived safety is measured, explained, and linked to safety-relevant outcomes and behaviours. A structured search was performed in the Scopus and Web of Science databases, following PRISMA-ScR guidance. After screening and assessing eligibility criteria, 26 studies concerning perceived safety in e-scooter and/or e-bike contexts were selected for inclusion. The extracted data were organised according to an evidence-type taxonomy comprising four main categories: Direct Perceived Safety (DPS), which includes self-reported perceptions of safety, comfort feelings of the users and risk perceived; Objective Safety Outcomes (OSO), such as crashes occurred and/or injury severity and near-miss events; Behavioural/Indirect Proxies (BIP), for example helmet use during riding, compliance with traffic regulations, choice of lane and speed during the use of the micromobility systems or braking patterns; System/Policy Context (SPC), encompassing regulatory measures of those systems of mobility, enforcement, practices during the right use of the vehicles according to the current legislation. The included evidence was analysed by combining descriptive quantitative mapping with narrative synthesis.

Across the reviewed studies, perceived safety was found to be primarily influenced by interactions with motorised traffic, the availability and quality of dedicated infrastructure and the presence of conflict points, such as intersections and shared spaces, which every user of the infrastructure can feel. There was a recurring finding of heterogeneity in perceptions across user groups, particularly with respect to characteristics like gender, age and riding experience. This suggests that identical environments may generate different safety perceptions depending on the characteristics of the user. The literature also documented behavioural adaptations associated with lower perceived safety, including avoidance behaviours such as riding on the sidewalk and, in certain contexts, limited use of protective measures, particularly among the users of the shared e-scooter services. When examined alongside objective safety outcomes, perceived safety emerged as a relevant proxy for risk. Furthermore, evidence based on near-miss events suggests that analysing the perceived safety dimension may capture important risk factors that crash data alone fails to detect.

Despite the growing body of literature especially during the last years, several important knowledge gaps persist: existing evidence is largely concentrated in a limited number of urban settings related to the biggest cities and the methodological approaches adopted are predominantly cross-sectional. Furthermore, perceived safety is measured using heterogeneous and often non-standardised indicators, while studies combining subjective perceptions with exposure-adjusted objective safety data are comparatively rare. Overall, this review's findings suggest that improving micromobility safety necessitates integrated interventions combining actions in the infrastructure design, traffic-speed management, policy changes, surveillance of the effects of those changes and enforcement actions, with explicit attention to equity-sensitive differences in perceived safety among various user groups.

Keywords: Micromobility; e-scooter; e-bike; road safety; traffic injuries; crash risk; near-miss events; infrastructure; regulation; urban mobility; vulnerable road users; perceived safety

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1. Introduction

1.1 Background

Electric micromobility, most notably in the form of electric scooters (e-scooters) and electric bicycles (e-bikes), has quickly become an integral part of everyday urban travel in Europe. Typically lightweight and electrically assisted, these vehicles are designed for short-to-medium trips; they offer a flexible alternative to private cars and complement public transport as a 'first/last mile' solution. The growth of electric micromobility has been driven by several factors: the push for decarbonisation and reduced local air pollution, the need to manage congestion in dense urban areas, and the expansion of shared mobility services (both dockless and station-based) that reduce barriers to adoption by lowering costs and eliminating ownership requirements [1].

On a European scale, the phenomenon linked to shared mobility has continued to grow steadily. According to the EU Urban Mobility Observatory, which draws on data from the European Shared Mobility Index, the number of shared mobility trips in Europe increased to 640 million in 2024. Those data suggests that the sector has reached maturity while continuing to expand in many large urban areas [2]. A similar trend has been observed locally in Italy, where the National Observatory on Sharing Mobility has emphasised the growing proportion of e-bikes in bike-sharing fleets, particularly in free-floating schemes, as well as the ongoing popularity of micromobility services accessible in the main cities by dedicated apps that can be downloaded by the users directly on their mobile phones. For instance, a national report indicates that free-floating e-bikes account for a significant proportion of bike-sharing fleets, and demand has grown year on year, with further growth anticipated [3].

Over the past few years, e-scooter sharing has been a major component of vehicle sharing in Italian cities, with demand stabilising at high volumes after the rapid expansion phase [4]. While micromobility can generate societal benefits, such as more active travel, fewer short car trips and improved network efficiency, it also introduces a clear road safety challenge. E-scooter and e-bike users are vulnerable road users by definition: they lack the physical protection of a vehicle body and are exposed to direct impacts in collisions with motor traffic, as well as single-vehicle falls caused by surface defects, obstacles or instability. The broader European road safety context highlights the importance of this issue. The European

Commission has emphasised that progress in reducing road fatalities has stalled, with vulnerable road users (pedestrians, cyclists, and powered two-wheeler users) accounting for nearly 70% of fatalities within urban areas, often in collisions involving cars and lorries [5]. This aligns with the Safe System approach promoted in EU road safety policy. This approach emphasises the importance of safer infrastructure, vehicles, speeds and road user behaviour, rather than placing responsibility solely on individuals [6]. The road-safety burden in Italy remains substantial, in fact according to official ACI–ISTAT statistics, there were 3,039 road deaths, 166,525 crashes and 224,634 people injured on the roads in 2023 [7]. Against this backdrop, which highlights the need for improvements in safety, the expansion of micromobility raises two closely related questions: how can injuries and severe outcomes among e-scooter and e-bike users be reduced, and how can safer conditions be ensured to support the sustainable uptake of these modes of transport without creating additional conflicts with pedestrians and other road users? The safety debate surrounding e-scooters and e-bikes cannot be understood solely through crash statistics. In many cities, users' experiences are shaped by a combination of factors, including interactions with motorised traffic, such as overtaking and close passing; discontinuities in the transport network, such as gaps in protected lanes and ambiguous priority rules; and street-level characteristics, such as pavement quality, signage, lighting and surface friction. These factors can influence both 'objective' risk (e.g. likelihood of conflicts and crashes) and perceived safety, which is a crucial determinant of whether people choose micromobility, where they ride and how they behave (e.g. whether they use protective equipment, avoid certain streets or move onto pavements). In other words, perceived safety is not only an attitudinal variable; it can also influence exposure patterns and behavioural adaptations that ultimately affect safety outcomes across the entire system.

Therefore, regulation and governance have become central to the micromobility safety agenda in Europe and Italy. Many jurisdictions have introduced limits on where e-scooters can circulate, maximum speeds and parking and user requirements, particularly for shared fleets. In Italy, recent updates to the national framework have reinforced safety provisions relating to e-scooters, including the obligation to wear a helmet and restrictions on riding on pavements, as set out in legislation published in the Gazzetta Ufficiale [8].

These changes demonstrate the direction of travel of the policy: micromobility is being integrated into the road system, with greater focus on risk management, user protection and sharing the road with pedestrians and cyclists. In this evolving context, one of the main challenges for research and decision-making are related to the significant methodological diversity evident in the micromobility safety literature. The existing studies differ substantially in their design nature, ranging from surveys and experimental approaches to naturalistic sensing and the analysis of administrative datasets. They also vary in how they conceptualise and measure safety aspects, including direct self-reported perceptions of safety, behavioural proxies and objective outcomes such as crashes datasets. This heterogeneity is further amplified by the variety of spatial and operational contexts in which the studies are conducted in the explored literature. Consequently, the available evidence is often difficult to compare and synthesise, which makes it more challenging for practitioners and policymakers to translate research findings into clear, actionable guidance for infrastructure design and regulatory interventions. Consequently, there is a strong rationale for synthesising and mapping the existing evidence base in a structured way, especially regarding perceived safety, which sits at the interface between user experience, behaviour and system performance.

For these reasons, this thesis takes a scoping review approach to map how the literature addresses road safety for e-scooters and e-bikes, focusing on perceived safety and its determinants. By identifying where evidence is concentrated, which outcomes are examined, and which contexts and methods are understudied, the review aims to inform more targeted research and, ultimately, more effective safety interventions that are consistent with European and Italian road safety objectives [9].

Building on the initial screening of the retrieved literature, the review ultimately narrowed its focus to perceived safety, a dimension that has historically received less attention in engineering-oriented road safety research. Traditional approaches tend to prioritise objective and easily measurable indicators, such as crash frequency and severity, operating speeds, traffic volumes or surrogate safety measures, under the assumption that these metrics provide the most reliable basis for diagnosis and intervention. However, for electric micromobility modes such as e-scooters and e-bikes, this perspective can be incomplete. The ways in which users perceive and interpret safety in the traffic environment often influence their behaviour, where they ride and whether they adopt protective strategies.

Perceived safety is therefore increasingly relevant because it offers insight into how infrastructure and regulation are translated into real-world use. Users' subjective assessments influence route choice, speed selection, gap acceptance, interactions with other road users and compliance with rules, ultimately affecting exposure to risk and the likelihood of unsafe manoeuvres or conflict situations. From a planning and design standpoint, incorporating perceived safety can provide practitioners with a more comprehensive understanding of 'safe' conditions — one that reflects not only physical risk, but also the usability and acceptability of the system. In this sense, perceived safety can serve as an interpretive bridge between technical performance and human behaviour, helping designers and policymakers develop infrastructure solutions and regulatory measures that are technically sound and aligned with how riders experience and navigate the road environment in everyday conditions.

1.2 Rationale

The use of electric micromobility, particularly e-scooters and e-bikes, is increasingly shaping the dynamics of urban mobility. While their growing popularity has the potential to make transport systems more sustainable, accessible and flexible, it also presents new challenges in terms of road safety. It is crucial to understand how these users interact with other road users and how infrastructural, regulatory and behavioural factors contribute to accident risk in order to develop safer and more inclusive urban environments.

However, the evidence available in the scientific literature regarding the safety of micromobility users, the methods employed to study this phenomenon, and the effectiveness of proposed countermeasures, remains fragmented. For this reason, a scoping review was conducted to systematically map existing research on the safety of electric micromobility, identify the main approaches to study and their outcomes, and highlight knowledge gaps that could inform future investigations, policy actions and infrastructure design guidelines. In this context, perceived safety was selected as a core domain because it directly influences users' willingness to adopt micromobility, providing actionable insight into how traffic conditions, network continuity and facility design affect safety-related behaviour and route choice.

1.3 Objectives and Research Questions

A scoping review was conducted to systematically map the current evidence on the road safety implications of electric micromobility (e-scooters and e-bikes) in urban environments.

The review focused specifically on perceived safety as a key dimension that shapes use, behaviour and policy relevance. This review was prompted by the rapid growth of micromobility in European cities, accelerated by post-pandemic mobility policies and investment programmes, which has increased the presence of e-scooters and e-bikes within already complex urban traffic systems. This rapid increase in numbers has raised practical questions about how these vehicles can be integrated into existing transport networks while ensuring that streets remain safe, legible and accessible for all users.

In the Italian context, this topic is particularly relevant because micromobility has evolved alongside a more detailed regulatory framework, including provisions in the 'Codice della Strada' and related implementing regulations. Rather than treating regulation as the sole object of analysis, this thesis uses the regulatory background as a contextual lens through which to interpret how perceived safety is shaped by the interaction between infrastructure conditions, traffic dynamics, user behaviour and governance choices (e.g. rules, enforcement and operational practices in shared systems).

Accordingly, the review is guided by three research questions that reflect the perceived-safety focus adopted throughout the thesis:

1. How is perceived safety of urban e-scooters and e-bikes conceptualised and assessed in the literature, and which measurement approaches are most commonly adopted? These include rating scales, scenario-based methods, behavioural proxies and objective indicators linked to safety perception.
2. In the context of urban e-scooters and e-bikes, what factors most consistently influence perceived safety, particularly in relation to the built environment and infrastructure, mixed-traffic interactions and psychosocial or user-level characteristics? How do these associations vary across transport modes and user groups considered in the literature.
3. To what extent is perceived safety linked to behavioural adaptation and safety-relevant outcomes, and what implications emerge for infrastructure design and system-level governance (including regulation and enforcement where addressed)?

To address these questions, the results were synthesised using an evidence-mapping approach, distinguishing between studies that primarily reported direct perceived-safety outcomes, those that relied on behavioural/indirect proxies, those that focused on objective safety outcomes (e.g. crash-related indicators) and those that addressed the system/policy context. This structure enables the thesis to highlight dominant themes within the evidence base, clarify how perceived safety has been studied and pinpoint areas where the literature is limited, particularly with regard to triangulation with exposure-adjusted objective outcomes and the evaluation of policy or infrastructure interventions.

1.4 Why a Scoping Review

A scoping review is the most suitable methodological approach for comprehensively mapping the existing body of evidence [10]. Unlike systematic reviews, which aim to answer specific and narrowly defined causal questions, scoping reviews examine the breadth, depth and characteristics of available knowledge across different study designs, populations and outcomes. This makes them particularly appropriate for topics where evidence is still fragmented across medical, engineering, and policy domains, and where methodological diversity precludes quantitative synthesis, such as the safety implications of e-scooters and e-bikes.

Furthermore, a scoping review can identify conceptual boundaries and research gaps that may inform future studies like systematic reviews or empirical investigations.

2. Methods

2.1 Review Design and Reporting Guidance

This work follows established scoping review methodological frameworks [11] and is reported in line with the PRISMA-ScR checklist.

2.2 Protocol and Registration

The structure and reporting of the protocol were informed by the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) checklist to ensure transparency and methodological consistency.

The research team engaged in iterative discussions to refine the research questions, eligibility criteria and data charting framework. The objective was to map the available evidence on road safety issues related to the use of electric scooters and e-bikes in urban contexts.

2.3 Eligibility Criteria

The eligibility criteria for inclusion in this scoping review were defined in advance to ensure methodological rigour and comprehensiveness of the material considered, as well as its alignment with the research objectives.

The eligibility criteria were limited to studies published in English because this language is the most widely adopted in scientific literature on road safety and transport research. This decision was made to ensure international comparability and enhance accessibility of the findings (Haddaway et al., 2015). This review specifically focuses on peer-reviewed studies examining the behaviour of e-scooter and e-bike users, particularly the aspects related to their interactions with road infrastructure and other road users in urban environments. Particular attention was also given to studies investigating the behaviour of motor vehicle drivers when interacting with micromobility users, for example during overtaking manoeuvres, at signalized intersections or within bike boxes (advanced stop lines), which are common in many Italian cities.

This review focuses on the urban environment because it is characterized by high traffic density, complex interactions between different road users and constantly changing traffic conditions. In this context, the agility and rapid acceleration of micromobility vehicles can lead to unpredictable movement patterns, increasing the risk of crashes for vulnerable road users. Therefore, understanding these dynamics is essential for informing effective safety measures and guiding infrastructure adaptations suited to urban mobility systems.

The review focuses on powered two-wheel micromobility vehicles, particularly electric scooters and bicycles, which have become increasingly widespread over the past two decades, as explained above. Their inclusion is consistent with the legal definitions established by the Italian regulatory framework: more specifically, the Article 1, paragraph 75, of the 2020 Budget Law [12] equates electric scooters with velocipedes, while the Article 50 of the Italian Highway Code [13] defines velocipedes as vehicles with an auxiliary electric motor of no more than 0.25 kW that provides assistance only when the rider is rolling the pedals, up to a maximum speed of 25 km/h. These legal references were needed to define the scope of the review and ensure the consistent inclusion of micromobility vehicles that are legally recognized within the Italian and European transport systems.

These normative definitions also specify several operational and safety-related requirements like the visibility conditions for daytime and night-time use, obligations regarding protective equipment such as helmets and lighting devices, and behavioural rules concerning speed limits and road sharing. As such, they are an essential point of reference for interpreting the empirical evidence examined in this review.

A scoping search was conducted across multiple databases, including Scopus and Web of Science, to ensure comprehensive coverage of interdisciplinary literature from engineering, transport, public health and policy perspectives. Moreover, the review process was conducted in accordance with PRISMA-ScR guidance to promote transparency, reproducibility and completeness in synthesizing the evidence.

The main variables included in this scoping review — specifically, speed; lateral position; reaction time; acceleration and deceleration; conflict indicators; and crash-related outcomes — were selected because they most effectively capture the two central dimensions underpinning the research question: behaviour and safety. The first group of variables is predominantly quantitative and directly related to rider behaviour. Although these indicators can be objectively measured through vehicle dynamics data or sensor-based technologies, they ultimately reflect the decisions and actions of users when interacting with the traffic environment surrounding them. They therefore provide a reliable representation of behavioural patterns that may shape exposure to risk.

Conversely, crash- and injury-related variables capture the safety dimension by describing the outcomes that occur when behavioural factors intersect with hazardous conditions. These measures include both minor and severe incidents, making it possible to understand how rider decisions translate into real-world consequences.

Selecting these variables ensures that the review captures how micromobility users behave in urban traffic and the implications of these behaviours for safety performance and vulnerability.

This scoping review includes studies that employ a variety of methodological approaches, including simulation studies, naturalistic studies, observational studies and survey-based studies. These studies offer complementary insights into micromobility behaviour and safety. These approaches differ substantially in terms of their data collection techniques, ecological validity and the type of insights they can generate.

Simulation studies provide a controlled environment in which specific scenarios, user behaviours and hazardous conditions can be precisely replicated [14]. The main advantage of simulations is the ability to isolate variables and systematically test behavioural responses without exposing participants to real-world danger. However, simulated environments inherently lack the risk perception and emotional engagement experienced in open-road conditions [15]. As a result, rider reactions may not fully represent genuine behaviour [16], given that participants are aware that they are not at risk of actual harm.

By contrast, naturalistic studies collect data in real-world traffic settings, reflecting authentic user behaviour and environmental complexity [17]. They have high ecological validity, capturing spontaneous interactions with infrastructure, other road users and unpredictable conditions. However, data obtained through naturalistic methods is often difficult to interpret due to noise, incomplete measurements or unreliable sensor performance [18]. As emphasised in supervisory discussions, the productivity of naturalistic studies can be reduced when the technology used to monitor behaviour fails to generate clean, interpretable datasets [19].

Observational studies are an intermediate approach that enables the systematic recording of rider behaviour in open environments without direct intervention [20]. Although they provide valuable insights into behavioural patterns and interactions, they are limited by the observer's perspective [21] and are unable to capture internal decision-making processes [22].

Survey-based studies were also included to map perceptions, self-reported behaviours and attitudes towards risk. While these studies provide useful contextual information, they are based on subjective assessments and are subject to recall and social desirability biases [23, 24, 25].

Due to these methodological differences, it is impossible to obtain a dataset that captures every aspect of rider behaviour and safety perfectly. For this reason, the review takes an integrative approach, combining insights from simulated, naturalistic and observational studies in order to provide the most comprehensive and realistic depiction possible of micromobility dynamics in urban environments.

The decision to start the review period in 2005 aligns with the development of the contemporary micromobility sector. While the first commercial introduction of electric bicycles dates back to the early 2000s, their diffusion accelerated markedly after 2005, leading to rapid global expansion [26, 27]. During this time, there was an increasing focus in the scientific literature on the safety performance of electrically assisted two-wheelers, in response to growing concerns about the integration of this new type of mobility mode into urban traffic systems and the increasing number of collisions involving vulnerable road users [28, 29]. Although shared e-scooter systems did not appear until 2017, the underlying technology had existed for a decade by that point, and safety studies accelerated shortly thereafter [30, 31]. Therefore, selecting 2005 as the starting point ensures that the review captures the onset of scientific enquiry into micromobility safety and the evolution of crash-related evidence over time [32].

The specific inclusion criteria adopted for this review are detailed and summarized below:

- Language: only studies published in English were considered
- Topic(s): the review includes studies addressing (i) e-scooter/bike rider behaviour, (ii) car-driver behaviour when interacting with micromobility users, (iii) urban road safety, (iv) infrastructure-design principles for micromobility users, (v) safety regulations and policies for micromobility inclusion into urban mobility systems
- Context: urban
- Vehicle type: e-scooters, e-bikes, powered monowheel, overboard, segway [33]
- Variables: vehicle speed, lateral position, reaction time of the users, acceleration/deceleration of the vehicles, conflicting measures during riding, crashes
- Type of study: simulation, naturalistic, observational, survey (questionnaire),

- Publication type: indexed journal papers
- Period of publication: 2005-june2025

2.4 Information Sources

This scoping review was conducted primarily using information retrieved from Scopus and Web of Science (WoS), which are two of the most comprehensive and internationally recognized bibliographic databases. These platforms provide extensive coverage of peer-reviewed journals and scholarly publications spanning multiple disciplines, including transportation engineering, public health, and urban planning. The selection of these databases ensures the scientific robustness and reliability of the evidence collected, as both include only sources that meet rigorous academic and editorial quality standards.

Table 1: Source databases

Source database	Description
Web of Science	This research platform, developed by Clarivate Analytics, provides access to a curated collection of scientific literature. It includes multiple citation indexes and enables bibliometric analyses and citation tracking, supporting evidence-based research and scholarly assessment.
Scopus	This bibliographic database developed by Elsevier indexes peer-reviewed publications across many disciplines and provides tools for citation tracking and bibliometric analysis, supporting systematic and scoping literature searches.

2.5 Search Strategy

In line with the eligibility criteria defined for this scoping review, a comprehensive and structured set of search terms was developed to ensure full coverage of key micromobility and urban road safety concepts. An exploratory review of terminology was first conducted using Google Scholar to identify preliminary keywords and recurring descriptors used in recent scientific literature, thus initiating the construction of the search strategy. This initial phase supported the refinement of the main search blocks and facilitated progression through subsequent PRISMA-ScR Checklist steps, particularly items 6, 7 and 8 concerning eligibility criteria, information sources and the search strategy.

A more systematic search strategy was subsequently developed using the Scopus Advanced Search interface. This proved to be an especially effective way of identifying suitable combinations of terms, synonyms and morphological variants. By analysing keyword roots and using truncation, different grammatical forms could be accounted for, including nouns, adjectives, and verbs. This ensured that the search covered the full semantic scope of the concepts under investigation. This step was important from a methodological perspective, as it enabled the construction of queries capable of retrieving broad and thematically diverse evidence from multiple research fields.

In consultation with the supervising professor and collaborators, three main macro-areas of terminology were identified to structure the systematic search.

- *Users and vehicle types*, including terms such as e-bike, electric bicycle, e-scooter, electric scooter, electric mobility, and micromobility user;
- *General concepts*, covering behavioural and safety-related dimensions such as behaviour, road safety, crashes, interactions, injuries, risk factors, and human factors;
- *Policy and infrastructure*, incorporating terms linked to the built environment and regulatory context, such as road, lane, cycling infrastructure, intersection, road markings, urban environment, and transport policy.

The final search strategy therefore integrates behavioural, infrastructural and contextual terminology to retrieve evidence describing the mechanisms and circumstances leading to crashes, as well as the systemic conditions shaping the everyday experiences of micromobility users in urban settings. This approach ensures broad yet methodologically robust coverage of the literature, consistent with the aims and standards of a scoping review.

After creating the initial search queries for Scopus and Web of Science, each adapted to the syntax and structure of the respective database, the first attempts yielded an excessively large number of results, often exceeding one thousand. This outcome was anticipated, as the preliminary query formulation prompted the search engines to extract matches from various fields, such as the title, abstract and full text, depending on the structure of the Boolean operators and keyword groups.

To obtain a more focused and manageable set of studies aligned with the aims of this review, several rounds of refinement were necessary. For example, exclusion of conference papers or book chapters.

This involved narrowing the scope of certain keyword groups, refining truncations and reorganizing Boolean combinations to exclude irrelevant thematic overlaps. Through this iterative process, the search strategy evolved from a broad, exploratory formulation to a more precise structure capable of retrieving a reasonable number of thematically coherent articles suitable for screening.

This strategic refinement process ensured that the final set of retrieved studies remained closely aligned with the research objectives and fully consistent with the predefined eligibility criteria. These operations, in fact, improved the methodological coherence of the review, reinforcing the relevance and reliability of the resulting findings.

The need for iterative refinement of the search strategy is widely recognized in methodological literature. As Siddaway et al. [70] have highlighted, researchers should carefully consider alternative terms and conceptualisations during the definition of terms to insert in the final research queries, since similar phenomena are often described using different terminology. This issue usually becomes apparent during the preliminary scoping stage, highlighting the importance of taking a broad, inclusive and flexible approach when developing search terms and query structures that subsequently will start the real collection from the databases. By systematically testing and adjusting the queries, this review identified the optimal balance between sensitivity (capturing as many relevant studies as possible) and specificity (excluding irrelevant records), resulting in a robust, replicable search protocol.

According to Siddaway et al., careful attention should be paid to the use of the following:

- singular versus plural forms, verbal forms, adjectives (e.g., “rider,” “riding”);
- different spellings (e.g., “powered two-wheeler,” “powered-two-wheeler”);
- synonyms (e.g., “crash”, “collision,” “micromobility”, “soft-mobility”);
- broader versus narrower terms (e.g., “Britain,” “England,” “Scotland,” “Wales”).

In their practical guide, Siddaway et al. emphasise the importance of balancing sensitivity (i.e. the ability to identify as many potentially relevant articles as possible) with specificity (i.e. ensuring that the selected articles are indeed relevant). At this initial stage, they recommend prioritising sensitivity when formulating search terms to minimise the risk of overlooking significant studies. Although this approach will produce a larger number of results, some of which may ultimately be irrelevant, it allows a large number of studies to be screened and refined efficiently, ensuring that important contributions are not omitted from the review.

The adopted search strategy is presented in Table 2. The specific search strings employed based on the search strategy adopted to identify relevant literature for this study are presented below. The downloaded datasets from Scopus and WoS were subsequently imported into the R environment, where they were merged and compared using the appropriate tools to identify and remove duplicate records. Duplicates were identified and eliminated using the find_duplicate function from the revtool package in R [34, 35], based on the title of each article.

Specifically, the Scopus search yielded N=369.

The WoS search yielded N = 163.

After screening on R, 125 duplicates were eliminated, leaving N = 407 articles.

In the table 2 below are reported the two research queries used to download the set of papers from Scopus and WoS.

Table 2: Search strings

Source	Search string
Scopus	(TITLE (e-scooter* OR "electric scooter*" OR electric-scooter* OR e-bike* OR "electric bike*" OR electric-bike* OR e-bicycle* OR "electric bicycle*" OR micromobility OR micro-mobility OR "soft mobility" OR soft-mobility OR "powered two-wheeler*" OR powered-two-wheeler* OR e-mobility OR electric-mobility OR "electric mobility" OR "electric mobility device*" OR monowheel* OR mono-wheel* OR segway* OR overboard* OR over-board*) AND TITLE (safety OR crash* OR collision* OR behaviour* OR behavior* OR conflict* OR near-miss* OR "near miss*") AND TITLE (infrastructur* OR road* OR lane* OR intersection* OR urban OR "bike box*" OR bike-box*)) OR (KEY (e-scooter* OR "electric scooter*" OR electric-scooter* OR e-bike* OR "electric bike*" OR electric-bike* OR e-bicycle* OR "electric bicycle*" OR micromobility OR micro-mobility OR "soft mobility" OR soft-mobility OR "powered two-wheeler*" OR powered-two-wheeler* OR e-mobility OR electric-mobility OR "electric mobility" OR "electric mobility device*" OR monowheel* OR mono-wheel* OR segway* OR overboard* OR over-board*) AND KEY (safety OR crash* OR collision* OR behaviour* OR behavior* OR conflict* OR near-miss* OR "near miss*") AND KEY (infrastructur* OR road* OR lane* OR intersection* OR urban OR "bike box*" OR bike-box*)) AND PUBYEAR > 2005 AND PUBYEAR < 2026 AND PUBSTAGE(final) AND DOCTYPE(ar) AND (LIMIT-TO (SUBJAREA,"ENGI") OR LIMIT-TO (SUBJAREA,"SOCI") OR LIMIT-TO (SUBJAREA,"PSYC") OR LIMIT-TO (

	SUBJAREA,"MULT")) AND (LIMIT-TO (LANGUAGE,"English"))
Web of Science	(TI=(e-scooter* OR "electric scooter*" OR electric-scooter* OR e-bike* OR "electric bike*" OR electric-bike* OR e-bicycle* OR "electric bicycle*" OR micromobility OR micro-mobility OR "soft mobility" OR soft-mobility OR "powered two-wheeler*" OR powered-two-wheeler* OR e-mobility OR electric-mobility OR "electric mobility" OR "electric mobility device*" OR monowheel* OR mono-wheel* OR segway* OR overboard* OR over-board*) AND TI=(safety OR crash* OR collision* OR behaviour* OR behavior* OR conflict* OR near-miss* OR "near miss*") AND TI=(infrastructur* OR road* OR lane* OR intersection* OR urban OR "bike box*" OR bike-box*)) OR (AK=(e-scooter* OR "electric scooter*" OR electric-scooter* OR e-bike* OR "electric bike*" OR electric-bike* OR e-bicycle* OR "electric bicycle*" OR micromobility OR micro-mobility OR "soft mobility" OR soft-mobility OR "powered two-wheeler*" OR powered-two-wheeler* OR e-mobility OR electric-mobility OR "electric mobility" OR "electric mobility device*" OR monowheel* OR mono-wheel* OR segway* OR overboard* OR over-board*) AND AK=(safety OR crash* OR collision* OR behaviour* OR behavior* OR conflict* OR near-miss* OR "near miss*") AND AK=(infrastructur* OR road* OR lane* OR intersection* OR urban OR "bike box*" OR bike-box*)) AND LA=(English) AND PY=(2005-2025) AND (SU=(Behavioral Sciences) OR SU=(Psychology) OR SU=(Social Sciences Other Topics) OR SU=(Engineering) OR SU=(Transportation)) AND DT=("Article")

2.6 Selection Process

The study selection phase is a crucial step in any scoping review, in fact, it involves carefully assessing the articles that have passed the initial screening process in order to identify the most relevant ones for the research question. This task requires an in-depth understanding of the predefined inclusion and exclusion criteria and also the ability to critically evaluate the methodological quality and relevance of each study.

Although this phase is often time-consuming and demanding in terms of methodology, it is essential to ensure that the scoping review is based on robust and reliable evidence base. In many scoping reviews, study selection is carried out by a single reviewer. However, this approach can reduce the validity of the results and increase the risk of selection bias. To enhance the reliability of the findings, therefore, the involvement of multiple reviewers is strongly recommended. It is equally important to use appropriate screening tools and maintain clear, transparent documentation throughout the review process to ensure reproducibility and accountability.

In the present study, four independent reviewers (Prof. Bassani, Prof. Tefa, Eng. Lioi and the author) participated in the screening phase. All reviewers had received academic training in civil and road engineering, ensuring an adequate level of subject-matter expertise for assessing the retrieved studies. While some methodological guidelines recommend initially screening titles, followed by abstract review, the present study found that titles alone often did not provide sufficient information to assess compliance with the eligibility criteria originally set. So, in the first moment, due to the high number of material downloaded from the databases, I did a first title and abstract review to select the relevant material and then the other reviewers alone conducted a second review of all the material, including the materials firstly not accepted.

As reported in Appendix C, each reviewer conducted the screening independently using the Metagear package for R [36]: this tool visualised titles and abstracts through a user-friendly graphical interface as shown in Figure 1, enabling reviewers to classify each record as 'YES', 'NO' or 'MAYBE'. In cases of uncertainty or disagreement, records were discussed collectively at dedicated meetings to reach a consensus. Articles considered potentially eligible were then subjected to full-text screening.

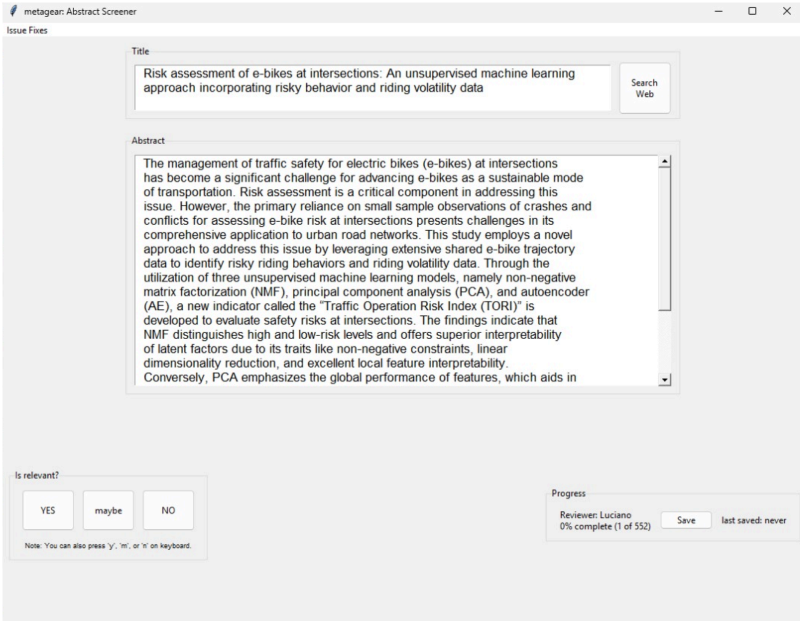

Figure 1 Graphical interface of Metagear package for R

Professor Bassani also contributed at this stage, serving as an independent evaluator. Leveraging his considerable expertise, he supported the reviewers in confirming whether the selected articles met the established inclusion and exclusion criteria, as well as assisting in resolving any ambiguities especially for articles firstly selected as ‘YES’ or ‘NO’ by me. Professor Tefa and Eng. Lioi reviewed together the ones selected as ‘MAYBE’, studies initially marked as 'uncertain'. At the end they selected the relevant and not relevant articles. In the cases in which the title and abstract did not provide sufficient detail to determine eligibility, a rapid full-text assessment was conducted to systematically apply all inclusion criteria.

To ensure methodological rigour and full compliance with international guidelines and PRISMA recommendations, the study selection process was structured using strategies designed to improve the reliability, consistency, and transparency of screening decisions [37]:

- *Clarification of inclusion criteria*: before the screening process began, a calibration exercise was conducted with all reviewers to promote consistent interpretation of the eligibility criteria established in the review protocol. In line with the PRISMA-ScR guidelines [38] and the JBI Manual for Evidence Synthesis [39], the reviewers assessed the titles and abstracts of an initial set of ten studies jointly, discussing their relevance and conformity with the inclusion criteria and resolving any uncertainties that arose during the evaluation process. This preliminary step was essential for minimizing inconsistencies in study selection and fostering a shared understanding of the characteristics of the studies considered relevant for this scoping review. This strengthened the transparency and reproducibility of the screening process.

- *Independent dual screening and conflict resolution*: article screening was conducted independently by three reviewers who had received academic training in road and traffic engineering. Any discrepancies in the reviewers' assessments were discussed until a shared decision was reached. If consensus could not be reached or uncertainty remained regarding study eligibility, a fourth reviewer, Professor Bassani, was consulted to provide expert judgement on the object of discussion. This procedure aligns with the recommended best practice for scoping reviews, reinforcing the transparency and methodological rigour of the study selection process.
- *Systematic documentation of decisions*: all decisions relating to inclusion and exclusion, along with their respective justifications, were systematically documented in the notes of the author.
- *Ongoing quality control and supervision*: Throughout the selection process, weekly coordination meetings were held among the reviewers to address ambiguous cases, align interpretations, and ensure methodological consistency. These checkpoints were critical quality control mechanisms that contributed to the overall coherence and validity of the review process, in line with established best practices [40].

Due to the large number of records retrieved through the search strategy, a preliminary thematic classification was necessary to keep the screening process manageable and transparent. In line with established scoping review practice, this initial mapping exercise was conducted using titles and abstracts only. The aim was to structure the evidence base and support the subsequent phases of eligibility assessment and data charting. At this stage, the retrieved studies were organised into five overarching domains: Driver Behaviour; Crash Data; Perceived Safety (questionnaire-based studies); Regulatory Aspects; Other findings. The latter included topics such as roadway geometry, pavement surface characteristics, and technical recommendations. These broad categories were then refined into more specific sub-categories based on the titles and abstracts to capture the main methodological and thematic differences in the literature.

- *Driver Behaviour (n = 107)*: studies that examined behavioural responses and interaction mechanisms. These contributions were further categorised according to the study setting and user perspective. Examples include laboratory or simulation-based experiments, observational field studies, naturalistic in-vehicle studies and analyses focusing on car drivers, passengers or both.
- *Crash Data (n = 83)****:*** studies that focused on safety outcomes derived from crash events. These were organised according to their main analytical focus, such as crash frequency, injury severity, crash dynamics and the related damage or consequences and the type of analysis undertaken. This included modelling approaches and empirical comparisons.
- *Perceived Safety (questionnaires) (n = 29)****:*** studies based on self-reported safety perceptions. These were further classified according to the instrument used (e.g. questionnaires or interviews), the target population, and the method of administration or distribution.
- *Regulatory Aspects (n = 26)****:*** included contributions that addressed the regulatory framework of micromobility. This domain was divided into two categories: studies that focused on vehicle typology and performance requirements, and studies that focused on traffic rules and legal provisions.
- *Other (n = 37)****:*** this category comprised studies that did not fall under the previous domains. These studies covered geometry-related issues, surface and pavement characteristics, and additional technical notes or recommendations.

In the figure 2 below the information were resumed.

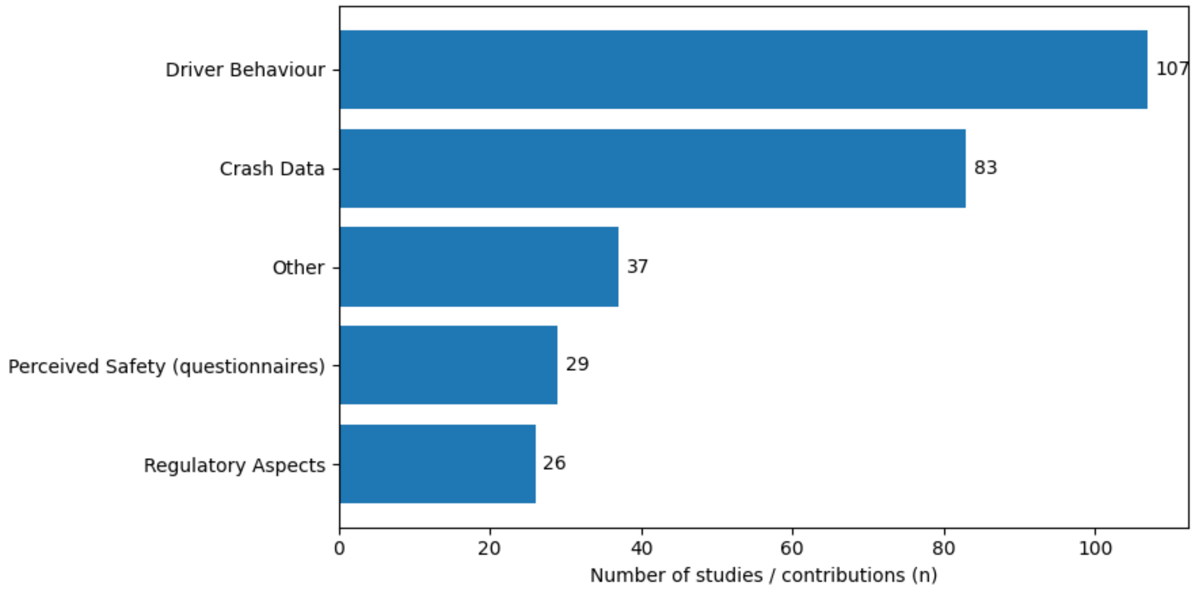

Figure 2 Distribution of included evidence by domain

Based on the outcomes of thematic grouping into macro-topics and sub-classes, the review was narrowed down to the 'Perceived Safety' domain. In particular, 29 articles were identified and selected for explicitly addressing aspects of perceived safety relevant to the scope of this work.

2.7 Data Charting Process

Data charting was carried out to systematically collect and organize information from each source of evidence included in the review, in a way that directly addressed the review questions. In accordance with scoping review guidance, the charting process was designed to be flexible and iterative so that the extraction framework could be progressively refined as additional types of evidence and outcome measures were identified during the review.

A structured data-charting form was developed in advance and implemented in a spreadsheet. Informed by the Population–Concept–Context (PCC) eligibility criteria and the PRISMA-ScR reporting items, the initial version of the charting process was designed to support both narrative mapping of the available evidence and descriptive quantitative synthesis.

Before full extraction, the form was piloted on a subset of included studies to test feasibility and consistency. During the pilot and throughout extraction, definitions were clarified, fields were added or merged when needed (e.g. to distinguish direct measures of perceived safety from behavioural or objective safety proxies), and a short codebook was maintained to ensure that similar variables were coded consistently across studies.

For each included source, the following information was charted (when available):

- Bibliographic details: author(s), year, title, country/region, and publication type.
- Study characteristics: study design, data source(s) (e.g., survey, administrative crash data, video or simulator experiment, GPS tracking), setting, sample size and population profile.
- Mobility mode(s): e-scooter, e-bike, bicycle, walking or motorized comparators; and ownership/use context (shared vs private) when reported.
- Outcomes and constructs: (i) Direct measures of perceived safety, comfort or risk perceived, ascertained using instruments such as Likert scales, ordinal ratings or scenario-based evaluations; (ii) Objective safety outcomes including crash involvement, injury severity and near-miss indicators; (iii) Behavioural proxies relevant to safety such as helmet use, compliance with traffic signals, mobile phone use while riding, choice of lane, speed and harsh braking events.
- Determinants and explanatory variables: the characteristics of the infrastructure and built environment are considered including aspects like facility type, crossings and surface conditions, as well as traffic exposure and environmental conditions. Socio-demographic and experience-related variables are also considered, such as previous crashes or near-miss events. Attitudinal and psychological factors are considered, as well as the broader policy and regulatory context where applicable.
- Quantitative outputs: including informations like effect estimates and associated statistical indicators such as odds ratios, regression coefficients, correlations, percentages and conditional probabilities, as well as measures of uncertainty such as confidence intervals, standard errors and p-values. Where available, metrics of model performance or fit are also included, such as R^2, AIC/BIC, RMSEA/CFI and, in the case of predictive models, accuracy or F1 scores.
- Data quality and reporting: including reporting and registration rates; potential issues with under-reporting; and any other limitations that could affect the interpretation of safety-related outcomes.

To improve comparability between different methods and metrics, a set of harmonization rules was applied during the charting process:

- Directionality was standardized so that higher values consistently corresponded to higher perceived safety or, conversely, to lower levels of risk, wherever possible. If individual studies employed the opposite coding scheme, this was explicitly documented.
- Measurement units, where possible, were normalised, for example, by expressing speed in kilometres per hour, distance in metres, time to collision in seconds and harsh braking events per kilometre. Where such conversion was not possible, the original units were retained and recorded carefully.
- Where multiple models or analytical specifications were reported within the same study, priority was given to the estimate most fully adjusted for the primary outcome of interest. Alternative specifications were nevertheless noted if they altered the interpretation of the results.
- In parallel, each study was assigned an evidence type flag to distinguish between direct perceived safety evidence and objective safety outcomes, as well as behavioural or proxy indicators. This classification enabled a more transparent synthesis and prevented the conflation of constructs that were not methodologically comparable.
- Where a study only reported the direction and statistical significance of an effect without providing a numerical estimate in the extractable text, the corresponding entry was coded as 'direction/significance only' and marked as 'numerically missing', with no attempt made to impute values.

Data management and quality control were integrated into every stage of the process. The version-controlled spreadsheet was checked for internal consistency, including verifying percentage denominators and ensuring coherence between reported coefficients and their narrative interpretation. The final charted dataset served two purposes: first, it was used to populate the summary tables, including those relating to the characteristics of the included sources and the extracted data items; and second, it supported the descriptive quantitative mapping of study characteristics, outcomes and determinants, together with the thematic synthesis presented in the Results section.

2.8 Synthesis of Results

The charted data were synthesized using descriptive quantitative mapping and narrative synthesis. Consistent with the aims of a scoping review, no meta-analysis was planned. Instead, synthesis focused on (i) characterizing the included literature, (ii) mapping how "safety" and "perceived safety" have been operationalized, and (iii) identifying patterns and knowledge gaps across mobility modes, contexts, and determinants.

A descriptive numerical summary was developed for the key characteristics of the included studies: year of publication, geographical setting, study design, data sources, sample size considered and mobility mode taken into account. Categorical variables were summarized using counts and proportions. Where continuous variables such as speed, lateral distance, time-to-collision or detour distance were reported, the values were retained in their original units and synthesized using the most appropriate descriptive statistics. Depending on the reporting format adopted in the primary studies, these were either the mean and standard deviation or the median and interquartile range. To avoid conflating conceptually distinct constructs, safety-related outcomes were synthesized separately by evidence type using a predefined taxonomy (see Table 2.A). This taxonomy consists of the following categories: Direct Perceived Safety (DPS), Objective Safety Outcomes (OSO), Behavioural/Indirect Proxies (BIP) and System/Policy Context (SPC). This taxonomy was applied to each included study as a mutually exclusive classification, and cross-tabulations were produced, for example, by mobility mode, contextual setting and determinant category.

Where effect estimates were reported, such as odds ratios, regression coefficients or correlations, these were extracted alongside the corresponding measures of uncertainty (including confidence intervals or standard errors) and information on statistical significance. Where numerical estimates could not be extracted, only the direction and significance of the result were coded, with no imputation of missing values. The evidence was then integrated through a narrative synthesis structured around three core dimensions: (i) how outcomes were operationalized within the DPS/OSO/BIP/SPC framework; (ii) which mobility mode or modes were investigated; and (iii) the main thematic domains of determinants, namely the built environment and infrastructure, traffic and interactions, environmental conditions, user characteristics and experience, psychological constructs, and the broader system and policy context.

Table 2.A. Evidence-type taxonomy used for quantitative mapping

Label	Definition (what is measured)	Typical outcomes extracted	Typical quantitative outputs
DPS (Direct perceived safety)	Direct self-reported ratings of safety, comfort, or perceived risk, including scenario-based assessments and perceived hazards.	Likert/ordinal safety or comfort scores; perceived risk ratings; perceived hazards; scenario/video evaluations; network-level perceived safety as link attributes/constraints.	Percent distributions by level; OR/β; correlations; SEM/latent parameters; detour distance or feasibility under safety thresholds.
OSO (Objective safety outcomes)	Objective events or severity indicators derived from crash/incident data or safety-critical event definitions.	Crash involvement/frequency; injury severity; near-miss/near-crash; conditional severity probabilities.	Count models (e.g., NB/RPNB); conditional probabilities; model performance (accuracy/F1); adjusted effect estimates.
BIP (Behavioural/indirect proxies)	Safety-relevant behaviours or operational indicators used as indirect measures of safety or risk.	Helmet use; violations; sidewalk riding; lane choice; phone use; speed/variability; harsh braking; GPS infrastructure shares; eye-tracking attention patterns.	Prevalences; OR/β; events/km; km/h; effect sizes (η, η^2); descriptive differences (with inferential tests when reported).
SPC (System/policy context)	Macro-level exposure, regulation/enforcement, campaigns, incentives, and structural reporting issues.	Policy support; exposure/crash burden; incentive thresholds/production pressure; under-reporting; regulatory framing.	Descriptive indicators (n, %); trends; quantified thresholds/rewards when available.

The table 2.B summarizes the planned synthesis outputs. Afterwards, Figures will be used to visualize the evidence map (e.g. distributions of evidence type, mode and determinants) and to support the identification of knowledge gaps.

Table 2.B. Planned descriptive synthesis outputs

Synthesis dimension	Variables charted	Summary metric
Study characteristics	Year; country/region; setting; design; data sources; sample size	n; %; median (IQR) where appropriate
Modes and use context	Mode(s); shared vs private; exposure indicators (frequency, trips, km)	n; %; descriptive ranges
Outcome operationalization	Evidence type (DPS/OSO/BIP/SPC); outcome categories	n; % by evidence type
Built environment determinants	Facility type; intersections; surface quality; signage/lighting; discontinuities	Counts by determinant; direction of association
Traffic/environment conditions	Traffic density; heavy vehicles; weather; visibility; time-of-day	n studies; direction/significance
User and psychological factors	Age; gender; experience; attitudes/norms; self-control; risk perception	n studies; direction; selected effect sizes

All summaries will be reported alongside the corresponding denominators to ensure transparency. Where studies report heterogeneous effect measures, results will be synthesized using directionality and contextual interpretation rather than pooled estimates

3. Results

3.1 Selection of Sources of Evidence

Following a literature search in two databases (Scopus and WoS), a total of 532 records were initially retrieved: 369 from Scopus and 163 from WoS. After removing duplicates based on title similarity, 407 unique records were retained for further screening.

As shown in the PRISMA flowchart (Figure 3), the study selection process was divided into several stages to ensure strict adherence to the predefined inclusion criteria. During the initial screening of titles and abstracts, the first reviewer unanimously excluded 172 records due to their irrelevance to the research objectives, and this selection was conducted again by two independent supervisors. In fact, emerged that some papers initially classified as 'YES' in reality were to classify as 'MAYBE' or 'NO' and vice versa. At the end of this first part 157 were classified as "YES", 82 as "MAYBE" and 168 as 'NO'.

Due to the uncertainty surrounding the 'MAYBE' category, Prof. Bassani supervised the screening of all 82 articles to resolve any remaining discrepancies and ensure methodological consistency with the review objectives. During this session, the 82 articles that had been subject to disagreement or uncertainty were examined in detail. It was unanimously decided to exclude 44 of these records.

Ultimately, 29 articles that met all the predefined inclusion criteria were included in the final analysis and full text screening. Of the 407 records assessed at this stage, 195 were deemed potentially relevant, while 212 were excluded. Following the macro-topic categorisation described previously, only 29 articles addressing the Perceived Safety domain were retained from the studies initially classified as 'YES'. These studies were identified through a rigorous, multi-phase screening process involving reviewer consensus and provide the basis for the critical appraisal and synthesis presented in this thesis. Ultimately, after reading the full texts, the results and findings of 26 out of the 29 papers were considered the basis for this work. In the Appendix D below are reported the 29 articles screened in the scoping review process.

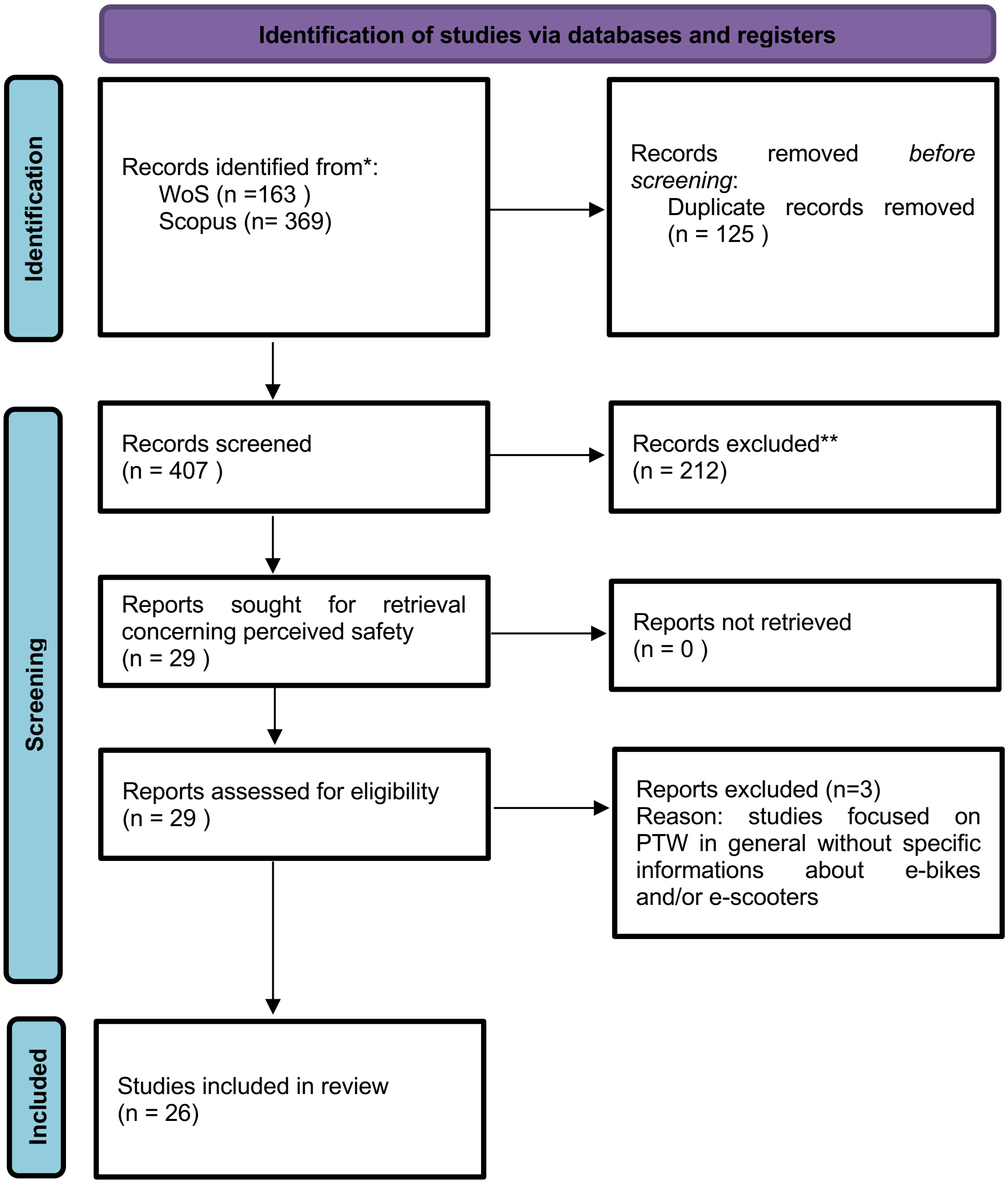

Figure 3 Prisma Flow Chart

3.2 Characteristics of Included Sources

A bibliometric analysis was conducted after the study selection phase. The articles included in the study were examined for publication trends and citation metrics, in order to assess their influence on the research field under investigation.

3.2.1 Bibliometric analysis of the papers included in the review

The bibliometric analysis of the included studies provided an overview of the current state of research by summarising previous findings and outlining the existing body of knowledge and the primary research areas within the field of interest.

3.2.2 Distribution of publications over time

This review included 29 articles, of which 26 were considered the sources of evidence addressing perceived safety in micromobility. Included studies were published between 2014 and 2025, with a marked increase in publication volume in recent years.

Most evidence was produced from 2022 onwards (23/29 studies), and 2025 alone accounted for 11/29 studies. Figure 3.2 summarizes the distribution by publication year.

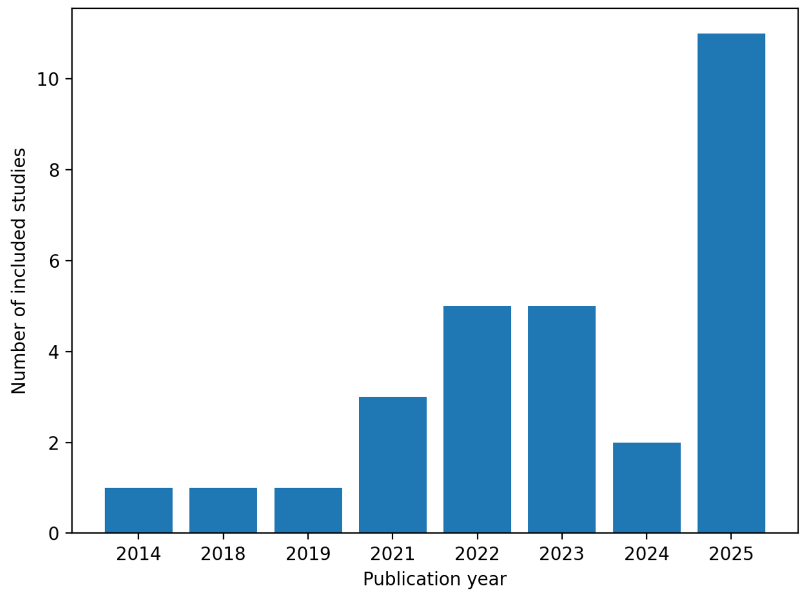

Figure 3.2 Included studies by publication year (n = 29).

In terms of study design and data sources, the predominant approach was survey-based (15 out of 29 studies). Typically, these studies used Likert-type items to measure perceived safety, comfort or risk, examining the associated determinants through methods such as regression analysis, ordered response models, structural equation modelling and path analysis. Additionally, emerged that four of the considered studies were based on field observation, for example using video-based behavioural measurements, while two relied on naturalistic GPS or telemetry data. Three further studies adopted experimental designs, incorporating processes that use simulation, eye-tracking and implicit-attitude paradigms. A limited number of contributions also employed modelling approaches or administrative datasets to supplement the evidence on perceived safety. The figure 3.3 below summarizes the characteristics presented in the last words.

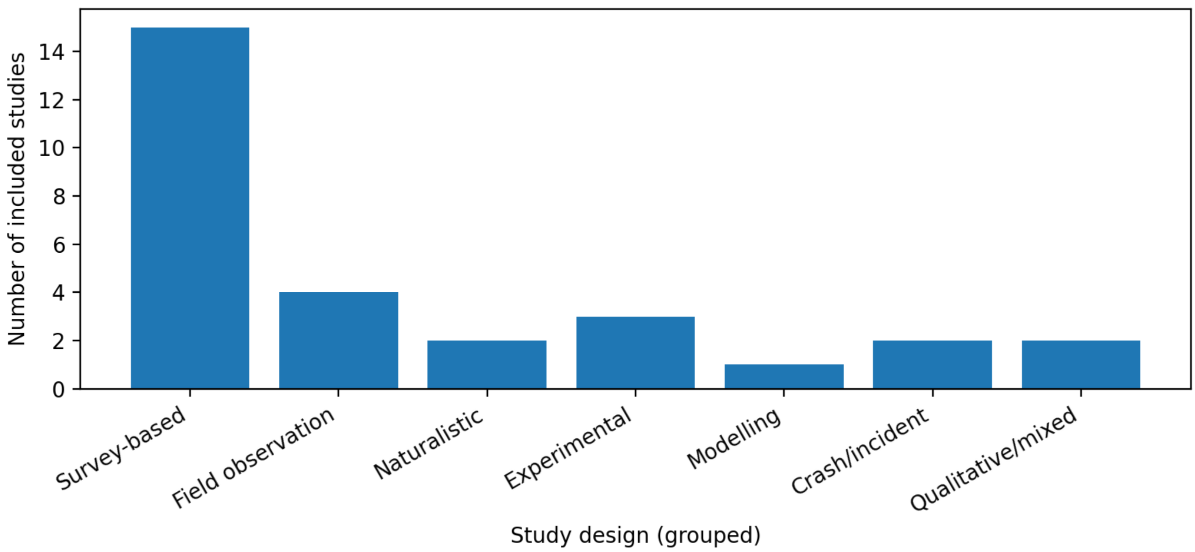

Figure 3.3. Study design and data sources

Where this information was available, sample sizes varied substantially across the included studies, ranging from small experimental samples (10 respondents) to large-scale surveys involving up to 37,093 respondents. Of the 25 studies for which an overall sample size could be derived from the charted notes, the median sample size was 254. It should also be noted that a part of the studies analyzed had different characteristics and were based, for example, on observational or administrative datasets, including databases comprising several thousand crash records, rather than participant samples informations.

Across the literature screened, perceived safety was most frequently modelled in relation to the following five main groups of determinants: (i) characteristics of the built environment and infrastructure, such as the presence and type of cycling or micromobility facilities, intersection complexity and route continuity; (ii) surface conditions and maintenance issues, such as potholes and uneven pavements; (iii) traffic interactions, particularly the proximity of and behaviour towards motor vehicles; (iv) user characteristics and experience, such as gender, age and riding frequency; and (v) psychological constructs related to risk perception and attention processes, including attitudes, self-control, implicit risk assessment and technology dependence.

The Table 3 below provides a structured overview of included sources, including design, setting, sample size, and high-level variables assessed.

Table 3 Characteristics of included sources of evidence

Study ID	Reference	Setting	Mode(s)	Design / data source	Sample size	Key variables
8	Tzouras et al., 2025	Greece; United Kingdom	E-bike/pedelec; E-scooter	Cross-sectional survey (quantitative modelling)	N=129	Traffic interactions
11	Emanuel-Cristian et al., 2025	Lisbon, Madrid	E-bike/pedelec; E-scooter	Cross-sectional survey (quantitative modelling)	N=873 (475 Lisbon, 398 Madrid)	Infrastructure/geometry, Psychosocial factors, Safety outcomes (crash/severity)
25	Delavary et al., 2025	Canada; Greece	Bicycle; E-scooter; Pedestrian	Cross-sectional survey (multi-country)	N=37093	Infrastructure/geometry, Traffic interactions, Behaviour/violations, Psychosocial factors
30	Anke et al., 2025	Germany	Bicycle; E-scooter; Pedestrian	Cross-sectional survey	Survey N=99 (after cleaning; 154 raw) + focus groups N=20	Infrastructure/geometry, Surface/maintenance, Traffic interactions, Behaviour/violations
31	Qu et al., 2025	China	Bicycle; E-bike/pedelec	Cross-sectional survey	N=285	Infrastructure/geometry, Traffic interactions, Safety outcomes (crash/severity)
41	Jia et al., 2025	China	E-bike/pedelec	Crash severity modelling (administrative data)	N=4424	Infrastructure/geometry, Traffic interactions, Safety outcomes (crash/severity)
43	Faus et al., 2025	Spain	Bicycle; E-scooter; PTW/motorcycle; Pedestrian	Content analysis / policy context	N=12	Traffic interactions, Psychosocial factors, Safety outcomes (crash/severity), Policy/legislation

Study ID	Reference	Setting	Mode(s)	Design / data source	Sample size	Key variables
48	Kazemzadeh et al., 2025	United Kingdom	E-bike/pedelec; E-scooter	Field observation (video/observational)	N=21	Infrastructure/geometry, Traffic interactions, Behaviour/violations, Psychosocial factors
51	Shahin et al., 2025	Israel	Bicycle; E-bike/pedelec; E-scooter; Pedestrian	Cross-sectional survey (quantitative modelling)	N=254	Infrastructure/geometry, Traffic interactions, Psychosocial factors
53	Hassanpour et al., 2025	Canada	Bicycle; E-bike/pedelec; E-scooter; Micromobility (general); Pedestrian	Cross-sectional survey (quantitative modelling)	N=1054	Infrastructure/geometry, Psychosocial factors
56	Meir et al., 2025	Israel	E-scooter	Experimental (scenario/implicit measures)	Study 1 N=46; Study 2 N=64	Infrastructure/geometry, Behaviour/violations, Psychosocial factors
81	Oh et al., 2024	China; South Korea	E-scooter	Simulator experiment	N=30	Infrastructure/geometry, Traffic interactions, Psychosocial factors, Safety outcomes (crash/severity)
121	Qian et al., 2024	China	E-bike/pedelec	Cross-sectional survey (quantitative modelling)	N=435	Infrastructure/geometry, Traffic interactions, Behaviour/violations, Psychosocial factors
133	Younes et al., 2023	United States	Bicycle; E-scooter; Micromobility (general)	Field observation (video/observational)	707 observed micromobility vehicles (507 bicycles); pre N=263, post N=396	Infrastructure/geometry, Traffic interactions, Behaviour/violations, Policy/legislation
153	Zheng et al., 2023	Canada; China	E-bike/pedelec	Field observation (video/observational)	N=563	Infrastructure/geometry, Traffic interactions, Behaviour/violations, Psychosocial factors
164	Tzouras et al., 2023	Athens	E-scooter	Network modelling / routing	N=129	Infrastructure/geometry, Traffic interactions
166	Bishop et al., 2023	United Kingdom; United States	Bicycle; Micromobility (general)	Cross-sectional survey (quantitative modelling)	N=191	Infrastructure/geometry, Behaviour/violations, Psychosocial factors
175	Cubells et al., 2023	Barcelona	Bicycle; E-scooter; Micromobility (general); Pedestrian	Naturalistic (GPS/telemetry)	N=89	Infrastructure/geometry, Traffic interactions

Study ID	Reference	Setting	Mode(s)	Design / data source	Sample size	Key variables
183	Chouhan et al., 2022	India	PTW/motorcycle	Crash frequency modelling	N=392	Infrastructure/geometry, Traffic interactions, Behaviour/violations, Safety outcomes (crash/severity)
201	Huang et al., 2022	Taiwan	Bicycle; E-bike/pedelec; Micromobility (general)	Cross-sectional survey (quantitative modelling)	N=273; 220 valid	Infrastructure/geometry, Traffic interactions
207	Tollazzi et al., 2022	China	Bicycle	Experimental (eye-tracking)	N=10	Infrastructure/geometry, Traffic interactions
208	Zhou et al., 2022	Germany	Bicycle; E-bike/pedelec	Cross-sectional survey	N=411	Infrastructure/geometry, Traffic interactions, Behaviour/violations, Psychosocial factors
212	Akgün et al., 2022	Palermo	Bicycle; Micromobility (general); Pedestrian	Cross-sectional survey (quantitative modelling)	N=200	Infrastructure/geometry, Surface/maintenance, Psychosocial factors
221	Ragot-Court et al., 2021	China; France	Bicycle; E-bike/pedelec; E-scooter; Micromobility (general); PTW/motorcycle	Cross-sectional survey	N=400	Psychosocial factors, Safety outcomes (crash/severity)
224	Wang et al., 2021	Wuhan	E-bike/pedelec	Qualitative / sociotechnical mapping	N=17	Traffic interactions, Psychosocial factors, Safety outcomes (crash/severity)
250	Twisk et al., 2021	Australia; Netherlands	Bicycle; E-bike/pedelec; Micromobility (general)	Naturalistic (GPS/telemetry)	N=46 commuters; 832 trips (7,563 km)	Psychosocial factors
298	Wang et al., 2019	Tianjin	Bicycle; E-bike/pedelec; Micromobility (general); Pedestrian	Field observation (video/observational)	N=16,859 total (field n=1,653; online n=15,206)	Infrastructure/geometry, Traffic interactions, Behaviour/violations, Safety outcomes (crash/severity)
304	Hertach et al., 2018	Switzerland	E-bike/pedelec	Cross-sectional survey	N=3658	Infrastructure/geometry, Surface/maintenance, Traffic interactions, Psychosocial factors
347	Sgarra et al., 2014	Rome	PTW/motorcycle	Cross-sectional survey (quantitative modelling)	Not a perception survey; ITS surrogate safety indicators (Rome case study)	Infrastructure/geometry, Traffic interactions, Safety outcomes (crash/severity), Policy/legislation

Moving from a broad mapping of the evidence to a closer inspection of how perceived safety has been investigated across the 29 included studies, Methods Table presented in the Appendix E below summarises the methodological approaches adopted in the literature. The aim is twofold. Firstly, it provides a clear overview of the specific study designs, data sources, instruments and analytical techniques used to operationalise perceived safety in the context of e-bikes and e-scooters. This allows the reader to understand the main strengths and weaknesses associated with each approach. Secondly, by reporting key methodological details for each paper, such as sample size and composition (e.g. gender and age distributions, and other relevant participant characteristics), the table enables a more informed evaluation of the robustness, transferability and interpretability of the evidence. This structured comparison also clarifies why certain methodological limitations were accepted in specific contexts (e.g. feasibility constraints, data availability or exploratory aims) and identifies recurring trade-offs and opportunities for methodological improvement in future research.

The analysis of the columns in the above extraction table reveals several recurring methodological patterns and cross-cutting insights that are particularly useful for interpreting the strength, scope and trade-offs of the evidence base.

The first shared feature concerns the primary exposure or determinant being examined. Across the included articles, explanatory variables repeatedly fall into three broad, frequently combined domains: (i) the built environment and infrastructure (e.g. facility typology, shared-space design, crossings, pavement condition, obstacles and network density/structure); (ii) traffic interactions (e.g. overtaking dynamics, conflicts with other road users, relative speed and mixed-traffic operation); and (iii) psychosocial factors (e.g. attitudes towards risk, subjective norms, self-control and safety knowledge/attitudes). In many studies, these domains are explicitly integrated in order to explain the differences observed between user groups (e.g. by gender, age or experience) and across urban settings. This highlights the fact that perceived safety is rarely attributable to a single factor in isolation.

With respect to outcomes, the literature is clearly dominated by perceptual measures, such as self-reported ratings of safety, comfort or risk, most commonly using Likert-type scales, and in some cases, scenario-based assessments, such as image- or video-based evaluations. While this approach provides a direct operationalisation of perceived safety, it also implies that the primary construct observed is perception itself, which may not necessarily coincide with real-world behaviour or crash involvement. Alongside these perceptual outcomes, a substantial subset of studies relies on behavioural proxies (e.g. violations, choice of lane/sidewalk, helmet use, phone use and speed-related indicators) or, where feasible, objective safety outcomes (e.g. occurrence/severity of crashes, near-crash events). It is notable that even when 'objective' outcomes are targeted, they are often derived from self-report or partial records, which introduces limitations such as underreporting and recall bias that are well known.

The analytical methods employed throughout the evidence base are generally consistent with the measurement strategies adopted by the included studies. Modelling approaches suited to ordinal outcomes, such as ordered logit models and related specifications (including mixed and latent-class extensions), are frequently employed. Similarly, methods designed to account for unobserved heterogeneity and contextual variation are commonly applied, including mixed logit models, mixed-effects models, generalised linear mixed models and multilevel models with random intercepts. In studies focusing on latent constructs, exploratory and confirmatory factor analysis, as well as structural equation modelling, are particularly prevalent, especially when the aim is to examine the relationships between attitudes, perceptions and behaviours within a coherent theoretical framework. Several studies adopt mixed-methods designs, combining surveys with focus groups, interviews or observational techniques. A smaller number rely on more systemic or modelling-driven approaches, such as Bayesian networks for crash analysis, route-choice or network modelling and structured socio-technical frameworks. These latter approaches are particularly valuable in capturing interactions among multiple actors and causal mechanisms that are difficult to infer from survey-based evidence alone.

With respect to covariates and control variables, the reviewed studies converge on a relatively consistent set of adjustments, including gender, age, education, socio-economic proxies, riding or driving experience, and a range of exposure indicators, such as frequency of use, distance travelled, time spent using the vehicle and years of use. Contextual controls are also common, especially those relating to infrastructure type, traffic conditions, time of day, weather and spatial setting, whether at the city, regional or national scale. In cross-city or cross-country analyses, the inclusion of geographical controls and/or random effects at the locality or country level contributes to greater robustness by accounting for structural differences that might otherwise confound associations across contexts.

Finally, the methodological notes highlight several recurring limitations that must be considered when interpreting the available evidence. These include:

- frequent reliance on convenience sampling strategies such as online panels, snowball recruitment and community-based channels, which can lead to sample imbalances and reduce generalisability;
- extensive use of self-reported behaviour and crash or near-crash histories, which can be affected by social desirability and recall bias, especially when the recall period is long;
- relatively small sample sizes are often seen in exploratory experimental or eye-tracking studies, particularly given the limited capacity of the facilities and resources available for carrying out this kind of analysis;
- limited availability of comprehensive objective datasets, including under-reporting of minor crashes and lack of behavioural variables in administrative records.

These constraints help to explain why many studies rely on perceptual or behavioural proxies as pragmatic alternatives, particularly in a field in which standardised, high-resolution safety data remains inconsistently available.

In summary, the literature included in this study consistently presents perceived safety in electric micromobility as an outcome of the interaction between the built environment, traffic dynamics and user-level characteristics (including demographic and psychosocial factors). Methodologically, the evidence base predominantly relies on perceptual measures and analytical models that are suitable for ordinal data and heterogeneity. This is complemented by behavioural proxies and, less frequently, event-based safety outcomes. Taken together, these recurring patterns provide a transparent basis for discussing what the literature can support with relatively strong confidence, where findings remain proxy-based and why certain methodological limitations have been routinely accepted. This evidence informs both the interpretation of current evidence and the prioritisation of future research needs.

3.2.2 Papers distribution across Journals

The distribution of the papers across journals has also been investigated and reported in table 4. As can be seen, all the articles considered have been published in different journals that focus on different subjects, as can be inferred from their titles.

Table 4. Distribution of included studies across journals.

Journal	Number of Articles	Percentage [%]
Accident Analysis & Prevention	5	17.2
Sustainability	4	13.8
Transportation Research Part F: Psychology and Behaviour	4	13.8
IATSS Research	2	6.9
Advances in Transportation Studies	1	3.4
Applied Sciences	1	3.4
Case Studies on Transport Policy	1	3.4
European Transport Research Review	1	3.4
Human Factors and Ergonomics in Manufacturing & Service Industries	1	3.4
International Journal of Industrial Ergonomics	1	3.4
Journal of Advanced Transportation	1	3.4
Journal of Cycling and Micromobility Research	1	3.4
Journal of Transport Geography	1	3.4
Safety Science	1	3.4
Systems	1	3.4
Traffic Injury Prevention	1	3.4

Journal	Number of Articles	Percentage [%]
Transportation	1	3.4
Urban Science	1	3.4

3.2.3 Research areas of authors

The research domains of the corresponding authors of the selected studies are reported in the table 5 below. These details were obtained by reviewing their academic profiles and primary areas of scientific research. Analysing this information illustrates the range of expertise involved and highlights the multidisciplinary contributions to the topic under investigation.

Table 5. Summary of the affiliation and research field of the selected papers' authors.

Study ID	Author	Affiliation/Institution	Country	Field of research
8	Panagiotis G. Tzouras Valentina Pastia Ioannis Kaparias	University of Athens, University of Southampton	United Kingdom, Greece	Transportation / Road safety
11	Adorean Emanuel-Cristian	A) University of Lisbon, B) Autonomous University of Madrid, C) Instituto Superior Técnico – University of Lisbon	Spain, Portugal	Psychology / Behavioural science
25	Milad Delavary	A) Traffic Injury Research Foundation (TIRF), Ottawa, Canada B) National Technical University of Athens (NTUA)	Italy, UK, US, Spain, Germany, Sweden, Greece, Switzerland, Portugal, Netherlands, Belgium, France, Australia, Canada, Japan, Denmark, Finland, Austria, Ireland, Israel, Brazil	Transportation / Road safety
30	Juliane Anke	Technische Universit¨at Dresden	Germany	Psychology / Behavioural science
31	Yayun Qu, Qianwen Wang and Hui Wang	Nanjing Forestry University	China, Switzerland	Transportation / Road safety
41	Bicen Jia, Jun Li and Qi Wang	Sun Yat-Sen University, Shenzhen, China; Sun Yat-Sen University, Guangzhou, China	China, Switzerland, Netherlands	Psychology / Behavioural science
43	Mireia Faus, Francisco Alonso, Cristina Esteban and José Luis Velarte	University of Valencia, Spain;	Spain, Switzerland	Transportation / Road safety

Study ID	Author	Affiliation/Institution	Country	Field of research
48	Khashayar Kazemzadeh	University of Cambridge, United Kingdom	United Kingdom, Sweden	Transportation / Road safety
51	Fadi Shahin and Wafa Elias	Israel Sami Shamoon College of Engineering	Switzerland, Australia, Israel	Transportation / Road safety
53	Amir Hassanpour	University of British Columbia, Vancouver, Canada	Italy, China, Greece, Australia, Canada, Singapore	Psychology / Behavioural science
56	Anat Meir	A) HIT Holon Institute of Technology, Holon, Israel b Ben-Gurion University of the Negev, Beer-Sheva, Israel	Israel	Psychology / Behavioural science
81	Taeho Oh	A) Southeast University Nanjing, China B) Korea Advanced Institute of Science and Technology, South Korea	China, South Korea	Psychology / Behavioural science
121	Qian Qian	Tsinghua University, Beijing, China	China	Psychology / Behavioural science
133	Hannah Younes	Edward J. Bloustein School of Planning and Public Policy, Rutgers, The State University of New Jersey	US, Australia, Brazil	Transportation / Road safety
153	Yubing Zheng	A) Hefei University of Technology, Hefei, China B) Toronto Metropolitan University, Canada C) Changsha University of Science of Technology, China	China, Canada	Psychology / Behavioural science
164	Panagiotis G. Tzouras, et al.	A) National Technical University of Athens, B) LKM Consulting Engineers and Planners, Athens, C) MoveNow Technologies P.C, Athens	United Kingdom, US, Greece, Switzerland	Transportation / Road safety

Study ID	Author	Affiliation/Institution	Country	Field of research
166	Daniel T. Bishop	A) Brunel University London, B) University of Louisville, US	United Kingdom	Psychology / Behavioural science
175	Jerònia Cubells	A) Universitat Autònoma de Barcelona	Spain	Transportation / Road safety
183	Shivam Singh Chouhan	A) Indian Institute of Technology Jammu, India C) CSIR-Central Road Research Institute (CRRI), New Delhi, India	United Kingdom, Australia, India, Turkey	Psychology / Behavioural science
201	Fei-Hui Huang	Asia Eastern University of Science, New Taipei City, Taiwan	China, Taiwan, Netherlands	Psychology / Behavioural science
207	Tomaž Tollazzi, Matej Moharić, Chiara Gruden	University of Maribor, Slovenia	Italy, US, Switzerland, Portugal	Transportation / Road safety
208	Dan Zhou, Mengying Chang, Guobin Gu, Xin Sun, Huizhi Xu, Wenhan Wang and Tao Wang	A) Guilin University of Electronic Technology, Guilin, China, B) Northeast Forestry University, Harbin, China;	China, Switzerland	Transportation / Road safety
212	Nurten Akgu Tanbay , Tiziana Campisi , Tayfun Tanbay , Giovanni Tesoriere	A) Bursa Technical University, Turkey B) University of Enna Kore, Enna Italy C) Newcastle University, Newcastle, UK	Italy, United Kingdom, Germany, Sweden, Netherlands, Australia, Denmark, Turkey	Transportation / Road safety
221	Isabelle Ragot-Court	Gustave Eiffel University, Salon de Provence, France	China, France	Transportation / Road safety
224	Linyang Wang Jianping Wu Mingyu Liu Kezhen Hu Katherine L. Plant Neville A. Stanton	A) Tsinghua University, Beijing,; B) China Academy of Information and Communication Technology C) University of Southampton, UK	United Kingdom, China	Human factors / Ergonomics

Study ID	Author	Affiliation/Institution	Country	Field of research
250	Divera Twisk, Agnieszka Stelling, Paul Van Gent , Jolieke De Groot, Willem Vlakveld	A) SWOV Institute for Road Safety Research, The Hague, B) Delft University of Technology, Delft, The Netherlands C) The Dutch Licensing Authority, Rijswijk, The Netherlands D) Queensland University of Technology, Queensland	Sweden, Netherlands, Australia	Transportation / Road safety
298	Zhuo Wang Richard L. Neitzel Xiaodan Xue Wenlong Zheng Guohong	A) Tianjin Centers for Diseases Control and Prevention, Tianjin; B) University of Michigan School of Public Health, Ann Arbor, Michigan	China	Transportation / Road safety
304	Patrizia Hertach et al.	Swiss Council for Accident Prevention, Bern	US, Switzerland	Transportation / Road safety
347	V. Sgarra et al.	"Sapienza" University of Rome	Italy	Transportation / Road safety

3.2.4 Geographic distribution of publication

Geographically, the literature spanned multiple regions, with studies primarily affiliated with Europe (n=12) and Asia (n=12), and additional contributions from North America (n=4) and Oceania (n=1). Several studies were grounded in specific urban case studies, including cities like Lisbon, Madrid, Athens, Palermo, Barcelona, Tianjin, Wuhan, and Rome.

In the figures 3.3.5 (a), (b), (c) below are reported the main information of the papers about the geographic distribution of publication.

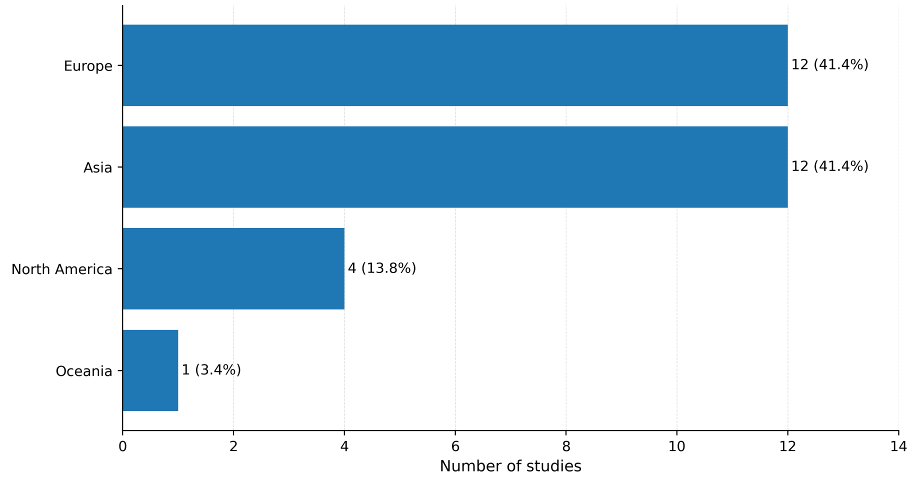

Figure 3.3.5(a) Distribution of included studies by continent

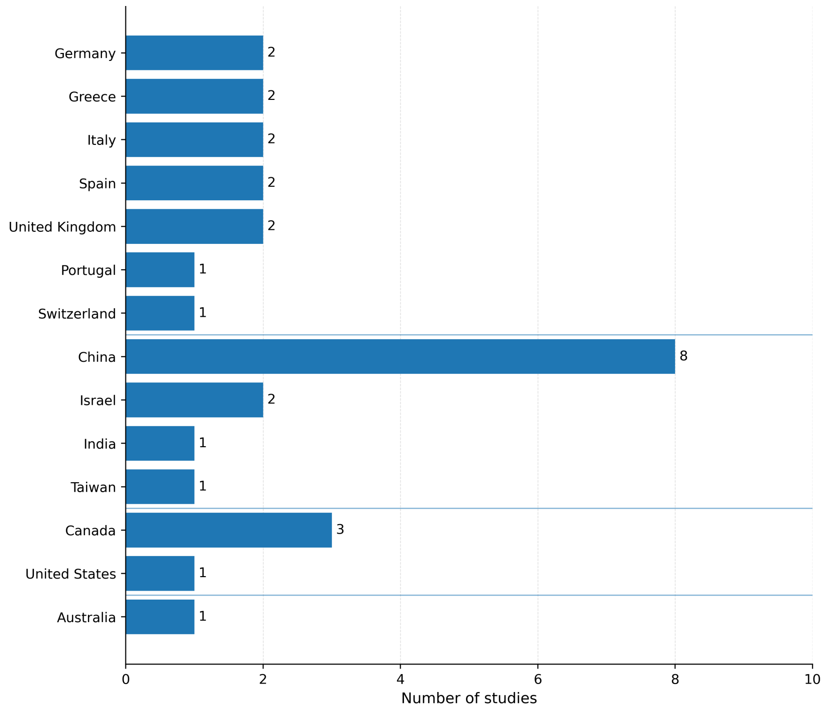

Figure 3.3.5(b) Distribution of included studies by country

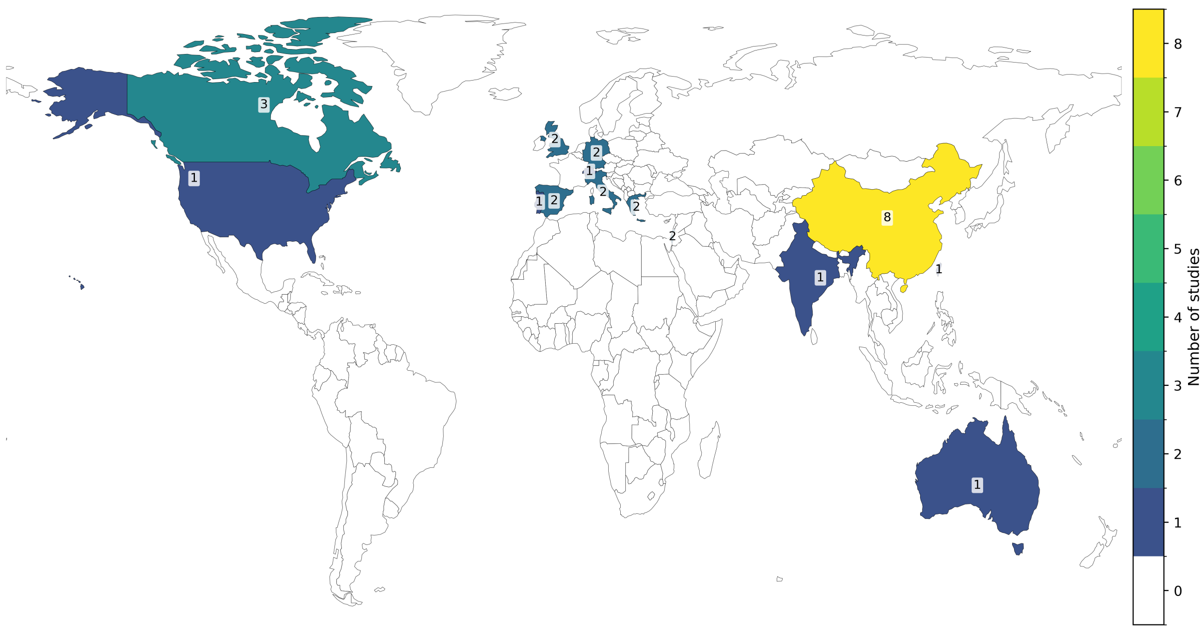

Figure 3.3.5(c) Geographic distribution of included studies

3.2.5 Keywords analysis

Keyword analysis is a vital part of bibliometric studies as it identifies the terms that appear most frequently in the literature under examination. Here, the literature is a collection of articles on driving technologies and user interaction. This enables researchers to quickly grasp the dominant themes and design targeted search approaches and robust analytical strategies.

In this study, a keyword cloud was generated and reported below by extracting the keywords/index terms provided by the authors in each of the 29 included papers and then visualising their frequency of occurrence across the dataset. The resulting word cloud shows the frequency with which each term appears: the larger the font size, the more frequently the term appears. This representation provides an immediate overview of the dominant concepts and thematic emphases within the selected evidence base. As shown in Figure 4 below, the most prominent terms are 'e-bike' and 'e-scooter', followed by broader umbrella concepts such as 'micromobility' and 'road safety'. The presence of perception- and behaviour-oriented terms, such as 'perceived safety', 'travel-behaviour' and 'traffic-safety', highlights the centrality of subjective evaluations and safety-related attitudes in the literature. Additional recurrent keywords, including 'cycling', 'cyclists', 'pedestrians', 'bicycle', and 'speed', further indicate that many studies frame perceived safety in terms of interactions among different road users and typical operational factors influencing risk in urban environments.

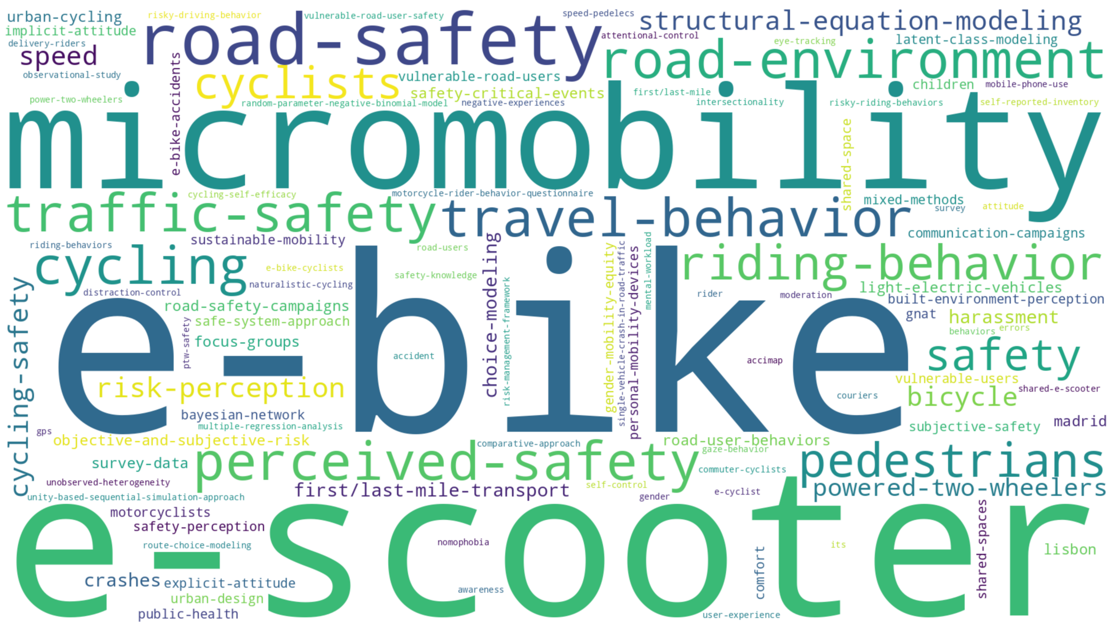

Figure 4 Keyword Cloud

3.3 Evidence Map

To facilitate a structured interpretation of the 29 included studies and to prevent the merging of non-comparable safety constructs, an evidence map was developed. This summarizes the type of safety-related evidence that each study primarily contributes, the most frequently used methods, the modes covered and the most consistently investigated determinant domains. The evidence map operationalizes the study-level taxonomy as previously mentioned, in which each article is assigned to one of the following primary evidence types: Direct Perceived Safety (DPS), Behavioural/Indirect Proxies (BIP), Objective Safety Outcomes (OSO) or System/Policy Context (SPC). This categorization is based on the paper's dominant outcome and data source, while recognizing that several studies may report secondary outcomes beyond the primary classification.

In the figure 5 below is resumed the distribution of the articles across the four categories:

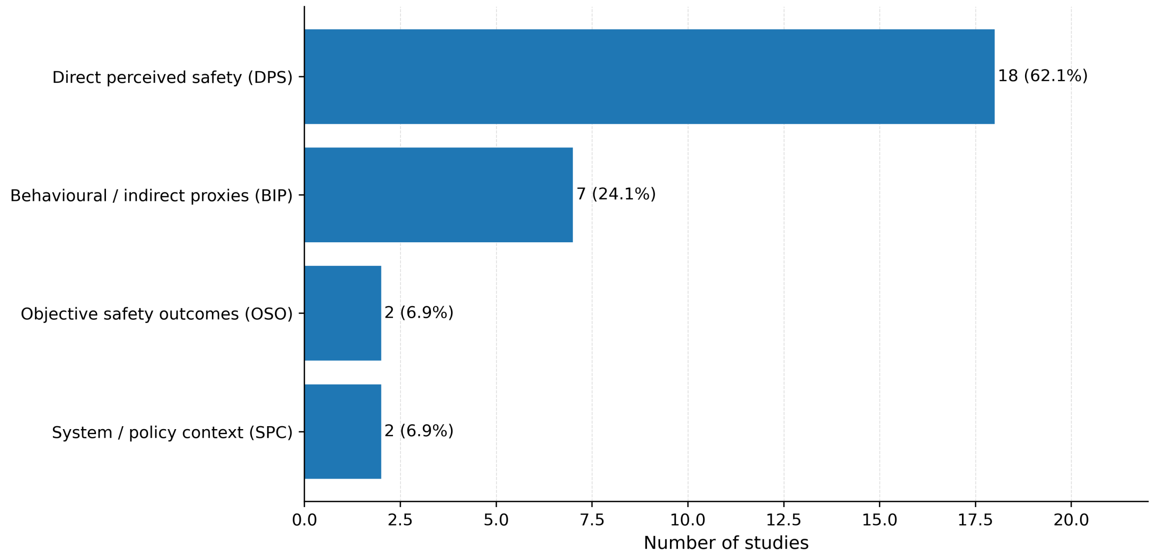

Figure 5 Distribution of included studies by primary evidence type

3.3.1 Evidence types and methodological concentration

The mapping reveals a clear focus of the evidence base on direct perceived safety. In practice, DPS evidence is predominantly produced through cross-sectional survey designs, assessing safety, comfort or perceived risk using Likert-type scales or scenario-based judgements. This suggests that the existing literature is particularly well developed in describing how safe users feel, and in identifying the factors associated with such perceptions. In contrast, evidence based on behavioural proxies (BIP) is less common than the previous category mentioned: the results of this category of studies tends to be derived especially from field observations or naturalistic tracking methods. Moreover, studies primarily considered as concerning with objective safety outcomes (OSOs), such as crashes, injury severity or event-based indicators, remain comparatively scarce. Finally, evidence relating to system and policy context (SPC) is present in only a limited number of studies, generally being examined in relation to policy measures, regulatory frameworks or awareness campaigns.

To clarify the methodological basis on which these forms of evidence are generated, the evidence map is useful in order to cross-reference each type of evidence with broad methodological categories. In this review, 'Survey' denotes questionnaire-based designs in which perceived safety is measured directly. 'Field observation' refers mainly to video- or observer-based measurement of behaviour under real traffic conditions. 'Naturalistic' identifies studies that rely on sensor, GPS, or telemetry data collected in real-world settings. 'Experimental' analysis includes controlled, scenario-based approaches such as simulator studies or attention-related paradigms. 'Modelling' primarily covers the aspects linked to network- and route-choice modelling approaches. 'Crash/administrative modelling' refers to analyses based on official crash databases often available from the reports collected by the public administrations. 'Qualitative/policy' includes mainly studies that are primarily concerned with policy, regulation or campaign-related issues.

The table 6 below reports the resulting cross-tabulation, making explicit where the review primarily relies on perceived-safety ratings versus behavioural proxies or event-based outcomes.

Table 6 Evidence map: method group by primary evidence type

Method group	DPS	BIP	OSO	SPC
Survey	15	0	0	0
Field observation	0	4	0	0
Naturalistic	0	2	0	0
Experimental	2	1	0	0
Modelling	1	0	0	0
Crash/administrative modelling	0	0	2	0
Qualitative/policy	0	0	0	2

3.3.1 Mobility modes covered in the evidence map

A closer analysis of the studies considered reveals that the modes of transport most frequently examined were e-bikes/pedelecs and conventional bicycles, each cited in 16 studies. This was followed by e-scooters, which appeared in 14 studies. This distribution is informative in two ways.

Firstly, it confirms that the body of evidence on 'electric micromobility' is not solely focused on e-scooters; rather, e-bikes and pedelecs are often considered alongside other light two-wheelers, with comparisons frequently being drawn with conventional cycling. Consequently, a significant proportion of the literature adopts a comparative approach, either contrasting electric and non-electric two-wheelers or comparing multiple micromobility options. This highlights both shared determinants, such as infrastructure quality and exposure to mixed traffic, and mode-specific vulnerabilities, including speed differentials, stability and interaction patterns.

Secondly, the inclusion of pedestrians (8 studies) and powered two-wheelers (4 studies) on fewer occasions, but still meaningfully, indicates that perceived safety is commonly investigated as a relational construct within the street environment. Pedestrians usually appear as either an affected group in shared or constrained spaces (e.g. sidewalks, shared paths and shared-space designs), or as a benchmark for understanding how micromobility affects perceived comfort and risk in pedestrian-priority areas. Powered two-wheelers, in turn, tend to be included as a higher-speed category for comparison, which is useful for situating micromobility within a continuum of two-wheeled mobility, as well as for interpreting behavioural norms (e.g. rule compliance, overtaking and lane positioning) that may transfer across vehicle classes.

Overall, this mode-coverage pattern has an important implication for the scoping review: perceived safety in micromobility is rarely considered an inherent property of a single mode. Rather, it is generally considered to be an interactional phenomenon, influenced by the presence of other road users (e.g. motor traffic, bicycles and pedestrians) and street design choices that regulate separation, interaction and priority when users’ paths inevitably cross at certain points. Consequently, the results should be interpreted in light of the specific 'interaction setting' considered in each study, such as mixed traffic versus protected infrastructure or pedestrian-dominant versus vehicle-dominant environments, because the same mode can elicit markedly different perceived safety responses depending on who shares the space, the rules they operate under, and the degree of physical or operational separation.

In the figure 6 below is reported the distribution of the modes reported across the analyzed papers:

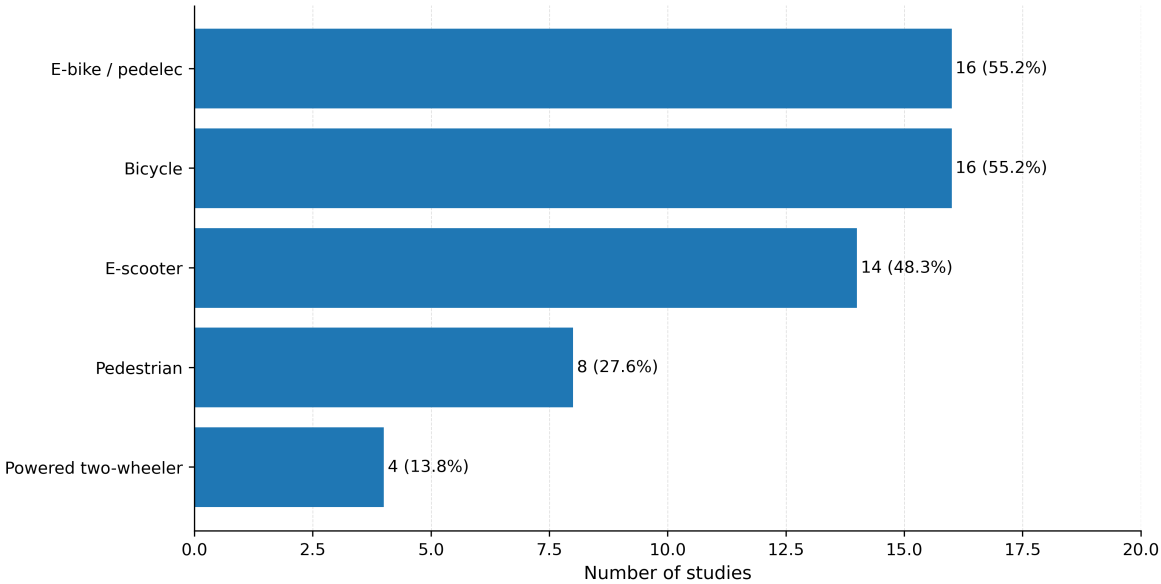

Figure 6 Coverage of mobility modes across included studies

3.3.2 Determinant domains: what is most often analyzed

In addition to the type of evidence and the design of the study, the evidence map also indicates whether each article examines one or more of the domains that could potentially influence perceived safety. It recognizes that a single study may contribute to multiple domains simultaneously. This multi-label coding is important because perceived safety is rarely explained by a single class of variables; rather, it is typically framed as the outcome of interacting environmental, traffic and user-level factors. The resulting distribution shows a clear focus on determinants relating to the built environment and infrastructure (24/29 studies) and traffic interactions (22/29 studies). This suggests that most papers conceptualize perceived safety as primarily a function of where micromobility is used (e.g. facility type, degree of separation, intersection and crossing design, and network continuity) and how it operates within mixed traffic (e.g. overtaking, relative speed, conflicts and negotiations with other road users). In other words, the dominant research agenda is strongly aligned with the idea that perceived safety is 'produced' by street design and the interaction rules and dynamics that it enables. At the same time, psychosocial factors also feature prominently (in 17 out of 29 studies), reflecting a parallel focus on who experiences the street environment and how individual differences influence perceived safety responses. Variables such as risk perception, attitudes towards safety, self-control, confidence/experience and demographic heterogeneity are often employed to explain why the same infrastructure or traffic situation may be perceived quite differently by different population groups. Notably, this domain often acts as an intermediary explanatory layer in the reviewed studies. Psychosocial constructs are used as both correlates of perceived safety and interpretative dimensions through which the differences between user groups can be understood. These differences may be related to factors such as gender, age, experience or user type. They also help, in fact, to explain behavioural adaptations that may mediate the relationship between the surrounding environment and the perceived safety experienced by the users in that environment.

By contrast, aspects related to surface- and maintenance-related factors (3/29 studies) and other concerning policy or legislation (3/29 studies) rarely appear as primary explanatory domains. This relative scarcity is noteworthy for at least two reasons. Firstly, it suggests that the current evidence base may underrepresent highly actionable determinants of urban policy and practice, such as pavement conditions, surface defects and debris. Moreover, the current literature reveals gaps in the analysis of regulatory frameworks that determine where and how micromobility can be used, or should try to determine this. Despite their likely relevance in influencing both comfort and risk, these factors are rarely considered. Secondly, it highlights a discrepancy between the prevalence of infrastructure/interaction-focused research and the limited number of studies that directly evaluate system-level levers, such as maintenance regimes, enforcement and regulatory interventions. All of these factors presented in the last sentence could play a fundamental role in translating insights into perceived safety into policy decisions. The table 7 summarises the number and percentage of studies covered by each of the determinant domains discussed earlier in this section, for the articles included in this scoping review.

Table 7 Coverage of determinant domains across included studies

Determinant domain	Studies (n)	Studies (%)
Infrastructure/geometry	24	82.8%
Traffic interactions	22	75.9%
Surface/maintenance	3	10.3%
Behaviour/violations	11	37.9%
Psychosocial factors	17	58.6%
Safety outcomes (crash/severity)	10	34.5%
Policy/legislation	3	10.3%

The figure 7 visualizes this distribution to facilitate rapid comparison across domains. Darker shading indicates higher coverage and thus clearer areas of research concentration.

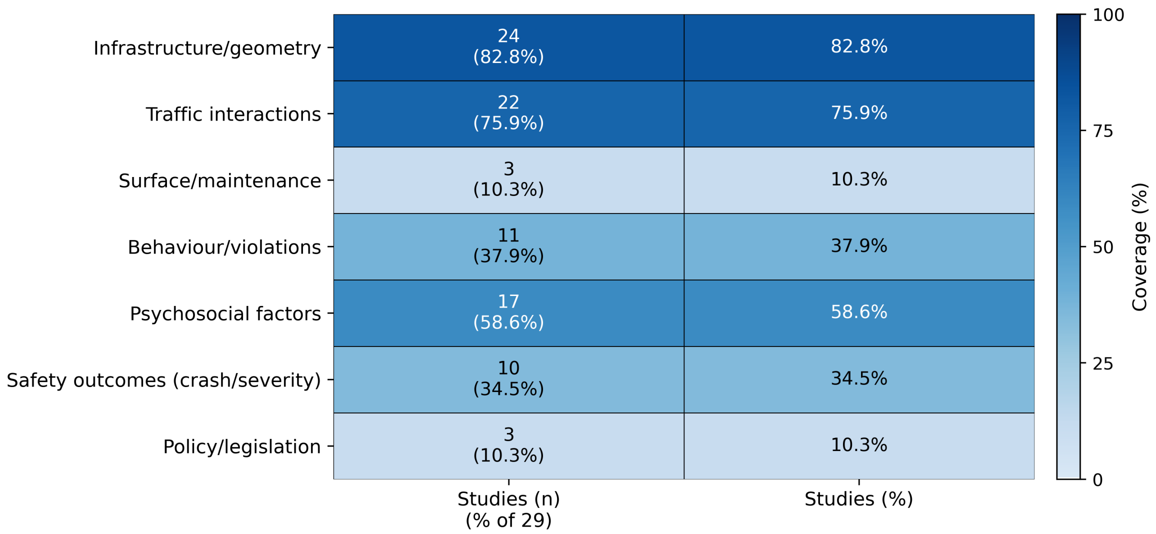

Figure 7 Evidence map: determinant-domain coverage across included studies

3.3.3 Interpretation of the evidence map

Overall, the evidence map indicates that the existing literature provides a solid foundation for describing perceived safety in electric micromobility and identifying the factors most consistently associated with it. The dominance of studies focusing on perceived safety outcomes, often measured using Likert-type ratings or scenario-based evaluations, means the evidence is well suited to answering questions such as: which situations and environments are interpreted as unsafe by users; which street design features are perceived as protective or threatening; and how perceived safety varies across user groups. The strong focus on infrastructure and traffic interaction further reinforces this: the literature provides substantial evidence of an association between perceived safety and the configuration of street space (e.g. separation, continuity and crossings) and the dynamics of mixed traffic (e.g. overtaking, relative speeds and conflict points).

At the same time, the mapping reveals a significant shortcoming of the existing research: the integration of different types of evidence remains limited. Only a limited number of studies concerning perceived safety focus primarily on objective safety outcomes, such as modelling crash frequency or injury severity. Similarly, evidence adopting a system-level or policy-oriented perspective is sparse. Furthermore, although studies based on behavioural or indirect proxies are more common than those focused on objective outcomes, these studies tend to be confined to a relatively narrow set of observational and naturalistic research designs. This imbalance has important implications for interpreting the available evidence. While the literature can characterize perceptions and their main correlates fairly consistently, it is less effective at addressing the evaluative and causal questions most relevant to applied road safety and transport planning. These include whether lower perceived safety reliably corresponds to higher exposure-adjusted risk and whether interventions that improve perceived safety lead to measurable reductions in crashes or severe conflict events. The limitation just presented is not merely methodological; it also reflects the structural constraints typically associated with a rapidly evolving field of research. Perceived safety is easier to capture on a large scale than objective events such as crashes, which are relatively rare, underreported (especially minor events) and poorly documented in terms of behavioural context and exposure. Consequently, many studies accept perceptual measures or behavioural proxies as pragmatic substitutes. While this supports breadth of coverage, it reduces the ability to validate findings against event-based outcomes. Similarly, the scarcity of studies focusing on system- and policy-level dimensions suggests that the field lacks a robust empirical basis on which to quantify the effects of regulatory changes, enforcement practices, and maintenance regimes. Despite these aspects being central to real-world implementation — especially in guaranteeing higher levels of perceived safety — there is a lack of research in this area. Consequently, the evidence map supports the following nuanced conclusion: the current literature can document which situations are perceived as unsafe by users with reasonable robustness, and with that, it can identify contextual and user-level factors associated with lower perceived safety. However, it remains comparatively weak in linking perceptions to objective safety metrics in an exposure-aware manner, and in estimating the effects of policy and infrastructure interventions capable of supporting causal inference. This structural pattern clearly explains the knowledge gaps and research priorities discussed in the next section, particularly the need for mixed-methods and longitudinal designs, the stronger use of naturalistic and observational data, and the greater integration of perceptual indicators and objective safety outcomes within comparable contexts.

3.4 Knowledge Gaps

This section summarizes the key knowledge gaps that were identified through the evidence mapping presented in Chapter 3.3. The gaps are organized across four complementary dimensions: (i) contextual and geographical coverage; (ii) methodological design and causal inference; (iii) outcome operationalization and triangulation; and (iv) equity-sensitive evidence and system-level governance. The aim is to clarify what is understudied and why these gaps matter for interpreting current results and informing future research and policy.

3.4.1 Limited contextual coverage and external validity

Although the included studies span multiple regions, the evidence base remains concentrated in a relatively narrow set of urban contexts, typically large cities with well-established micromobility markets and comparatively well-defined infrastructure (e.g. cycling networks, traffic calming and clearer rules for micromobility operations). This raises a core concern regarding external validity: the same user, vehicle and trip purpose can result in substantially different perceived safety responses depending on the characteristics of the surrounding system, including road hierarchy, prevailing traffic speeds, modal split, driver yielding norms and the degree of separation or mixing between modes. Consequently, findings derived from mature, central-city environments may not be easily transferable to contexts where micromobility is newer, infrastructure is more discontinuous, or motor traffic operates at higher speeds and volumes.

Small and medium-sized cities, peri-urban corridors and non-core neighbourhoods are under-represented in the literature despite having distinct exposure profiles. These environments often have wider main roads, fewer protected facilities, longer distances between crossings and lower network redundancy. These factors may limit the range of available routes for the users of the infrastructures and increase reliance on mixed-traffic environments. In such circumstances, the perceived danger may be amplified even when the actual risk is not necessarily elevated due to the higher volume of traffic in smaller areas (higher traffic density). At the same time, these conditions of traffic may generate different behavioural adaptations, such as in the case of congestion that determines lower travel speeds where the users are pushed, for example, to ride more frequently on pavements or other forbidden paths, saving time but representing a concrete risk for the other users of the infrastructures. Furthermore, cross-context variations in governance arrangements and enforcement practices make the generalizability of the findings more complex. Regulatory regimes (e.g. where riding is permitted, speed limits, helmet regulations), enforcement intensity and fleet management practices (e.g. parking controls, geofencing, training and app-based warnings) differ widely between cities and countries. These variations can systematically influence both perceived safety and observed behaviour.

Finally, climatic and temporal conditions, such as rain, snow/ice, darkness, seasonal lighting variations and peak versus off-peak traffic, are inconsistently represented even though they are likely to affect surface quality, visibility, braking distance and interaction dynamics (e.g. overtaking and yielding). The limited scope of these contexts and conditions restricts the ability to draw robust conclusions about the perceived safety of micromobility as a whole. This underscores the need for comparative, multi-city research designs that encompass a broader range of urban forms, regulatory settings and environmental conditions. These designs must also provide sufficient detail in their reporting section to enable meaningful interpretation of the studies' results across different contexts.

3.4.1 The predominance of cross-sectional designs and the limited amount of causal evidence.

A major weakness of the current evidence base is its reliance on cross-sectional survey designs. While these studies analysed are useful for describing perceived safety and identifying associations with factors such as infrastructure type, traffic interactions and user characteristics, they only measure exposures and outcomes at one point in time. Consequently, while they can show which factors are associated with perceived safety, they provide limited insight into causal relationships and are more vulnerable to confounding and selection effects. A particularly important issue in this respect is self-selection: individuals who are more risk-averse may avoid high-speed corridors, opting for protected routes like sidewalks, or deciding not to cycle at all. In such cases, the observed relationship between infrastructure and perceived safety may be influenced as much by route choice and rider composition as by the effect of the infrastructure itself. Likewise, heterogeneity in exposure, including frequency of use, travelled distance and time of day, together with unmeasured contextual factors such as enforcement intensity, network continuity and local traffic culture, may confound observed associations, particularly in studies comparing different cities or neighbourhoods without robust enough controls.

A second limitation that can be detected from the review of the material is the scarcity of longitudinal evidence that can capture how perceived safety evolves through experience, adaptation and learning. Perceived safety is not static: novice users may initially report high levels of fear that diminish with familiarity. However, negative experiences such as near misses, harassment or poor surface conditions may increase sensitivity to risk over time. Without repeated-measures data over time on almost the same sample, it is difficult to distinguish between stable differences between individuals, such as attitudes and confidence, and changes within individuals driven by accumulated exposure or changing conditions. This also constrains the analysis of causal pathways. For example, it is unclear whether improved perceived safety leads to greater use and therefore increased exposure, which could affect crash risk. Alternatively, it could be that more frequent use produces habituation and consequently alters safety perceptions in the users.

Relatively few before-and-after evaluations or quasi-experimental studies estimate the effects of real-world improvement interventions such as: installing protected lanes, redesigning intersections, reducing speed limits, implementing parking management measures, using geofencing or introducing regulatory changes. However, these designs are crucial for advancing beyond descriptive findings and determining which interventions are effective, for whom, and under what conditions. Therefore, future research should prioritise stronger causal approaches, such as natural experiments, difference-in-differences designs, interrupted time-series analyses and longitudinal panel studies. These should ideally be combined with exposure-aware measures and, where feasible, objective behavioural or safety outcomes. Expanding this causal evidence base is crucial for translating research and theories into a real actionable guidance for planners and policymakers, as well as for assessing whether interventions that improve perceived safety also deliver measurable benefits in terms of safety and broader system performance.

3.4.2 Measurement heterogeneity and limited standardization of perceived-safety constructs

Another critical issue highlighted by the consult of the material is the lack of standardization in how perceived safety is defined and measured across the included studies. This concept is operationalized using a variety of instruments, such as single-item ratings, multi-item scales, scenario-based judgements using images or videos and composite indices combining multiple dimensions. Even when Likert-type measures are used, there is still substantial variation in terms of scale length, anchor wording and scale directionality. This diversity complicates interpretation and limits comparability across studies. Consequently, contributions that appear to address the same construct may, in practice, capture related yet not fully equivalent psychological dimensions. This heterogeneity is further made worse by the inconsistent treatment of the conceptual boundaries between perceived safety, comfort and risk perceived. In some studies, these terms are used interchangeably, whereas in others, they are presented as distinct constructs without clear theoretical justification or separation in their operationalization. This aspect is important because the different constructs may follow different pathways: for instance, comfort may be strongly influenced by vibration and surface quality, whereas perceived risk may be more sensitive to speed differences or the frequency of conflicts. When these constructs are conflated, it becomes difficult to determine whether the findings reflect safety perception, or the broader experiential qualities of riding and sharing space.

Moreover, many studies provide limited evidence on measurement quality. Reliability indicators (e.g. internal consistency), validity checks (e.g. construct validity) and tests of measurement invariance across key subgroups (e.g. gender, age and experience level) are not routinely reported. Without invariance testing, observed group differences may reflect how respondents interpret scale items rather than true differences in perceived safety. Similarly, the limited reporting of missing data, scale construction and uncertainty (e.g. confidence intervals) reduces transparency and constrains the extent to which results can be synthesised quantitatively or compared across contexts.

For these reasons analysed, the methodological priorities for future research are going to be oriented to the wider adoption of validated, multi-item constructs that are aligned with clear, conceptual definitions, as well as the consistent reporting of anchors, directionality and scoring procedures. Another priority is the routine reporting of psychometric data, such as reliability, validity and, where relevant, invariance across subgroups. In parallel, greater harmonisation of core measurement items would substantially improve comparability and enable more robust synthesis of effect magnitudes and contextual differences across studies.

3.4.3 Limited triangulation with exposure-adjusted objective outcomes and behavioural evidence

A major issue emerged in the course of the scoping review is the lack of triangulation between what users report (perceived safety) and what can be observed in the real world through behavioural evidence and event-based safety outcomes. The evidence map shows that most studies primarily provide direct measures of perceived safety; in contrast, research based on behavioural proxies, such as rule compliance, lane or space choice and speed-related behaviours, or the ones based on objective outcomes including crashes and related injury severity, remains comparatively limited. This is particularly important because perceived safety is an outcome of interest in its own right and may also serve as an indicator of underlying risk mechanisms. However, the current literature rarely investigates whether patterns in perceived safety correspond to measurable differences in actual safety performance.

A key limitation is that perceived safety is rarely linked to exposure-adjusted, event-based outcomes. In practice, many studies that refer to crashes or incidents rely on self-reported counts or binary indicators, often without robust exposure denominators such as distance travelled, riding time or trip frequency. Without appropriate exposure adjustment, it is difficult to determine whether higher crash counts reflect a greater risk per unit of travel or simply a greater volume of riding. At the same time, administrative crash datasets tend to underrepresent minor events and near misses, and often lack behavioural context — for instance, with regard to overtaking dynamics, riding on pavements or speed selection. This further restricts the ability to validate findings on perceived safety against objective safety indicators.

Behavioural evidence can only partially bridge this gap. Currently, this evidence is limited to a relatively small number of observational and naturalistic studies, which are characterised by limited standardisation by definition. Different studies across the included ones measure behaviour in different ways, such as self-reported violations, video-coded manoeuvres and GPS-derived speed measures. This makes it more difficult to synthesise results from different studies. Furthermore, near-miss and conflict outcomes, which are particularly important where crashes are infrequent or underreported, are inconsistently defined across the literature, for instance through different thresholds, indicators or subjective versus objective classifications. Consequently, even when studies move beyond perceptions, they often generate measures that cannot be directly compared across settings or datasets.

Future research would benefit from integrated, multi-source designs that can measure perception, behaviour and context using comparable units of analysis. One particularly promising approach would be to combine the following: (i) standardised perceived-safety instruments based on multiple items; (ii) GPS and IMU telemetry to quantify exposure and riding dynamics, including speed profiles, braking and acceleration patterns, route choice and time of day; (iii) video-based conflict indicators, including automated methods where feasible, to capture interaction mechanisms at conflict points; (iv) contextual infrastructure variables such as facility type, intersection design, degree of separation and surface condition.. This would enable researchers to investigate whether perceived safety aligns with measurable conflict rates or risk-relevant behaviours once exposure has been taken into account, and whether perceived safety captures risk signals that may not be evident in administrative crash data. Furthermore, triangulation would enable more robust intervention evaluation by pairing perceived safety outcomes with behavioural and conflict metrics before and after infrastructure or policy changes. This would allow future studies to progress from merely describing perceptions to assessing whether improvements in perceived safety are accompanied by meaningful improvements in safety performance.

3.4.4 Under-studied populations and equity-sensitive evidence gaps

Although several of the included studies explore heterogeneity in perceived safety according to broad characteristics such as gender, age or riding experience, equity-sensitive analysis is not yet a consistent or systematic component of the evidence base. Often, subgroup differences are reported descriptively or as secondary findings, without sampling strategies designed to ensure adequate representation of vulnerable or understudied groups. This creates an important gap, given that perceived safety is shaped by both individual capabilities (e.g. physical stability, reaction time, confidence and sensory limitations) and environmental demands (e.g. surface quality, intersection complexity and speed differentials). This means that a superficial 'one-size-fits-all' interpretation can mask substantial variation in real-world safety needs.

Several populations remain under-represented. For example, older adults are rarely targeted in studies despite their likely heightened sensitivity to instability, braking demands and injury severity. They may also face stronger consequences from near-misses, surface defects or sudden evasive manoeuvres. Similarly, adolescents and young users are infrequently studied, even though they may have distinct exposure patterns related to the daily life (e.g. school-related travels), different risk-taking profiles related to the low experience and varying levels of formal road safety knowledge (e.g. driving licence). Similarly, novice users, who may be susceptible to negative experiences early on and adapt their behaviour quickly (e.g. by avoiding certain routes or abandoning micromobility), are not consistently identified as a group. This limits our understanding of how perceived safety develops during the adoption phase. Finally, people with mobility or sensory impairments are almost entirely absent from micromobility perceived-safety research, despite being directly affected by factors such as pavement riding, ambiguous shared spaces, and shared parking for vehicles (micromobility vehicles from sharing services are parked practically everywhere), which can obstruct pedestrian paths and reduce accessibility.

Disparities related to equity also emerge at spatial and socioeconomic levels. In fact, socioeconomic gradients and neighbourhood-level inequalities, including unequal distributions of protected infrastructure, poorer surface conditions in some urban areas, higher traffic volumes and lower lighting quality during nighttime, are rarely explicitly incorporated into models of perceived safety. This is a significant limitation because both perceived safety and exposure are likely to be strongly influenced by where people live and travel, reflecting their access to safer networks and their ability to choose less stressful routes. Without addressing these structural differences, the literature risks over-representing experiences from better-served areas and underestimating perceived safety barriers in disadvantaged contexts.

Closing these gaps requires more deliberate methodological choices. Priority areas include:

- targeted recruitment and stratified sampling to ensure adequate representation of older adults, novices, adolescents and pedestrians;

- routine subgroup modelling (including interaction terms or multilevel approaches) to test whether determinants operate differently across populations;

- stronger integration of contextual variables relevant to equity (e.g. neighbourhood deprivation, infrastructure availability, lighting and maintenance quality).

Furthermore, to pedestrian perspectives in shared spaces and around shared-device parking hotspots should be given more attention, as accessibility concerns and so perceived safety impacts may be concentrated there.

3.4.5 Scarcity of system- and policy-level evidence and implementation evaluation

A final and particularly significant gap concerns the limited availability of system- and policy-level evidence on the safety of electric micromobility, particularly with regard to perceived safety. While many studies acknowledge that perceived safety is shaped by the broader governance environment, such as where riding is permitted, how speeds are regulated, whether helmet use is mandatory and how shared fleets are managed, relatively few papers treat these factors as measurable explanatory variables. In existing literature, policy and regulation are often only acknowledged in passing, rather than being analysed systematically as determinants capable of producing quantifiable effects. This restricts the usefulness of the evidence for decision-making, especially since many of the most actionable tools available to cities operate precisely through regulation, enforcement and broader system design.

A key issue is that even when regulatory changes are introduced, such as revised speed limits, restrictions on riding on pavements, designated parking schemes or licensing and age requirements, few studies attempt to systematically evaluate their impact or document their actual implementation. Without measures of compliance and enforcement intensity, it is difficult to determine whether differences in the values of perceived safety are consequences of the changes occurred in the policy itself, the level of adherence to them, or broader contextual factors. These include public awareness campaigns related to the changes in the policy, designed to educate users about the behaviours they should adopt to feel safer. Similarly, despite their potential impact on user behaviour and public perception, the adoption of certain platform practices in shared micromobility systems, such as brief in-app training, warnings when the user opens the app, incentives, penalty structures and parking controls via photos are rarely considered when seeking to explain behaviour or changes in it.

Another dimension that has not been examined enough concerns aspects related to maintenance regimes and operational management. The comfort and stability experienced by micromobility users may be substantially affected by surface quality, debris and minor defects, while the consistency of maintenance and the speed with which problems are identified and resolved may determine whether hazards persist long enough to shape perceptions of safety and actual incident risk.

However, maintenance is rarely measured directly and the relationship between maintenance practices and perceived safety is largely unexplored. The evidence base under consideration is further limited by under-reporting and fragmented reporting channels. In fact, many minor collisions and near-miss incidents – which may be caused by infrastructure maintenance issues and the presence of debris or potholes on the road surface – are not always captured in administrative datasets, and even when they are recorded, they often lack the contextual information necessary to interpret their impact on perceived safety. This weakens the connection between objective safety statistics and the lived experience of safety and could complicate cross comparisons such as between different cities or countries where reporting practices differ substantially.

Strengthening this domain requires an explicit shift towards implementation-aware policy evaluation. Priorities for methodology include quasi-experimental and natural experiment designs (e.g. before–after studies, difference-in-differences and interrupted time series), which can exploit policy roll-outs or infrastructure implementation phases. These approaches should be complemented by systematic measurement of enforcement and compliance. This can be achieved through means like the observation of behaviour and the citation and/or enforcement records. Additionally, more robust forms of data linkage are required between different administrative records such as hospital and emergency medical service sources (where available), platform operational data and user-reported incidents or perceptions. This would help to reduce under-reporting bias and recover behavioural and contextual information often absent from individual data sources. Finally, clearer reporting standards would make studies more comparable by ensuring that regulatory conditions, enforcement contexts and infrastructure implementation characteristics are documented with sufficient specificity to support interpretation and other uses like cross-city transferability, which can help significantly the designers and decision makers.

The following table 8 reports the priority knowledge gaps that emerged from the analysis of the articles considered in this scoping review. The table also reports the suggested future research directions linked to those aspects.

Table 8 Priority knowledge gaps and suggested future research directions.

Gap area	What current evidence covers (typical)	Why this matters	Suggested future work (priority)
Geography & context	Mostly large-city, urban-core settings; limited range of regulatory regimes; sparse coverage of weather/seasonality and night-time conditions.	Limits transferability to different infrastructure baselines, traffic mixes, and enforcement realities.	Multi-city comparative studies including small/medium cities and peri-urban networks; explicit reporting of temporal/weather conditions.
Causal evidence	Predominantly cross-sectional surveys and one-off experiments.	Determinants may be confounded; intervention impacts cannot be estimated reliably.	Before–after and quasi-experimental evaluations of infrastructure/policy interventions with adequate follow-up; longitudinal cohorts.
Measurement standardization	Heterogeneous perceived-safety scales; limited validation and invariance testing.	Reduces comparability and prevents synthesis of effect magnitudes.	Validated multi-item constructs; harmonised anchors and directionality; reporting standards for uncertainty and missing data.
Triangulation with objective/behavioural data	Limited linkage to exposure-adjusted crashes, near-misses, or conflict indicators; behavioural evidence concentrated in few designs.	Perceived safety may capture risk signals not visible in crash data; weak validation reduces policy confidence.	Integrated studies combining perception surveys with GPS/IMU/video conflict metrics; exposure-aware outcomes and common near-miss definitions.
Equity & vulnerable groups	Fragmented subgroup analyses; under-representation of older adults, novices, disabled users, and socioeconomically disadvantaged contexts.	Infrastructure and policies may widen or reduce inequities; limited evidence for targeted design.	Equity-focused models; targeted sampling; pedestrian accessibility impacts in shared spaces and parking hotspots.
System & governance	Few studies quantify regulation/enforcement/platform practices or evaluate implementation.	Policy levers are central to practice; without evaluation, guidance remains speculative.	Policy natural experiments; enforcement and compliance metrics; linkage between user reports and administrative data to address under-reporting.

4. Discussion

This chapter discusses the results of the scoping review in a more interpretative way. Rather than only restating the evidence map, the aim here is to clarify what the selected studies actually contribute to the understanding of perceived safety in urban micromobility, what is already reasonably well established, and which gaps still remain open. To make this discussion more transparent, the first part follows the included papers in ascending StudyID order, as reported in Appendix D, while the second part draws together the main cross-cutting implications for theory, planning, and future research focuses.

Overall, the evidence confirms that perceived safety is not a secondary issue or a purely subjective feeling detached from objective risk. On the contrary, it is one of the main ways through which users interpret the road environment, evaluate their vulnerability and decide whether an e-scooter or an e-bike is usable in practice in the real world. For this reason, perceived safety should be read alongside crash and injury data, not in opposition to them, because it helps to reveal in an objective way the forms of exposure, discomfort, instability, and exclusion that are often invisible in administrative safety statistics alone.

4.1 Summary of Evidence

In this section, all 29 of the reviewed and analysed articles will be summarised briefly. To facilitate reading and comprehension given the large number of articles involved, they will be grouped into sets of approximately five. As previously stated, a summary of the contributions and limitations of each study will be provided, followed by an overall analysis of the available material to highlight the current state of knowledge and general limitations.

The first key finding to emerge from the sequential reading of the included studies is that perceived safety is not a unidimensional construct, but rather a multifaceted one that is shaped by physical, behavioural, social and contextual factors. This complexity is evident in Tzouras et al. (Study ID 8), who demonstrated that perceived safety plays a concrete role in the choice of transport mode for the first and last miles trips, influencing not only the willingness to use micromobility, but also the willingness to accept a detour to travel along a safer route. In this sense, perceived safety does not merely appear as a subjective evaluation, but as a factor capable of directly shaping aspects like the travel behaviour and the route decision to reach a destination.

This broader interpretation is supported by Adorean et al. (Study ID 11), who explicitly distinguished between the concepts of safety and security. This highlights that users' perceptions of unsafety cannot be reduced to crash occurrence alone. Their findings showed that locations identified as dangerous through crash data did not necessarily coincide with those perceived as unsafe by users. Furthermore, in their study, perceived insecurity was associated not only with traffic-related risk, but also in case of harassment, in fact, resulted that gender is a statistically significant predictor of safety-related experiences. This suggests that the experience of safety in micromobility encompasses different dimensions like the objective administrative reports and the social characteristic of the users.

Delavary et al. (Study ID 25) added a further level of complexity by introducing a cross-cultural and behavioural perspective. Their results showed that risk-related behaviours are influenced by traffic conditions as well as individual and social characteristics such as age, gender, student status, crash history and attitudes towards rule violations like: helmet non-use, riding with more than one passenger, crossing red light and riding on sidewalks. These findings suggest that perceived safety is deeply intertwined with broader behavioural dispositions and social norms rather than being determined exclusively by the external road environment conformation.

The everyday and experiential dimension of perceived safety is particularly evident in the study by Anke et al. (Study ID 30), which found that riders perceive higher levels of risk, especially when interacting with drivers and when riding on poor surfaces. Their findings emphasise that perceived safety is shaped by routine encounters within the traffic environment and the quality of infrastructure and not only one of those factors. Similarly, Qu et al. (Study ID 31) showed differences in the perception of safety between different gender of users. In fact, especially female e-bike riders, tend to evaluate the built environment more critically and are more likely to avoid narrow, noisy or otherwise stressful street settings. These findings highlight that perceived safety is not experienced uniformly across user groups, but varies according to gender and experience specific to a particular mode of transport, emphasising the importance of equity-sensitive interpretations of the evidence.

In order to allow a better understanding of the main contents of this first group of papers taken into account, a brief summary is proposed here: taken together, these studies suggest that perceived safety is a multidimensional concept reflecting infrastructure and traffic conditions, social experience, behavioural predispositions and user group diversity. Rather than being a simple reaction to objective danger or objective data like crashes, perceived safety emerges as a broader interpretative lens through which users assess the rideability, acceptability of risk and liveability of micromobility environments.

The second cluster of studies suggests that perceived safety should not merely be interpreted as an individual reaction to isolated hazards, but rather as an indicator of how effectively — or not — the wider transport system accommodates micromobility. This systemic dimension is clearly evident in the study by Jia et al. (Study ID 41), in which e-bike crashes were analysed from a Safe System perspective. The study showed that risk is generated by the combined effect of multiple factors, including infrastructure deficiencies, wrong rider behaviour, adverse weather and visibility conditions, interactions with heavy vehicles, weak regulation and limited enforcement of it. This study is important because it shifts the focus from the behaviour of individual riders to the broader configuration of infrastructural, regulatory, and environmental factors that influence the value of perceived safety expressed by the users.

A related institutional dimension emerges from the study by Faus et al. (Study ID 43), which found that communication campaigns conducted in Spain have devoted limited attention to vulnerable road users, with even less attention given to newer micromobility users. This suggests that institutional communication has not evolved at the same pace as urban mobility itself, resulting in a significant discrepancy between the rapid adoption of new transport modes and the public narratives, educational initiatives and awareness strategies required to facilitate the safe integration of the micromobility in the transport system. In this sense, perceived safety is influenced not only by the physical characteristics of the road environment, but also by the extent to which institutions recognise, represent and address the needs of emerging user groups in the different traffic scenarios. This interpretation is further supported by the findings of Kazemzadeh (Study ID 48) and Shahin and Elias (Study ID 51). Both studies showed that low safety perceptions are strongly associated with unclear, ambiguous or openly hostile riding environments, particularly for the category of e-scooter users and, even more so, for the users reported in the female gender. Their findings suggest that perceived safety is closely related to the legibility and inclusivity of the transport environment. When space allocation is uncertain, protection of the routes is inadequate or interactions with other road users are perceived as conflictual, the system itself, due to the way it has been designed and conceived, gives off a sense of insecurity. This is particularly pertinent for user groups who may already experience greater vulnerability or lower confidence in mixed-traffic conditions, which are, of course, more sensible to adverse events.

The analysis conducted by Hassanpour and Bigazzi (Study ID 53) add another dimension to the picture of perceived safety by demonstrating that the comfort and safety of facilities depend not only on the presence of micromobility devices, but also on their operating speed and degree of motorisation, as well as the visual perspective between those who are riding this systems and other users like car drivers. This highlights that perceived safety in shared environments is relational in nature, shaped by the characteristics of the vehicles involved, the behaviour of their drivers and how different users interpret coexistence within the same space and time.

The studies of this second group of five papers, taken together, suggest that perceived safety depends not only on roadway geometry and traffic exposure, but also on governance arrangements, communication practices and campaign, regulatory clarity and how different categories of users coexist in everyday situations. From this perspective, perceived safety is a useful lens through which to assess the broader functioning of the urban mobility system, including its capacity to integrate new flexible and eco-friendly transport modes in an intelligible and socially sustainable way.

The subsequent group of studies enriches the knowledges further by showing that the perceived safety area is not solely determined by external conditions, but is also filtered through psychological, cognitive and behavioural processes. In this respect, the study by Meir et al. (Study ID 56) can be considered particularly relevant, as the researchers moved beyond explicit self-reports to explore implicit attitudes. The analysis was carried out by examining the high-risk situations involving users of electric scooters. Their findings suggest that certain hazardous scenarios, particularly those involving not wearing a helmet or performing secondary tasks during the riding, elicit strong automatic reactions that certainly have implications in the values of perceived safety reported in the questionnaires. This implies that safety judgements are not always the result of fully conscious and articulated evaluations, but may also be shaped by rapid, implicit cognitive responses determined by the distraction of the micromobility user.

Similarly important shifts in perceived safety perspective are provided by Oh et al. (Study ID 81), who showed that the respondents have evaluated an overtaking manoeuvre as considerably less safe when they re-experienced it from the perspective of the e-scooter rider than when they had performed the manoeuvre originally as drivers. This result is particularly meaningful because it highlights that perceived safety depends not only on the objective characteristics of the manoeuvre itself, but also on positional perspective and the embodied experience of vulnerability in traffic interactions. In other words, the same event may be interpreted very differently depending on the road user's role Furthermore, it can be said that the review of this paper highlights the need for awareness campaigns and practical experiences that truly help all users of such infrastructure to understand the feelings one experiences when in a vulnerable position – a situation that is certainly encountered when using micromobility systems, where users are more exposed to serious consequences in the event of collisions with vehicles such as cars or heavy vehicles.

Qian et al. (Study ID 121) conducted an analysis that introduce an additional layer of complexity by incorporating an occupational dimension. Their study showed that greater safety knowledge and a stronger perception of risk severity among food-delivery riders can reduce some aberrant behaviours that most of times they perform. However, these factors are not sufficient to neutralise the structural pressures associated with this type of platform-based work, such as delivery deadlines and strictly performance demands. This finding is significant as it suggests that unsafe behaviour and related safety perceptions cannot be fully explained by individual attitudes or awareness campaigns alone. It is also necessary to consider perceived safety in relation to broader organisational and economic constraints. These factors push workers to commit traffic offences at the expense of the safety of the infrastructure users in order to save time needed to complete work and consequently to increase their earnings.

Observational evidence of some studies consulted points in the same direction: Younes et al. (Study ID 133) found that in the context of the services of shared micromobility, e-scooter users displayed fewer visible protective behaviours than cyclists. This suggests differences in practice and in the behavioural cultures surrounding different micromobility modes. Some differences in safety behaviour, as reported also in other studies, are evident between the gender of the user and the context in which they operate (time of the day or path choice). Furthermore, Zheng et al. (Study ID 153) showed that risks connected to phone use while riding an e-bike is associated with self-control, personal attitudes and the phenomenon of 'nomophobia', an irrational fear, anxiety or panic at the thought of being disconnected from the internet, without a smartphone or unable to use it. This confirms that unsafe conduct is mediated by psychological factors that extend beyond the roadway design, but as demonstrated, they have a significative impact in the experiences of the users and consequently in their referred perceived safety.

Taken together, these third group of studies make it clear that perceived safety cannot be attributed solely to the physical environment conditions. Instead, it emerges from the interaction between environmental conditions and a broader range of mediating factors, such as attitudes, behavioural norms, cognitive framing, implicit reactions and, in certain contexts, work-related pressures. This means that perceived safety is a more complex construct than simply reflecting infrastructure or traffic exposure. It also suggests that any attempt to improve safety of micromobility users must consider not only the structural design of the infrastructures where people ride, but also how do they interpret, experience and respond to the situations they encounter in their daily life.

Another contribution of the literature is showing that perceived safety has, in reality, concrete spatial and behavioural consequences rather than being purely subjective. In other words, it not only describes how users feel about the travelled environment, but also actively shapes how they move through it and the routes they choose. Furthermore, all the factors reported in the last sentences influence how the vulnerable users (e-bike and e-scooter riders) adapt their behaviour in response to perceived risk. This dynamic is clearly evident in the study conducted by Tzouras et al. (Study ID 164), in which the researchers translated perceived safety into a routing variable. They have demonstrated that penalising unsafe connections results in a reduction in the size of the mobility network that can be used, a change that is particularly significative for electric scooters. Their findings are significant because they demonstrate that inadequate infrastructure reduces not only comfort, but also accessibility, resulting in longer detours. Thus, the perception of safety directly influences the spatial usability of the urban network, determining overcrowded safer paths and empty paths scored as unsafe. Bishop et al. (Study ID 166) through a quantitative evidence study on psychological determinants of safety-relevant behaviour proxies (mistakes and rule's violations of the users) and adverse road-user interactions (negative experiences of the users) highlight a related behavioural dimension. The study shows that distraction control and self-efficacy can influence on-road behaviour in non-linear ways. Notably, higher self-efficacy attitudes did not invariably correspond to safer conduct; in certain instances, it appeared to border on overconfidence. This finding complicates any straightforward interpretation of confidence as a protective factor, suggesting that high perceived competence may encourage risk-taking behaviour under certain conditions. Cubells et al. (Study ID 175) reinforce this perspective further by providing GPS-based evidence that the choice of route and speed maintained along the trip by micromobility users varies according to gender, age, parenthood and the type of infrastructure on which they travel. Their results suggest that perceived safety is filtered through individual circumstances and social roles, which in turn influence everyday mobility decisions. Therefore, differences in perceived safety referred by the partecipants manifest not only in their attitudes, but also in other measurable variables that include route selection and operating speed.

The study by Chouhan et al. (Study ID 183) focused more broadly on the perceived safety of powered two-wheeler users and there isn't a specific connection to the vehicles considered in this study (e-scooters and e-bikes). Therefore, the results of this paper remained irrelevant for the scoping review conducted.

The analysis performed by Huang (Study ID 201) adds a further layer of complexity: has been shown that factors of different nature as speed, mental workload, anxiety and user experience can all influence the perception of safety when riding an e-bike. This suggests that perceived safety is influenced not only by external environmental factors, but also by the cognitive and emotional demands placed on the rider. Consequently, the perception of safety emerges from the interaction between infrastructure, external riding conditions and the user's internal state.

Taken together, the studies of the fourth group analysed suggest that perceived safety should not simply be understood as something that users report when asked, but rather as an active mechanism that influences in a significative way everyday mobility. Aspects related to perceived safety affect route selection and the operating speed of micromobility vehicles, as well as exposure to different traffic conditions. This can generate, for example, coping behaviours among micromobility users (choose of the same paths perceived as safer) that may either reduce or redistribute risk. From this perspective, perceived safety becomes a key factor in understanding how users interpret and navigate the transport environment in the real practice.

Later studies broaden the discussion further by demonstrating that perceived safety is influenced not only by infrastructure and traffic interactions, but also by attention processes, safety knowledge, regulatory conditions, measurement methods and the particular operational features of various micromobility devices. Thus, perceived safety emerges as a construct embedded within a wider system rather than as a simple response to immediate road conditions.

The studies conducted by Tollazzi et al. (Study ID 207) were oriented towards aspects related to powered two-wheelers in general. As this is not the main focus of this scoping review, the findings from this paper were disregarded.

Zhou et al. (Study ID 208) made a complementary contribution to the collection of information relating to perceived safety through their analysis. They found that electric bicycle users often have limited safety knowledge and awareness of traffic safety, and frequently engage in risky driving behaviour. In the absence of specific training or education, they tend to rely on their riding skills rather than observing traffic laws. The study also showed that improving safety knowledge can help reduce negligence-related risky behaviours. However, the significance of safety knowledge improvements in affecting intentional violations or aggressive behaviour is negligible. Furthermore, the study revealed that aggressive behaviour appears to be more closely associated with group behaviour attitudes. Additionally, the findings revealed significant differences based on personal and social characteristics: male riders, individuals with prior violation records and riders aged 17 to 45 were more likely to exhibit aggressive and negligent behaviours. Conversely, these risky behaviours tended to diminish with the user's age. This distinction is important because it suggests that improving perceived safety and reducing risky behaviour cannot be achieved through information and training alone. Some unsafe practices are embedded in broader behavioural cultures and therefore require more extensive interventions than only knowledge-based strategies.

Akgun-Tanbay et al. (Study ID 212) introduce an important new dimension by adding the concept of perceived chaos to the existing considerations of safety and comfort in shared spaces. Their study showed that infrastructure quality, age and gender of the user and familiarity with the area all influence the way in which such environments are experienced. This contribution is particularly relevant because it suggests that perceived safety should be understood not only in terms of danger or protection, but also in relation to the degree of order, legibility and predictability perceived by users in their surroundings, especially when they are performing trips using vehicles.

From a methodological point of view, Ragot-Court et al. (Study ID 221) made an important contribution by proposing A-TRIBE, a tool that enables risky behaviours to be compared across different categories of two-wheelers, for data collection. This is valuable because during this scoping review emerged that a recurring problem in the literature was the difficulty of comparing findings across transport modes and measurement approaches. A more standardised assessment framework could therefore strengthen the comparability and cumulative value of future research on perceived safety and related user behaviours.

Wang et al. (Study ID 224) then provide a broader sociotechnical interpretation, examining e-bike safety in China. They show that vehicle standards (and illegal upgrades of vehicle), weak enforcement, company policies, and delivery-platform incentives all operate as higher-level determinants of risk, pushing the users to use these systems without all needed cautions. Their findings are significant because they shift the focus from individual riders to organisational and regulatory structures. In this context, perceived safety is influenced not only by the road environment, but also by the rules, incentives, and institutional arrangements that shape everyday mobility practices.

Twisk et al. (Study ID 250) wrote in this article shows that speed pedelecs differ significantly from pedelecs and traditional bicycles in terms of speed, variability in speed and tendency to exceed speed limits. This is an important finding because it shows that electric micromobility cannot be treated as a homogeneous category. Different devices generate different operating conditions, which are likely to affect both actual risk and how safety is perceived by riders and other road users.

The study conducted by Wang et al. (Study ID 298) highlights the gap between theoretical knowledge and actual behaviour, demonstrating that users may be aware of the rules but still fail to follow them consistently. This gap between awareness and practice in the real world and daily life reinforces the idea that perceived safety and safe behaviour are not solely determined by knowledge but are also influenced by other factors such as: habits, situational pressures and broader behavioural norms. Hertach et al. (Study ID 304) then demonstrated that a significant proportion of e-bike accidents are linked to skidding, slippery surfaces, tracks and loss of balance. A significative part of those events occurs in single-vehicle crashes. These findings are significant as they highlight a lesser-known aspect of safety that is frequently overlooked in discussions centred on conflicts with motor vehicles or other infrastructure users. They also highlight the importance of the infrastructural performance dimension: surface conditions and in general the condition of the facility can affect significantly vehicle stability and so the perceived safety.

Finally, Sgarra et al. (Study ID 347), referred to powered two-wheelers in general and so the findings related to it wasn't considered.

Taken together, the studies included in this last group of papers demonstrate that the argument of perceived safety is embedded within a broader sociotechnical system comprising aspects related to different spheres such as attention, knowledge, behavioural norms, vehicle characteristics and performances, regulatory frameworks, monitoring tools and infrastructure dimension. So, rather than being attributable to a single factor, perceived safety emerges as the product of multiple interacting layers ranging from the cognitive and behavioural dimension to the organisational and regulatory one.

When considered collectively, 26 studies were included as evidence base of the review. The findings presented reveal that the literature does not yet converge on a single, stable operationalisation of perceived safety, thus addressing the first research question. Instead, perceived safety is approached through a variety of measurement strategies in fact in some studies, it is assessed directly using safety ratings, comfort scores, perceived-risk scales or scenario-based evaluations. In others, it is captured more indirectly through indicators such as route choice, lane choice, helmet use, phone use while riding, near-miss experience, risky-riding inventories, workload measures or broader, system-level analyses of collisions and governance arrangements. This diversity of approaches for the same 'problem' is not a weakness in itself. In fact, it is fully consistent with the initial purpose of a scoping review, which is to map how a field has been conceptualised and investigated across different disciplinary and methodological traditions. The variety of approaches found in the literature is therefore beneficial and is a key strength, as it demonstrates the various ways in which perceived safety and the factors linked to it has been examined in the years. Moreover, the literature review highlights the relevance of watching at perceived safety across behavioural, infrastructural, psychological and governance-related perspectives.

However, this diversity also highlights an important limitation of the current evidence base examined: its persistent conceptual fragmentation. Constructs such as perceived safety, perceived risk, comfort, chaos, workload and behavioural caution are often considered closely related and are sometimes used interchangeably, without a clear separation. Yet these dimensions are not fully equivalent, either conceptually or empirically. Each dimension captures a slightly different aspect of the user experience. Therefore, if their overlap is not made explicit, it becomes more difficult to compare studies and to analyse carefully their findings. For this reason, the literature is better at identifying recurring mechanisms and broad patterns than at providing a standardised, directly comparable measurement framework. In other words, existing studies are increasingly effective at showing which factors tend to shape users' sense of safety, but they are less consistent in defining exactly how perceived safety should be distinguished from related constructs. Consequently, to measure uniformly aspects related to perceived safety results difficult. This suggests that a key priority for future research is to strengthen the conceptual clarity and methodological consistency of the field, as well as expanding the empirical evidence through analyses designed to measure specific key parameters.

With regard to the second research question, the reviewed studies reveal a consistent pattern regarding the factors associated with lower perceived safety. Among these, infrastructure emerges as one of the most prevalent and influential factors. Lower safety perceptions, in fact, are repeatedly associated with problems like: discontinuous networks, the absence of dedicated facilities, narrow lanes, inadequate separation from motorised traffic, conflict-prone intersections, mixed-flow environments and poor surface conditions. The findings emerged from the literature review suggest that perceived safety is strongly influenced by the extent to which the built environment can provide sensations such as continuity, clarity and protection for micromobility users. For e-scooters in particular, the infrastructural dimension appears to be of even greater importance: this is due to the vehicle's design, which features small wheels and a standing riding position. Consequently, this type of vehicle is undoubtedly more sensitive to the characteristics of the surface on which it travels. Several studies, in fact, suggest that those micromobility systems are particularly sensitive to potholes, tram tracks, thresholds of sidewalk and uneven pavements. Therefore, the same infrastructural deficiency may generate different levels of discomfort and perceived danger depending on the type of device being used. This confirms that perceived safety cannot be analysed without considering the interaction between infrastructure and vehicle characteristics.

At the same time, the review clearly shows that infrastructure alone cannot explain how safety is experienced by the users. A variety of user-level and psychosocial factors consistently influence how the same street environment is interpreted. Some characteristics of the group analysed across the studies such as gender, age, riding experience, self-control, self-efficacy, anxiety, social norms, exposure to harassment, ownership model and work-related pressures all emerge as factors that can amplify or reduce safety perceptions. This means that identical physical conditions may be experienced very differently depending on the characteristics, expectations and vulnerabilities of the user. Taken together, these findings suggest that perceived safety should be understood as a relational construct. It is shaped not only by the material characteristics of the street, but also by who is using that space, in what circumstances, to what degree they are familiar with it and how vulnerable or in control they feel during riding. From this perspective, another time, lower perceived safety does not simply reflect problems related to the infrastructural dimension; rather, from the literature review conducted emerged that lower perceived safety experienced by the users could be determined from the interaction between environmental conditions, traffic dynamics, vehicle properties and the user's personal and social position within the mobility system.

The third research question considers the extent to which perceived safety influences user behaviour. The reviewed evidence on this topic is relatively consistent and so, through the researches and findings presented in the literature, is possible to give an answer to this question. The evidence base indicates that perceived safety substantially influences how micromobility is used, although this relationship is not always linear or uniform across contexts. Generally speaking, when the environment is perceived as safe, users appear more willing to use micromobility, take more direct routes and be adherent to the designated infrastructure rules. Conversely, when safety is perceived as lower, users adapt their behaviour to reduce their perceived exposure to danger during their trips. Examples include lowering speed, taking detours, avoiding specific routes or manoeuvres, scanning the environment more actively for threats and shifting towards pavements and other spaces regarded as less intimidating, representing, on the other hand, a risk for other users like pedestrians. At the same time, in fact, the literature also makes clear that a stronger perception of risk does not automatically translate into safer behaviour. In many cases, behavioural responses are shaped by a combination of safety perceptions, external pressures and individual dispositions. For example, time constraints and productivity demands imposed by the platform they are working for may cause delivery riders to continue to engage in risky practices. More experienced users may normalise exposure to risk over time, treating hazardous conditions as routine rather than exceptional ones. Similarly, higher self-efficacy does not always correspond to greater caution; in some cases, it may reflect overconfidence rather than genuinely safer behaviour. This is one of the most important findings that emerged from the review because it shows that, while perceived safety is clearly linked to behavioural adaptation, this adaptation is also influenced by a broader set of factors including incentives, habits (good or bad ones), accumulated exposure, identity and the psychological characteristics of the user. Therefore, perceived safety should not be interpreted as a simple trigger of behavioural change, but rather as one element within a more complex decision-making process in which users continuously negotiate risk, convenience in that moment, time pressure and their own sense of competence and vulnerability.

4.2 Implications for Infrastructure, Policy and Practice

From a planning and transport policy perspective, one of the clearest implications of this review is that perceived safety should not be regarded as a secondary or subjective variable in the decisions regarding the infrastructures. Rather, it should be treated as a concrete planning criterion because, as demonstrated by several researches analysed, it directly influences the adoption of micromobility, how users move through the network and which urban environments are considered acceptable for performing everyday travels in safer way. In this respect, perceived safety could be watches as a crucial bridge between the technical performance of the road system and the behaviour of its users. This aspect can be considered particularly important because, although a road may formally permit the use of electric scooters or electric bicycles and comply with regulations, it may still prove impractical if users perceive it as stressful, ambiguous or hostile. The formal availability of space does not necessarily coincide with its effective usability. In fact, if users perceive an environment as unsafe, they may avoid it by choosing a different route, riding more defensively or abandoning the mode of transport altogether. Therefore, the practical success of micromobility systems and their safety depends not only on the existence of infrastructure, but also on its perceived intelligibility, continuity and protective capacity. For this reason, the design of safer infrastructures for micromobility systems must not rely solely on crash statistics, legal compliance or technical design standards. While these elements remain essential, they are insufficient on their own to capture how safety is experienced in everyday mobility by the users of e-scooters and e-bikes. Therefore, any planning approach aiming to sustainably integrate micromobility into transport systems and to make infrastructure safer must explicitly incorporate the user's perspective. This means recognising perceived safety as an important aspect of the micromobility user system and infrastructural performance, rather than an additional, less important factor.

The first implication for planning and transport policy relates to infrastructure design aspects. The most consistent finding across the reviewed studies is that perceived safety improves when users can rely on continuous, clearly legible and protected networks, rather than fragmented, ambiguous or interrupted road environments. Therefore, isolated facilities are unlikely to be effective if they are connected by conflict-prone junctions, poorly designed crossings or abrupt transitions into mixed traffic. From this perspective, micromobility infrastructures should be conceived as a coherent network that integrates into the road system without disrupting traffic flow equilibrium. In fact, facilities designed for e-scooter and e-bike mobility shouldn't be a set of individual and disconnected elements, but rather they should have characteristics such as continuity, readability and predictability. These characteristics represent the central objectives that should be clearly present in an accurate design phase or that could lead the decision-making process for maintenance interventions. It is not only the presence of dedicated space that matters, but also the extent to which that space enables users to move through the urban environment without repeated interruptions, unclear priorities or sudden losses of protection. Particular attention should therefore be devoted to path junctions, overtaking conditions and separation from fast or heavy motorised traffic, as these situations are most frequently associated with lower levels of perceived safety. Surface pavement quality is equally relevant: although it is examined less frequently than other factors, the reviewed evidence suggests that maintenance, pavement regularity, debris removal and treatment of tracks and potholes are particularly important for e-scooter users. In this regard, perceived safety depends not only on the provision of new infrastructure, but also on how well existing infrastructure is maintained over time. Taken together, these findings suggest that improving perceived safety necessitates shifting from a fragmented, facility-based approach to a more systemic understanding of infrastructure provision. Safer micromobility environments cannot be created simply by adding individual lanes by drawing new lines on pavements as can be seen simply by walking through the streets of various Italian urban environments; rather, they must be designed so that the network as a whole is understandable, continuous, and physically suited to the operational characteristics of the vehicles using it.

Secondly, although physical design of the infrastructure is essential, it is not sufficient on its own to ensure safer facilities for micromobility systems. The evidence reviewed in this thesis repeatedly demonstrates that perceived safety is also influenced by the broader governance framework within which micromobility operates. Factors such as the management of shared spaces, speed regulation, clear priority allocation, parking control, enforcement practices and institutional communication all influence whether users find the infrastructure system understandable, predictable and trustworthy. This is particularly pertinent in dense traffic urban environments, where various modes of transport share limited space. The uncertainties derived by unclear rules and unexpected users' behaviours in such a limited space can itself generate discomfort and a sense of danger. From this perspective, is important to highlight that perceived safety is co-produced by multiple interacting dimensions, including infrastructure, operational rules, institutional communication and enforcement of the rules. In practice, improving the safety of micromobility users requires integrated action, with regulation, governance and infrastructure design developed in a coordinated way, rather than being treated as separate, independent policy domains. Only under these conditions can the urban mobility system become genuinely intelligible, credible and safe in the eyes of its users, as well as formally accessible.

A third implication relates to operational practice and day-to-day implementation. The review suggests that some of the most actionable determinants of perceived safety are comparatively under-explored in the current literature, particularly those related to maintenance regimes of the infrastructures and post-intervention reporting systems after changes relating to the road environment or to the policies governing the movement of road users and vehicles travelling on it. This is a significant point because cities and decision-making operators can often intervene more quickly and directly in these areas than through large-scale infrastructural change alone. In other words, perceived safety is shaped not only by the design of the infrastructural system, but also by its management, monitoring and maintenance over time. From a practical perspective, for example, regular maintenance of riding surfaces or interventions related to the road markings play an important role in shaping the experience of micromobility users' safety in everyday use. These are not marginal implementation aspects, but concrete operational levers through which the infrastructure's functionality can be improved. Moreover, after structural or regulatory interventions, it is possible to determine the actual quality of the intervention through infrastructure management and monitoring systems, thereby establishing whether it has improved or worsened users' perceptions of safety. Therefore, a practice-oriented approach to micromobility users' safety must extend beyond the solely interventions of maintenance of the infrastructure. This approach should incorporate operational controls, monitoring systems and governance tools that address how the system functions day-to-day over time. Therefore, improving perceived safety also requires attention to the everyday management of the infrastructures travelled by micromobility users, since many of them, during riding, could encounter conditions that can decrease their perceived safety.

Another major suggestion emerging from the review concerns equity and inclusion. The literature, in fact, shows with considerable consistency that perceived safety is not distributed evenly across user groups, but varies according to the user gender, age, experience and role within the traffic system. The studies analysed in this scoping review highlighted that women frequently report lower levels of perceived safety and express stronger preferences for more protected, clearly legible and lower-conflict environments. Similarly, novice users, as well as some older riders, may tend to experience the same street conditions as substantially more stressful than users who are more confident or more experienced. Occupational users, such as delivery riders, are exposed to an additional layer of constraint, since their behaviour is shaped not only by personal preference or risk perception, but also by work-related pressures and organisational demands. The concept introduced in the last words has an important implication for planning aspects, because it suggests that perceived safety is not simply a matter of comfort but also one of accessibility, usability and fairness. Specifically, a network may be formally available to all users and may even satisfy technical or regulatory requirements, while still functioning in practice as an exclusionary system. This even more if it can be used comfortably only by riders who are confident, skilled, faster or socially advantaged. In this sense, the effective accessibility of micromobility depends not only on the legal or physical condition of the infrastructure, but also on whether different categories of users are able to experience that infrastructure as intelligible, manageable and sufficiently protective. From this perspective, perceived safety is a valuable way of evaluating not only whether micromobility infrastructure exists, but also who it actually benefits in practice. So, designing in a way in which perceived safety plays an important role also means designing for broader and more equitable access to urban mobility. This ensures that the benefits of a high-performance infrastructure are not limited to users who are best equipped to tolerate risk or much smarter in interpreting ambiguities.

Overall, this review reveals that safer micromobility infrastructures cannot be achieved through isolated or purely sectoral interventions. Rather, the evidence suggests the need for an integrated package of measures combining network continuity, safer intersections, surface maintenance, speed management, regulatory clarity, enforcement of the rules, parking governance (especially for sharing micromobility services), institutional communication and explicit attention to more vulnerable user groups. In other words, the perceived safety of micromobility users depends not on any single intervention taken in isolation but on the extent to which the urban mobility system operates as a coherent, legible and well-managed whole. Within this broader perspective, perceived safety should be recognised as a policy-relevant dimension for urban mobility infrastructures, alongside more traditional indicators such as crashes and injuries. While objective safety outcomes remain indispensable, they do not fully capture whether a road system is better usable, understandable and acceptable under everyday conditions. Perceived safety, so, adds an essential layer of interpretation because it reveals how users experience the system in practice and whether they regard it as sufficiently reliable and easy to navigate for their trips. This point is particularly important for planners and policymakers, especially for design and planning interventions on infrastructures for micromobility users. For this reason, improving perceived safety should not be considered an optional complement to conventional road-safety, but an integral part of creating facilities that are not only safer on paper, but also genuinely workable, inclusive and sustainable in real urban life.

4.3 Future Research and limitations

The limitations identified in the reviewed literature also played an important role in suggesting some areas for future research to focus on, in order to strengthen the field's support for planning, policy and safety assessments. Currently, the literature can identify the infrastructures conditions, interactions between different road users and general environmental conditions that are most frequently associated with lower levels of perceived safety. However, a more precise understanding of how stable these patterns are across different urban contexts, how they change over time and the extent to which improvements in infrastructural dimension correspond to measurable improvements in micromobility users' behaviour and objective safety outcomes remains less developed. Therefore, the next stage of research should be seen as a process of methodological and conceptual consolidation, rather than simply an increase in the number of studies. This in order to make the evidence base more cumulative, comparable and practically available to designers and policymakers.

One of the most evident needs is for a broader range of contexts to be included in the evidence base. Much of the current research focuses on relatively visible, well-established environments, which are often large urban areas where micromobility systems like e-bikes and e-scooters have become integrated into everyday mobility patterns. Consequently, there is a much more limited body of evidence for smaller cities, peri-urban corridors, transitional settings and urban areas where the infrastructures are more fragmented and the desity of traffic tend to be lower. Yet it is precisely in the contexts less analysed across the literature that the experience of perceived safety may vary considerably, and analysing these contexts can help to broaden our understanding on the topic of this scoping review. The same riding environment can be interpreted very differently by the users depending on different factors: traffic speed, network continuity, local interaction norms, lighting environment conditions, modal mix of the traffic and the clarity with which space is organised and governed. Climatic and temporal conditions deserve, also, more systematic attention since factors such as darkness, rain, seasonal variation and changing traffic intensity can all affect how safety is experienced in practice by the users. Therefore, broadening the geographical and contextual scope of future studies would improve the general validity of the findings and reduce the risk of drawing conclusions based on evidence that takes into account only better-resourced or more advanced settings.

At the same time, the field would benefit considerably from research designs that can capture changes over time and assess more effectively the effects of specific interventions on the infrastructures by principally two different perspectives: structural and regulatory one. Much of the current evidence is cross-sectional, making it useful for identifying associations, but far less effective at determining whether perceived safety changes as infrastructure improves, regulations evolve or users gain experience. A more mature research agenda should therefore increasingly rely on longitudinal approaches, before-and-after studies, natural experiments and quasi-experimental evaluations linked to infrastructure redesign, speed management measures and regulatory changes. These designs would enable to examine not only whether users report higher values of perceived safety, but also whether these changes are accompanied by other shifts like route choice, speed, behavioural adaptation, in order to guarantee the higher performances on the whole road network especially for the category of micromobility users which are the main focus of this research. In this respect, future research should move beyond merely describing the factors that influence perceived safety and begin to systematically evaluate which interventions can meaningfully and durably improve it.

Further progress will depend on future research being able to establish a more convincing link between perception and other spheres such as behaviour, exposure and objective safety outcomes. Currently, perceived safety is frequently considered a meaningful outcome in its own right, albeit still too often in isolation from behavioural and event-based indicators that could validate its broader significance. This is an important gap because perceived safety is likely to capture dimensions of vulnerability and discomfort that are not adequately reflected in conventional crash statistics, particularly where minor incidents and near misses are underreported. Therefore, future studies should aim to strengthen triangulation by combining self-reported perceptions with GPS traces, telemetry, structured observation, near-miss reporting, video-based conflict analysis. The aim is to add further data, for example, to existing datasets containing records of crash events. This will make it even easier to identify hazardous locations, thereby enabling more precise planning of infrastructure improvements that can reduce the number of crashes and near-miss events, thus improving perceived safety.

This would enable us to understand also more precisely whether environments perceived as unsafe are associated with higher conflict density, more unstable manoeuvres, greater route avoidance or higher levels of exposure-adjusted risk. It would also clarify whether perceived safety can function as both a subjective descriptor of user experience and a robust, objective policy-relevant indicator of infrastructure's performance.

Finally, the next phase of research should engage more directly with heterogeneity among users and the broader question of equity. While gender differences are already relatively visible in the literature, many other differences of the people included in the samples remain only partially explored. For example, older adults, novice riders and adolescents exposed to conflicts in shared spaces, people with sensory impairments have not been examined with the same consistency as more common micromobility users' profiles. This aspect is important because perceived safety is not distributed evenly across populations, and transport environments that seem acceptable to experienced or confident riders may still be stressful, exclusionary or unusable for others. Therefore, future work should pay closer attention to how vulnerability is differentiated in terms of not only demographic data, but also in terms of experience, trip purpose, confidence level and familiarity with the road environment. In this sense, heterogeneity should be treated as a foundamental condition for understanding how inclusive or exclusive the infrastructures for micromobility systems actually are, rather than a secondary refinement of the analysis.

So, resuming and taking together all the considerations presented in the previous words, the suggestion is that future research on perceived safety for micromobility users should be more integrated. A better collection of data relating to perceived safety – as proposed in this section in which are resumed the future research priorities – is oriented to push the role of perceived safety in a dimension of practical help to improve the stages of design and decision-making process and to predict how certain measures or interventions may improve or, conversely, worsen safety of the user users who make daily use of the road network.

5. Conclusions and Main findings

In this thesis was conducted a scoping review to map the current evidence on the road safety implications of electric micromobility in urban environments. The review focused specifically on perceived safety among e-scooter and e-bike users in mixed-traffic contexts. Adhering to

PRISMA-ScR principles, the review considered 29 peer-reviewed studies. During the full-text review, 3 studies were excluded as they concerned powered two-wheelers in general, without any specific reference to the class of vehicles on which this literature review focuses, namely e-bikes and e-scooters. Consequently, the contributions considered in this scoping review are drawn from 26 articles. Their contents have been organised and summarised using a descriptive mapping and an evidence-map framework. The aim was to clarify how perceived safety is conceptualized and measured, which determinants are most consistently associated with it and how it relates to behaviour, exposure and safety-relevant outcomes. Structuring the literature in this way provides both a consolidated overview of a rapidly evolving research field and a transparent basis for identifying methodological limitations and priorities for future work.

The scoping review conducted confirms, also, that perceived safety is particularly important for micromobility users, as these transport systems operate in highly interactive and often ambiguous urban environment. Users are exposed not only to objective crash risk, but also to uncertainty, discomfort and various forms of vulnerability that are not always visible in conventional safety statistics. In this sense, the work developed in this thesis is intended to emphasise the importance of perceived safety as a practical means of improving design and decision-making processes, and of predicting how certain measures or interventions may affect the safety of users of the road network.

The reviewed literature presented perceived safety as a layered and clearly multidimensional construct. In fact, one of the most convincing aspects of the evidence is that it resists overly narrow interpretations. In Tzouras et al. (Study ID 8), for instance, perceived safety is presented as a factor that materially influences travel behaviour, affecting the willingness of the micromobility user to accept a detour in order to move through an environment deemed safer. A similar expansion of the concept can be seen in the study by Adorean et al. (Study ID 11), in which the authors distinguished between the topics of safety and security. With their findings the researchers showed that locations identified as dangerous through crash data do not necessarily coincide with those perceived as unsafe by users. In their study, low perceived safety was also associated with harassment, under-reporting and the ownership model, making it clear that perceived safety cannot be reduced to aspect related to collision risk alone. This broadening of the concept continues in the study by Delavary et al. (Study ID 25), in which risk-related behaviours of the micromobility users were linked not only to traffic conditions, but also to other characteristics such as age, gender, student status and crash history, that is, whether the user had been involved in a crash event. Anke et al. (Study ID 30) and Qu et al. (Study ID 31) reinforce this view from different angles: the former highlighted the role of driver interactions and poor surface conditions; the latter showed that women, especially female e-bike riders, assess the built environment more critically. In fact female riders are more likely to avoid narrow, noisy or stressful street settings. So, taking together these studies is possible to say that perceived safety is linked with different dimensions like: infrastructural, behavioural, social and experiential ones.

Another key point that emerges from the literature is that perceived safety should not be interpreted as merely an individual response to isolated hazards, in fact it also reflects how effectively — or not — the wider transport system accommodates micromobility users. This systemic dimension is particularly evident in the study by Jia et al. (Study ID 41), in which the authors approached e-bike crashes in this way: they demonstrated that risk arises from the interaction of infrastructure deficiencies, inappropriate rider behaviour, adverse weather and visibility conditions, presence of heavy vehicles, weak regulation and limited enforcement of the rules. This is an important implication because it shifts attention away from a simplistic reading centred only on the rider, instead framing perceived safety of the users as something co-produced by the broader mobility environment. A similar point emerges in the study by Faus et al. (Study ID 43), which found that communication campaigns conducted in Spain devoted only limited attention to vulnerable road users, and even less to newer micromobility users. This suggests that institutional communication has not evolved as rapidly as urban mobility itself. Kazemzadeh (Study ID 48) and Shahin and Elias (Study ID 51) further reinforce this idea, linking lower safety perceptions to unclear or openly hostile riding environments, particularly for e-scooter users and especially for those who belong to the female gender. Hassanpour and Bigazzi (Study ID 53) explore this issue in greater depth, demonstrating that the safety and comfort perceived on the infrastructure depend not only on the presence of micromobility devices, but also on their speed and level of motorisation, as well as on the perceptions of those who ride these devices and those with whom they share the space. In this sense, perceived safety reflects not only the geometry of the road, but also the quality of regulation and coexistence among users.

At the same time, the reviewed studies make it clear that perceived safety is filtered through psychological and behavioural processes, rather than being solely determined by the physical characteristics of the environment. In this respect, the studies conducted by Meir et al. (Study ID 56) are especially relevant because they moved beyond explicit questionnaires to investigate implicit attitudes towards risky e-scooter situations: they showed, in fact, that some scenarios may cause strong automatic reactions of the users, particularly when are involved non-use of helmets and secondary tasks performed during riding. Moreover, Oh et al. (Study ID 81) offer a similarly revealing shift in perspective: they showed that overtaking manoeuvres were judged as much less safe when participants re-experienced them from the e-scooter rider's perspective than when they had originally performed them as drivers. In other words, the same event can be experienced in radically different ways depending on the position occupied within the traffic interaction, determinig different impacts in reported perceived safety. Qian et al. (Study ID 121) expand on this argument by demonstrating that safety knowledge and perceived risk severity among delivery riders may reduce some of their aberrant behaviours; at the same time, those aspects are insufficient to counterbalance the structural pressures generated by the nature of that work and delivery times. Younes et al. (Study ID 133) and Zheng et al. (Study ID 153) provide further support for this interpretation: the former demonstrate that shared e-scooter users exhibit fewer visible protective behaviours than cyclists; the latter show that risky behaviours like phone use while riding an e-bike is influenced by self-control, attitudes and nomophobia. This body of work suggests that perceived safety is influenced by different spheres like the cognitive, normative and habitual one so it is more complex than a direct reflection of the street environment.

Moving on, Tzouras et al. (Study ID 164) illustrated perceived safety as a routing variable. They demonstrated that penalising perceived low-safety facilities causes the practical road network to contract for micromobility users, especially for the ones that prefer e-scooters. This force the micromobility users to take detours and reduces functional accessibility of the infrastructures. In this case, perceived safety effectively restructures the usable road network. Bishop et al. (Study ID 166) complement this area of knowledge by demonstrating that distraction control and self-efficacy of the riders influence on-road behaviour in nonlinear ways. Higher self-efficacy does not necessarily correspond to safer conduct of the micromobility users; sometimes higher values of self-efficacy translate into overconfidence. Cubells et al. (Study ID 175) demonstrated through GPS-based analysis and reported perceived safety that route choice and speed vary according to gender and age of the micromobility user and also according to infrastructure conditions. Huang (Study ID 201) added that speed, mental workload, anxiety and user experience all affect how safety is perceived while riding an e-bike.

The final part of the list of studies analysed broadens the discussion further by showing that perceived safety is embedded in a wider sociotechnical system linked to attention, knowledge, measurement tools, regulation and monitoring of the performances. Zhou et al. (Study ID 208) found that safety knowledge reduces negligent e-bike users' behaviour, but is less effective against deliberate violations or aggression, which depend more strongly on attitudes and group norms of the micromobility users. Akgün-Tanbay et al. (Study ID 212) introduced the dimension of perceived chaos alongside safety and comfort in shared spaces. They showed that infrastructure quality and some characteristics of the rider such as age, gender and familiarity with the area all affect how such road environments are experienced. In terms of methodology, Ragot-Court et al. (Study ID 221) proposed a tool for comparing risky behaviours of the users of different types of two-wheeled vehicles, while Wang et al. (Study ID 224) demonstrated that vehicle standards, weak enforcement, company policies and platform incentives act as system-level determinants of e-bike users' perceived safety. The paper from Twisk et al. (Study ID 250) illustrated the heterogeneity of devices by demonstrating that speed pedelecs differ substantially from pedelecs and conventional bicycles in terms of speed and variability of speed, which is an important objective variable that affects the perceived safety of the user. Moreover is a crucial factor to take in account in the design phase of an infrastructure, to allow to the users to feel comfortable and safe while travelling on it. Meanwhile, Wang et al. (Study ID 298), Hertach et al. (Study ID 304) complete this picture: this study draw attention to single-vehicle crashes linked to slippery surfaces, tracks and loss of balance. These are factors that undoubtedly have a negative impact on the confidence and perceived safety of users of micromobility systems.

At this point, so, taking together all these findings it can be said that these studies enable the three research questions of the thesis to be addressed coherently, without being overly reductive or schematic. Regarding the first question, the reviewed literature clearly shows that in general there is still no stable, consistent definition of the aspects that influences perceived safety. Direct measures, such as safety indices, comfort scales and assessments of perceived risk, coexist with more indirect approaches based on factors such as route choice, users' risky behaviour, workload and near-miss incidents. Although this diversity does not necessarily represent a weakness, as it reflects the breadth of the field of study analysed in this thesis, it does imply that the dataset remains conceptually fragmented. As regards the second question, the most common factors contributing to a lower sense of safety among users of micromobility systems are primarily linked to infrastructure and user interactions in traffic. Discontinuous cycle and pedestrian networks, a lack of dedicated facilities, poor road surface quality, conflict-prone junctions and ambiguous mixed-use environments are recurring themes in all studies. However, the review also shows that these determining factors are never experienced uniformly, as they are filtered through user-related variables such as gender, age, experience and anxiety. Finally, with regard to the third question, the data consistently show that perceived safety affects users' choice of route, speed, exposure to risk, and behavioural adaptation. However, this influence may be affected by habits, overconfidence, or work-related pressures that cause users to underestimate risks. Overall, the literature reviewed in this thesis suggests that perceived safety is a relevant and reliable dimension that can assist designers in planning infrastructure interventions and legal experts in amending legislation. Perceived safety is an important indicator because it helps to explain how safe users judge a system to be. In this sense, perceived safety is more than just an attitudinal addition to more conventional, objective safety indicators. It is a key dimension through which design and regulatory choices can be made to ensure better conditions for micromobility system users and all other road users.

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Appendices

Appendix A: Full search strings (Scopus and Web of Science)

SCOPUS

(TITLE (e-scooter* OR "electric scooter*" OR electric-scooter* OR e-bike* OR "electric bike*" OR electric-bike* OR e-bicycle* OR "electric bicycle*" OR micromobility OR micro-mobility OR "soft mobility" OR soft-mobility OR "powered two-wheeler*" OR powered-two-wheeler* OR e-mobility OR electric-mobility OR "electric mobility" OR "electric mobility device*" OR monowheel* OR mono-wheel* OR segway* OR overboard* OR over-board*) AND TITLE (safety OR crash* OR collision* OR behaviour* OR behavior* OR conflict* OR near-miss* OR "near miss*") AND TITLE (infrastructur* OR road* OR lane* OR intersection* OR urban OR "bike box*" OR bike-box*)) OR (KEY (e-scooter* OR "electric scooter*" OR electric-scooter* OR e-bike* OR "electric bike*" OR electric-bike* OR e-bicycle* OR "electric bicycle*" OR micromobility OR micro-mobility OR "soft mobility" OR soft-mobility OR "powered two-wheeler*" OR powered-two-wheeler* OR e-mobility OR electric-mobility OR "electric mobility" OR "electric mobility device*" OR monowheel* OR mono-wheel* OR segway* OR overboard* OR over-board*) AND KEY (safety OR crash* OR collision* OR behaviour* OR behavior* OR conflict* OR near-miss* OR "near miss*") AND KEY (infrastructur* OR road* OR lane* OR intersection* OR urban OR "bike box*" OR bike-box*)) AND PUBYEAR > 2005 AND PUBYEAR < 2026 AND PUBSTAGE(final) AND DOCTYPE(ar) AND (LIMIT-TO (SUBJAREA,"ENGI") OR LIMIT-TO (SUBJAREA,"SOCI") OR LIMIT-TO (SUBJAREA,"PSYC") OR LIMIT-TO (SUBJAREA,"MULT")) AND (LIMIT-TO (LANGUAGE,"English"))

Web of Science

(TI=(e-scooter* OR "electric scooter*" OR electric-scooter* OR e-bike* OR "electric bike*" OR electric-bike* OR e-bicycle* OR "electric bicycle*" OR micromobility OR micro-mobility OR "soft mobility" OR soft-mobility OR "powered two-wheeler*" OR powered-two-wheeler* OR e-mobility OR electric-mobility OR "electric mobility" OR "electric mobility device*" OR monowheel* OR mono-wheel* OR segway* OR overboard* OR over-board*) AND TI=(safety OR crash* OR collision* OR behaviour* OR behavior* OR conflict* OR near-miss* OR "near miss*") AND TI=(infrastructur* OR road* OR lane* OR intersection* OR urban OR "bike box*" OR bike-box*)) OR (AK=(e-scooter* OR "electric scooter*" OR electric-scooter* OR e-bike* OR "electric bike*" OR electric-bike* OR e-bicycle* OR "electric bicycle*" OR micromobility OR micro-mobility OR "soft mobility" OR soft-mobility OR "powered two-wheeler*" OR powered-two-wheeler* OR e-mobility OR electric-mobility OR "electric mobility" OR "electric mobility device*" OR monowheel* OR mono-wheel* OR segway* OR overboard* OR over-board*) AND AK=(safety OR crash* OR collision* OR behaviour* OR behavior* OR conflict* OR near-miss* OR "near miss*") AND AK=(infrastructur* OR road* OR lane* OR intersection* OR urban OR "bike box*" OR bike-box*)) AND LA=(English) AND PY=(2005-2025) AND (SU=(Behavioral Sciences) OR SU=(Psychology) OR SU=(Social Sciences Other Topics) OR SU=(Engineering) OR SU=(Transportation)) AND DT=("Article")

Appendix B: PRISMA-ScR checklist

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	
Limitations	20	Discuss the limitations of the scoping review process.	
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.
* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.
† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).
‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.
§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

Appendix C: R code / scripts

```
### DUPLICATE REMOVING PROCESS ###

# Install packages
install.packages("RefManageR")
install.packages("bibliometrix")
install.packages("dplyr")
install.packages("synthesisr")
library(RefManageR)
library(bibliometrix)
library(dplyr)
library(synthesisr)
library(tools)
library(stringr)


# Load the database

file_path_scopus <- "file path_database_Scopus_reviewer_1"
file_path_WoS <- "file path_database_WoS_reviewer_1"

# Read the database
database_scopus <- read_refs(
  filename = file_path_scopus,
  return_df = TRUE)
database_WoS <- read_refs(
  filename = file_path_WoS,
  return_df = TRUE)

# Show the attribute names of the databases to understand how to merge them
colnames(database_scopus)
colnames(database_WoS)


# Find common columns between the two databases
common_columns <- intersect(names(database_scopus), names(database_WoS))


# Select common columns and merge the two databases
database_scopus_common <- database_scopus[, common_columns, drop = FALSE]
database_WoS_common <- database_WoS[, common_columns, drop = FALSE]
database_final <- bind_rows(database_scopus_common, database_WoS_common)
database_final <- database_final %>%
  mutate(title_original = title)

# Normalize the 'title' column
database_final <- database_final %>%
  mutate(title = str_replace_all(title, "[-]", " "),
         title = str_replace_all(title, "[^[:alnum:] ]", ""),
         title = str_squish(title),
         title = str_to_lower(title))

titles <- database_final$title

# Find duplicates using title column
duplicate_check <- find_duplicates(titles)

# Extract unique rows based on found duplicates
database_unique <- extract_unique_references(database_final, matches =
duplicate_check)

database_unique <- database_unique %>%
  mutate(title = title_original)
```

```
# Reset the 'title' column to its original values
database_unique <- database_unique %>%
  select(-title_original)

### SCREENING PROCESS ###


install.packages("BiocManager");
BiocManager::install("EBImage")

library(BiocManager)
library(EBImage)
library(metagear)

#
install.packages("metagear_0.7.tar.gz", repos = "https://cran.r-project.org", type
= "source", dependencies = TRUE)


# Initialize the reference database
theRefs <- effort_initialize(database_unique)

# Add STUDY_ID, REVIEWERS and INCLUDE columnsand reader the columns
theRefs_base <- theRefs %>%
  mutate(STUDY_ID = row_number(), INCLUDE = "not vetted")


# Create file for Reviewer
theRefs_Reviewer_1 <- theRefs_base %>%
  mutate(REVIEWERS = "Reviewer 1") %>%
  select(STUDY_ID, REVIEWERS, INCLUDE, everything())
write.csv(theRefs_Reviewer_1, "effort_Reviewer_1.csv", row.names = FALSE)

# Verify that the files have been created

print(list.files(pattern = "effort"))

# literature screening
abstract_screener("effort_Reviewer_1.csv", aReviewer = "Reviewer_1",
abstractColumnName = "abstract", titleColumnName = "title" )
```

Appendix D: Included Articles table

Study ID	Author (year)	Title
STUDYID_8 [41]	Tzouras et al. (2025)	Exploring the effect of perceived safety in first/last mile mode choices
STUDYID_11[42]	Adorean et al. (2025)	Perceptions of safety and security among e-bike and e-scooter users in Iberian capital cities: Implications for urban mobility planning
STUDYID_25 [43]	Delavary et al. (2025)	E-scooter riders: A cross-cultural analysis of traffic safety attitudes and behaviors
STUDYID_30 [44]	Anke et al. (2025)	How e-scooter riders navigate road safety hazards – Understanding the perceptions and strategies of regular riders
STUDYID_31 [45]	Qu et al. (2025)	Urban Built Environment Perceptions and Female Cycling Behavior: A Gender-Comparative Study of E-bike and Bicycle Riders in Nanjing, China
STUDYID_41 [46]	Jia et al. (2025)	Understanding Electric Bike Accidents Through Safe System Approach in Guangzhou, China: A Mixed-Methods Study
STUDYID_43 [47]	Faus et al. (2025)	More Sustainable but More Dangerous Cities: The Role of Communication Campaigns in Protecting Vulnerable Road Users
STUDYID_48 [48]	Kazemzadeh (2025)	Assessing e-scooter rider safety perceptions in shared spaces: Evidence from a video experiment in Sweden
STUDYID_51 [49]	Shahin and Elias (2025)	Risk Perception and Barriers to Electric Scooter Prevalence
STUDYID_53 [50]	Hassanpour and Bigazzi (2025)	Perceptions toward pedestrians and micromobility devices in off-street cycling facilities and multi-use paths in metropolitan Vancouver, Canada
STUDYID_56 [51]	Meir et al. (2025)	Ready, set, scoot! Investigating implicit attitudes toward risky e-scooter riding situations: A go/no-go association task study
STUDYID_81 [52]	Oh et al. (2024)	Enhancing mutual understanding of e-scooter user's perspective in overtaking maneuver through replaying own driving trajectory
STUDYID_121 [53]	Qian et al. (2024)	Analysis of factors influencing aberrant riding behavior of food delivery riders: A perspective on safety attitude and risk perception
STUDYID_133 [54]	Younes et al. (2023)	Gender split and safety behavior of cyclists and e-scooter users in Asbury Park, NJ
STUDYID_153 [55]	Zheng et al. (2023)	Nomophobia, attitude and mobile phone use while riding an E-bike: Testing a dual-process model of self-control
STUDYID_164 [56]	Tzouras et al. (2023)	Describing Micro-Mobility First/Last-Mile Routing Behavior in Urban Road Networks through a Novel Modeling Approach
STUDYID_166 [57]	Bishop et al. (2023)	Psychological and experiential contributors to experienced cyclists' on-road cycling behaviour: A path analysis study

STUDYID_175 [58]	Cubells et al. (2023)	Gendered travel behaviour in micromobility? Travel speed and route choice through the lens of intersecting identities
STUDYID_183 [59]	Chouhan et al. (2022)	Evaluating the correlation between risky riding behaviour and self-reported crashes in India: Minimizing unobserved heterogeneity
STUDYID_201 [60]	Huang (2022)	Exploring the factors influencing e-bike road safety: A survey study based on the experiences of Taiwanese cyclists
STUDYID_207 [61]	Tollazzi et al. (2022)	A Preliminary Assessment of Rider/Driver Gaze Behaviour in Slovenian Urban Areas
STUDYID_208 [62]	Zhou et al. (2022)	Analysis of Risky Driving Behavior of Urban Electric Bicycle Drivers for Improving Safety
STUDYID_212 [63]	Akgün-Tanbay et al. (2022)	Modelling Road User Perceptions towards Safety, Comfort, and Chaos at Shared Space: The via Maqueda Case Study, Italy
STUDYID_221 [64]	Ragot-Court et al. (2021)	Assessing self-reported risky behavior among two-wheeled vehicle users: an exploratory analysis comparing e-bikers to other riders
STUDYID_224 [65]	Wang et al. (2021)	Sociotechnical view of electric bike issues in China: Structured review and analysis of electric bike collisions using Rasmussen's risk management framework
STUDYID_250 [66]	Twisk et al. (2021)	Speed characteristics of speed pedelecs, pedelecs and conventional bicycles in naturalistic urban and rural traffic conditions
STUDYID_298 [67]	Wang et al. (2019)	Awareness, riding behaviors, and legislative attitudes toward electric bikes among two types of road users: An investigation in Tianjin, a municipality in China
STUDYID_304 [68]	Hertach et al. (2018)	Characteristics of single-vehicle crashes with e-bikes in Switzerland
STUDYID_347 [69]	Sgarra et al. (2014)	An application of ITS devices for powered two-wheelers safety analysis: the Rome case study

Appendix E: Methods tables and main characteristics of the studies

Study ID	Publication year	Study design / approach	Data source & setting	Sample (N) & population	Exposure / intervention (what is being studied)	Outcomes / measures (how measured)	Analytical method (stats / qualitative / modeling)	Key covariates / controls	Notes on method (bias, limitations, timeframe)
STUDYID_8	2025	Tzouras et al. — Quantitative; image-based double stated preference experiment (third-person ratings + choice task).	Online survey with road-environment images; Athens, Greece (NTUA community).	N=129 participants; response rate ~83%. 51.9% men (67), 48.1% women (62). 71% aged 18–30; mainly potential micromobility users (students). 64% NTUA students or graduates; avg monthly net income ~€1,250. High motorization: 96.9% households own a car; 43.1% report daily car use.	Perceived traffic safety across urban road-environment scenarios (cross-section/infrastructure types, objects/traffic conditions). Effect of perceived safety (plus time & cost) on first/last mile mode choice (car, e-bike, e-scooter, walk).	Perceived safety rating: 7-point Likert (1 very unsafe – 7 very safe) per mode and image. Mode choice for a first/last mile trip (to nearest metro) under stated travel time & cost. Derived indicators of willingness to detour / Value of Safety (VoS).	Ordered logit (ordinal logistic regression) for perceived safety ratings. Mixed logit for mode choice (panelized data; random parameters to capture heterogeneity). Experimental design: block randomization; orthogonal design linkage between safety and choice tasks.	Gender, age, education level, monthly income. Road-environment attributes; travel time and travel cost.	Convenience sample (university-oriented; mostly young) may limit generalizability. Third-person image ratings (not field/VR) capture perceived safety rather than operational behavior.

Study ID	Publication year	Study design / approach	Data source & setting	Sample (N) & population	Exposure / intervention (what is being studied)	Outcomes / measures (how measured)	Analytical method (stats / qualitative / modeling)	Key covariates / controls	Notes on method (bias, limitations, timeframe)
STUDYID_11	2025	Emanuel-Cristian et al. — Mixed-methods: survey-based quantitative analysis + spatial (crash/hotspot) analysis + qualitative discourse analysis.	ArcGIS Survey123 online survey + municipal/national crash data; Lisbon (PT) and Madrid (ES); spatial analyses on 500m × 500m grid.	N=873 valid responses (Mar 2022–May 2023). Lisbon: 475 (e-bike 320; e-scooter 155). Madrid: 398 (e-bike 233; e-scooter 165). Shared users 62.5% of total; renters: Lisbon 52% (e-bike) & 48% (e-scooter); Madrid 67% (both). Gender (city totals): Lisbon 70.1% men, 28.6% women; Madrid 59.5% men, 36.7% women. Age (city totals): Lisbon 18–24 10.9%, 25–34 28.4%, 35–44 27.6%, 45–54 22.7%, 55–64 8.2%, 65+ 1.9%; Madrid 18–24 20.6%, 25–34 25.9%, 35–44 25.9%, 45–54 20.1%, 55–64 6.8%, 65+ 0.8%. Education (city totals): University degree or higher 81.7% (Lisbon) and 71.4% (Madrid). Professional situation (city totals): Employed 83.2% (Lisbon) and 74.1% (Madrid); Students 11.8% (Lisbon) and 22.9% (Madrid).	Perceived safety (traffic risk) and perceived security (harassment/intimidation) among e-bike/e-scooter users (private vs shared). Spatial-contextual risk: infrastructure distribution, slope/altitude, crash hotspots; mismatch between objective vs perceived risk.	Survey measures: safety/security perceptions, experiences, mobility practices (e.g., helmet use, parking and circulation preferences). Spatial measures: crash counts and hotspot zones; slope/altitude; cycling infrastructure density; "unsafe areas" mapped by respondents. Qualitative outcomes: narratives on harassment/underreporting and perceived vulnerability.	Descriptive statistics; Chi-square tests across groups (city, mode, ownership, gender, etc.). Spearman correlations linking perceived safety with spatial variables. Spatial Risk Index (SRI): 500m grid, normalized layers, multiplicative combination; hotspot mapping. Thematic discourse analysis of open-text responses (Braun & Clarke) for users reporting harassment (n=290; 184 provided narratives).	City, vehicle type (e-bike vs e-scooter), ownership model (own vs shared). Gender, age, residence time, education, professional situation. Use frequency, helmet use, parking and circulation preferences.	Non-probability convenience sample; inferential stats used as exploratory (no population generalization). Integration of self-reported perceptions with crash statistics and spatial modeling.

Study ID	Publication year	Study design / approach	Data source & setting	Sample (N) & population	Exposure / intervention (what is being studied)	Outcomes / measures (how measured)	Analytical method (stats / qualitative / modeling)	Key covariates / controls	Notes on method (bias, limitations, timeframe)
STUDYID_25	2025	Delavary et al. — Cross-sectional, cross-cultural analysis of secondary survey data (ESRA3).	ESRA3 standardized online panel surveys (2023) in 39 countries; questionnaire translated into 49 languages; weighted for national representativeness by gender and age.	Total sample: N=37,093 respondents (adult population) from 39 countries. Gender: 48.6% men, 51.2% women, 0.2% another gender. Age distribution: 35–44 (20.3%), 25–34 (20.0%), 55–64 (16.9%), 18–24 (11.9%), 65–74 (11.9%). Residential context: 81.6% urban/semi-urban; 18.4% rural. E-scooter users (use ≥ few days/year): America n=2,533; Europe n=4,589; Asia/Oceania n=1,342 (total n=8,464).	Self-reported unsafe e-scooter behaviors (e.g., impaired riding, sidewalk riding, red-light running, multi-passenger, helmet non-use). Predictors: demographics (gender/age), student status, crash history, attitudes toward traffic laws; regional/cultural differences.	Risky behaviors in past 30 days: 5-point Likert (never to almost always), then dichotomized (never vs at least once). E-scooter usage frequency (past 12 months) and crash involvement (injury crash in past 12 months).	Descriptive statistics by region, gender, and age; Chi-square tests and Cramer's V. Mixed-effects logistic regression (GLMM) with fixed + random effects (country-level random intercepts); ORs reported. Model selection via corrected AIC; random effects assessed via likelihood tests and Bayes Factor. Software: SPSS, R, Stata (models in R using lme4).	Gender, age group, student status, crash history, attitudes toward safety regulations / traffic laws. Region and country (random effect).	Self-reported behaviors (potential social desirability/recall bias). Dichotomization improves interpretability for logistic models but reduces response granularity.

Study ID	Publication year	Study design / approach	Data source & setting	Sample (N) & population	Exposure / intervention (what is being studied)	Outcomes / measures (how measured)	Analytical method (stats / qualitative / modeling)	Key covariates / controls	Notes on method (bias, limitations, timeframe)
STUDYID_30	2025	Anke et al. — Sequential explanatory mixed-methods: online survey + semi-structured online focus groups; survey results reported first, complemented by focus-group insights.	Germany; online survey (Sosci Survey) open 03–30 Sep 2021; recruitment via e-scooter online communities (social media/message boards). Online focus groups via Zoom (Nov 2021).	Survey: N=99 regular e-scooter riders (after cleaning from 154). 91% male; age 16–65 (M=37.8, SD=12.1). 97% private e-scooter owners. Focus groups: 6 groups (3–5 per group), total N=20 (17 men, 3 women); age 21–56 (M=36.7, SD=9.5); 17 owners, 3 rental users.	Riders' perceived road-safety hazards and safety-critical events; coping/protective strategies; preferences for infrastructure and road-safety campaigns.	Survey items on: usage patterns; perceived safety/hazards; crash/near-crash experiences; preferred infrastructure; campaign preferences; sociodemographics. Focus groups discussed: (I) safety-critical events/hazards, (II) strategies, (III) campaign ideas.	Quant: descriptive/statistical summaries of survey responses. Qual: deductive qualitative content analysis + inductive thematic analysis; verbatim transcription; coding in MAXQDA 2020 by two trained coders; category system based on topic guide + survey response options.	Not hypothesis-testing; collected socio-demographics (gender, age, education, employment), ownership, usage frequency, trip purpose.	Self-selected online sample; strong skew to private owners and men. Incentives: raffle for survey; €30 compensation for focus groups. Potential recall/social-desirability bias in self-reported events.

Study ID	Publication year	Study design / approach	Data source & setting	Sample (N) & population	Exposure / intervention (what is being studied)	Outcomes / measures (how measured)	Analytical method (stats / qualitative / modeling)	Key covariates / controls	Notes on method (bias, limitations, timeframe)
STUDYID_31	2025	Qu et al. — Cross-sectional intercept questionnaire; gender-comparative analysis of perceived street built environment (PSBE) effects on cycling behavior (e-bike vs bicycle).	Gulou District (Nanjing, China); May–Oct 2023. Spatial–gender stratified random sampling across 12 main roads, 34 secondary roads, and branches; questionnaires distributed at bicycle parking spots + face-to-face after one ride; ethics approval.	N=285 valid (of 300): 138 men, 147 women; 236 e-bike riders, 49 bicycle riders (private users; shared-bike users excluded). Mean age: men 44.69, women 37.66 (with age/SES & caregiving attributes reported in Table 2).	Perceived Street Built Environment (PSBE): facility accessibility, road accessibility, safety perception, comfort perception (Likert-type indicators; reverse scoring for negative items).	Cycling behavior variables: weekly cycling frequency & proportions by purpose (commuting/housework/ leisure), trip duration, purpose, tool (bicycle vs e-bike), and route choice (shortest vs non-shortest). Cycling probability index used as dependent variable in regression (Box-Cox transformed).	Mann–Whitney U-tests + crossover analyses for gender differences. Linear regression: PSBE → cycling probability index (N=285), incl. male/female models. Binary logistic regression: PSBE → non-shortest route choice (sub-sample with clear routes: N=239; e-bike N=202).	Linear regression controls: age, gender, education, family obligations (youngest child <13; avg household working hours), driver's license, avg household bicycles & e-bikes. Logistic controls: travel purpose + road redundancy (network density within 500 m OD range).	Route-choice analyses exclude respondents with unclear route descriptions; small bicycle sub-sample in route model. Cross-sectional/self-report design.

Study ID	Publication year	Study design / approach	Data source & setting	Sample (N) & population	Exposure / intervention (what is being studied)	Outcomes / measures (how measured)	Analytical method (stats / qualitative / modeling)	Key covariates / controls	Notes on method (bias, limitations, timeframe)
STUDYID_41	2025	Jia et al. — Mixed-methods "Safe System" approach. Study 1: quantitative Bayesian network (BN) analysis of crash data. Study 2: qualitative on-road observations + stakeholder interviews to capture behavioral/system interactions missing from crash records.	Guangzhou (China). Study 1: official police-recorded structured dataset of e-bike–motor vehicle collisions (Jan 2017–Oct 2018). Study 2: observations at 1 intersection (OP1) + 1 road section (OP2) on 27 & 29 Jul 2020 (12 h/day); follow-up interviews across 2020–2025.	Quant dataset: N=4424 complete crash records (e-bike vs motor vehicle), 14 variables selected. Qual: observations recorded by 5 observers. Interviews: 18 food delivery riders + 18 residents (drivers, bicyclists, pedestrians, daily-commuter e-bike riders) + 1 expert on-site officer (TP1).	Safe-system components and their interactions leading to e-bike crashes (infrastructure, e-bikes, riding behavior, rider characteristics, other road users; plus time/weather/visibility).	Study 1 outcome: crash severity classified into 3 levels (property damage/slight injury; severe injury; fatal injury) and conditional probabilities of severity across factors. Study 2 outcomes: narratives/themes on violations, infrastructure conflicts, and stakeholder perspectives on causal mechanisms.	Study 1: BN classifier + inference; Pearson correlations used to rank variables before BN structure learning; model performance via accuracy/sensitivity/specificity/F1; implemented in Jupyter Notebook. Study 2: qualitative synthesis of observation notes + interview notes (saturation-guided).	Not traditional covariates; BN nodes include multiple crash-context variables (e.g., infrastructure/lighting, vehicle type, time/visibility/weather).	Crash dataset limited to e-bike–motor vehicle collisions; rider behavior absent in crash records → addressed via Study 2 observations/interviews. Data availability restricted (confidentiality).

Study ID	Publication year	Study design / approach	Data source & setting	Sample (N) & population	Exposure / intervention (what is being studied)	Outcomes / measures (how measured)	Analytical method (stats / qualitative / modeling)	Key covariates / controls	Notes on method (bias, limitations, timeframe)
STUDYID_43	2025	Faus et al. — Quantitative + qualitative content analysis of traffic/road-safety TV campaigns targeting vulnerable road users; exploratory comparison with accident figures (no causal evaluation).	Spain; national campaigns by DGT (Dirección General de Tráfico) broadcast 1960–2024; retrieved Mar–Jun 2024 from DGT website/online video platforms (e.g., YouTube). Accident/victim figures for VRUs for 1993–2023 from official statistics (DGT "en cifras").	Audiovisual campaigns: 119 campaigns identified as available; 28 met inclusion criteria (VRU focus, national scope, DGT issuer, TV format, available to view). Coding performed by 3 independent judges. No human participant sample.	Communication campaigns aimed at VRUs (pedestrians, cyclists, e-scooter users, motorcyclists; also children and elderly): campaign message/slogan, target group, and communication strategy (informative-real/animation; metaphorical; emotional-impact/testimonial).	Prevalence and evolution of VRU-focused campaigns across historical periods; distribution by VRU type and message strategy. Contextual comparison vs. VRU accident/victim percentages (dead or seriously injured).	Manual content analysis by 3 judges; campaigns coded on predefined variables and classified into strategy categories. Descriptive statistics (% by period/type) + qualitative description; graphical representation. Exploratory trend comparison with accident figures.	Campaign period (stages), target VRU group, subject matter (specific vs broader campaign), strategy category.	Selection limited to nationally broadcast DGT campaigns with available TV/audiovisual material (regional/local initiatives excluded). Impact on accident rates cannot be isolated from other concurrent road-safety measures; authors state no direct causal relationship can be affirmed.

Study ID	Publication year	Study design / approach	Data source & setting	Sample (N) & population	Exposure / intervention (what is being studied)	Outcomes / measures (how measured)	Analytical method (stats / qualitative / modeling)	Key covariates / controls	Notes on method (bias, limitations, timeframe)
STUDYID_48	2025	Kazemzadeh — Quantitative online video experiment (stated-perception): participants rate perceived safety as e-scooter riders in shared-space interaction scenarios (passing vs meeting).	Sweden (Gothenburg & Stockholm); online survey (LimeSurvey) distributed via Dynata panel (Jun 2023). Video clips (10 s) show interaction scenarios used in experiment.	Collected N=1,146 responses; reduced to N=920 after quality screening (contradictory responses, fast completion <2.5 min, missing values). Gender: 44% female (binary-coded: female vs otherwise). Age: <18 3%, 18–39 44%, 40–59 29%, 60+ 24%. Other sample shares: university education 56%; employed 74%; income >40,000 SEK/month 27%; live with partner 56%. Crash-involved subset: n=197 (21%) reported an e-scooter crash.	Perceived safety in shared spaces during two interaction types: • Overtaking (passing) scenario • Encounter (meeting) scenario Plus individual history/experience variables (e.g., conflicts, helmet use, prior accidents).	Perceived safety ratings for each scenario (3-level ordinal: safe / neutral / unsafe). Additional measures: conflicts with other road users, helmet use, accident history (bike/e-bike/e-scooter), perceived impact of improperly parked e-scooters, socio-demographics.	Latent-class random-effects ordered logit model estimated via maximum likelihood. Number of classes tested and selected via AIC/BIC (preferred: 2 classes). Stepwise variable selection; multicollinearity checks (exclude r>0.7).	Key covariates coded (Table 1): gender, age group, university education, employment, high income, partner status, conflict experience, helmet use, accident history (bike/e-bike/e-scooter). Some correlated variables excluded during model selection (e.g., income vs employment; accident vs conflict).	Online panel + self-reported measures; binary coding of gender. Quality-filtering reduced sample from 1,146 to 920. Potential wording effects acknowledged; outcomes are perceptions (not observed behavior).

Study ID	Publication year	Study design / approach	Data source & setting	Sample (N) & population	Exposure / intervention (what is being studied)	Outcomes / measures (how measured)	Analytical method (stats / qualitative / modeling)	Key covariates / controls	Notes on method (bias, limitations, timeframe)
STUDYID_51	2025	S. & E. — Cross-sectional online survey with Structural Equation Modeling (SEM): CFA for latent constructs + SEM relationships; complemented by descriptive analysis of risks/barriers and ES travel behavior.	Ashdod (southern Israel); online questionnaire distributed via WhatsApp and other social media using snowball sampling.	N=254 participants; age 13–74 (mean 28.2, SD 12.8). Gender: 160 male (63%), 94 female (37%). Age groups: ≤20 31%; 21–30 42%; 31–40 9%; 41–50 11%; 51–60 4%; 61–70 2%; ≥70 1%. ES users: n=50. Driving license: 64% with; employment: 71% employed. Belief system: secular 33%, traditional 35%, religious 32%.	Determinants of e-scooter (ES) adoption/acceptance and perceived risk, including gender-related attitudes toward female ES riders, subjective norms, support for shared ES services, willingness to share/use shared services, and perceived safety of the local environment.	Multi-part questionnaire: 1) Risk perception statements (5-point Likert: totally disagree–totally agree) 2) Attitudes toward female ES riders (4-point Likert) 3) Support for ES and shared ES services (5-point Likert) 4) ES users' travel behavior (purpose, near-misses, helmet use, where/how often). Also: socio-demographics and perceived local environment safety (1–5).	CFA (factor loading threshold 0.4; Cronbach's alpha threshold 0.7) to validate latent variables; SEM to estimate relationships among latent constructs. Implemented in RStudio; model fit reported (e.g., CFI, TLI, RMSEA, SRMR).	Sociodemographics and perceived safe environment score; latent constructs include: risk perception, positive attitudes, subjective norms, support for shared ES service, willingness to share personal ES, willingness to use shared ES service, female attitudes, female risk, safe ES environment.	Convenience snowball sample from a single city; self-reported measures. Authors note sample size may limit definitive conclusions for some subgroup analyses (e.g., gender-specific perceptions).

Study ID	Publication year	Study design / approach	Data source & setting	Sample (N) & population	Exposure / intervention (what is being studied)	Outcomes / measures (how measured)	Analytical method (stats / qualitative / modeling)	Key covariates / controls	Notes on method (bias, limitations, timeframe)
STUDYID_53	2025	Hassanpour & Bigazzi — Intercept survey of off-street path users + observed context data; mixed-effects linear regression with nested random effects (respondent within sampling location).	Metropolitan Vancouver (Canada); 12 off-street cycling facilities / multi-use paths. On-site QR-code Qualtrics survey (Sep 21–Nov 15, 2020) linked to observed mode shares and speeds at the same locations.	N=1,054 usable survey responses (1,343 raw; 289 incomplete removed). Gender: 50.8% male; 49.2% female/other. Age: <30 15.1%; 30–49 38.2%; 50–69 36.6%; ≥70 10.1%. Mode at intercept: 60.0% walking/running; 33.3% conventional bike; 3.5% e-bike; 3.2% other PMD.	Perceived comfort sharing paths with different wheeled users (conventional bicycles, e-bikes, other PMDs). Perceived vs observed PMD mode shares and speeds; facility type (multi-use vs separated).	Comfort ratings (−10 to +10) for sharing with each PMD type. Perceived mode share (% by PMD type) and perceived speeds (0–50 km/h). Self-reported incidents in past year; comfort taking risks; modal travel frequency (walk/bike/transit/auto).	Mixed-effects linear regression: Comfort_inm = βX + u_i (location) + b_in (respondent) + ε_inm. R (v4.1.1) with lme4; nested random effects respondents-within-location; no sampling weights.	Perceiver: gender (male dummy), age (bin midpoints), university degree (BA+), incident experience, comfort taking risks, modal frequencies and active-density index. Context/vehicle: electric-assist, observed average speeds, facility type (multi-use path indicator).	Convenience intercept sample; representativeness not testable (no population demographics for path users) so no weighting. Self-report + 12-month recall for incidents; Qualtrics cookies used to flag duplicates; parallel-facility respondents removed.

Study ID	Publication year	Study design / approach	Data source & setting	Sample (N) & population	Exposure / intervention (what is being studied)	Outcomes / measures (how measured)	Analytical method (stats / qualitative / modeling)	Key covariates / controls	Notes on method (bias, limitations, timeframe)
STUDYID_56	2025	Meir et al. — Two-stage experiment: picture riskiness ratings to classify safe vs risky stimuli, then within-subject online GNAT to measure implicit risk attitudes and compare with explicit attitudes.	Israel; participants completed tasks remotely on personal computers. Pre-study via Qualtrics picture ratings. Main study used a custom GNAT implemented in C# (Visual Studio), 1000 ms stimulus duration, and 4 blocks (positive/negative × safe/risky).	Pre-study: N=46 (17F, 29M), age 22–56 (mean 28.66). Main study: N=64 (39F, 25M), age 21–29 (mean 25.22). All had e-scooter riding experience.	Implicit and explicit risk attitudes toward e-scooter riding situations varying helmet use, riding location (road/sidewalk/trail), and secondary task/device use; contextual priming with positive vs negative words within GNAT blocks.	Pre-study: riskiness ratings (1–6) used to select 30 stimuli (22 risky, 8 safe). Main study: implicit attitude via GNAT sensitivity (d′) and derived GNAT score; explicit risk-attitude questionnaire (Likert 1–6); response accuracy.	Pre-study: GLMM on picture riskiness ratings (participant random effect) with backward elimination and Holm correction. Main study: GLM for d′ (d′-risky) and GLMM logistic regression for correct responses (random effects: participants and pictures nested within blocks) with backward elimination.	Gender, age, driving and e-scooter experience (frequency/purpose), crash history; task/helmet/location factors; GNAT block (positive/negative × safe/risky), response required, explicit attitude score and interactions.	Convenience samples (main study largely young adults 21–29). Image-based tasks capture attitudes to depicted scenarios rather than observed riding; remote at-home testing may add noise.

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STUDYID_81	2024	Oh et al. — Indoor sequential simulation experiment with perspective change: participants drove a vehicle simulator (overtaking an e-scooter) and then rode an e-scooter simulator (being overtaken), with surveys before/after.	South Korea; lab-based driving simulators with HMD (HTC Vive Pro2) in a Unity environment. Two-lane Road overtaking scenario; vehicle and e-scooter trajectories recorded; driving inputs and kinematics logged.	Recruited N=32 (22M, 10W), mean age 28.21 (SD 5.32); 2 excluded for motion sickness → N=30 analyzed. All had driver's license (≥2 years); all had prior e-scooter experience.	Effect of experiencing both dominant (car driver) and recessive (e-scooter rider) perspectives on overtaking behavior and perceived safety. Focus on overtaking interactions between cars and e-scooters and attitudes toward VRUs.	Behavioral metrics at overtaking: - side-by-side: relative lateral distance, relative speed; - overtaking initiation: speed, acceleration, relative longitudinal distance, steering wheel angle, TTC; plus gas/brake pedal position. Surveys: KDBQ (caution/yield), attitudes toward VRUs (dominance/legitimacy), interaction behavior; perceived safety/threat from both perspectives.	Pearson correlation between survey factors and overtaking behavior. Survey factor analysis: PCA with varimax rotation (factor loadings <0.5 excluded). Mann-Whitney U tests to compare safety perception groups (felt threatened vs felt safe).	Driving status (before vs after riding an e-scooter); survey-derived factors (yield/caution, VRU dominance/legitimacy, interaction behavior). Participant identity variables (e.g., driving experience) examined in correlations.	Simulator-based behavior may differ from real-world overtaking; small sample and motion-sickness exclusions. Participants were licensed drivers with prior e-scooter experience, limiting generalizability.

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STUDYID_121	2024	Qian et al. — Cross-sectional questionnaire survey; factor analysis + SEM to model links between safety knowledge, safety attitudes, risk perception, and aberrant riding behaviors among food delivery riders.	China (Pu'er City, Yunnan Province; urban area + 5 surrounding counties). Online anonymous survey via hyperlink distributed at rider break/gathering spots; May 1–7, 2022; incentive 2 RMB; screening items used to remove invalid responses.	N=435 valid (from 576 collected; 75.5% usable). Food delivery riders. Gender: 412M (94.71%), 23F (5.29%). Age: 18–30 (70.11%), 31–40 (25.06%), 41–55 (4.83%). Education: junior middle/below 36.32%; high school 46.90%; college+ 16.78%. Full-time 90.8%.	Psychological predictors: perceived safety knowledge (SK), safety attitudes (toward responsibility and laws), and risk perception (severity & probability) in relation to aberrant riding behaviors (self-reported).	Measures: Personal/occupational attributes + crash/penalty experience; SK (3 items, 5-point informedness); Safety attitude & risk perception scale (14 items; 4 dimensions: SA-r, SA-l, RP-s, RP-p; 5-point agree); Aberrant riding behavior scale (18 items initially; 5-point frequency; EFA retained 14 items → 3 factors: general violations; distraction & mistakes; aggressive riding).	EFA + CFA (split sample to reduce overfitting) and SEM (AMOS) with separate models for each behavior factor; plus t-tests/ANOVA (SPSS) to examine associations with personal/occupational attributes.	Supplementary analyses consider demographics/occupation variables (e.g., age, years in occupation, work intensity) and crash/penalty experience; SEM focuses on latent constructs (SK, SA, RP → behavior factors).	Limitations: self-report and perceived (not objective) safety knowledge; cross-sectional; single small-to-medium city; some latent factors had only two items; limited set of predictors due to questionnaire length.

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STUDYID_133	2023	Younes et al. — Observational traffic camera study; pre/post temporary bike-lane demonstration project; behavior coding from video and regression modeling of helmet use and lane choice.	Asbury Park, New Jersey (USA). AXIS P1427-LE traffic camera footage manually coded 4–6 h/day for 7 days (35 h total): 3 days pre-installation (15 h) + 4 days post-installation (20 h). Historical weather data (NOAA) used to note wet/rain conditions.	N=707 observed micromobility vehicles (riders): 507 bicycles (71.7%) and 200 shared e-scooters (28.3%). Gender (observed): cyclists 392M/108F (21.3% women); e-scooters 97M/103F (~even split). Group riding: 36.1% cyclists vs 80.5% e-scooters rode in groups.	Mode and context effects (bicycle vs shared e-scooter) and protective conditions (helmet use; presence of temporary bike lane) on safety-related behaviors (lane use, sidewalk use, group riding).	Outcomes coded from video: helmet use (yes/no), lane use (bike lane vs road vs sidewalk; before/after), riding alone vs group, observed gender, time of day (AM/PM), weekday/weekend, direction/turn; counts summarized in tables.	Descriptive statistics; multinomial logistic regression for lane usage (bike lane reference vs road/sidewalk) during post-installation period; binomial logit regression for helmet use among cyclists; VIF checked for multicollinearity; report coefficients + odds ratios.	Controls in regressions include mode (cyclist vs e-scooter), helmet use, group riding, gender, time of day, weekday/weekend, and direction/turn (important for lane-use model).	Limitations: single site/small shore community and off-peak period; observational coding (no rider age/experience, no frequency-of-use per person); potential misclassification—ambiguous cases excluded; results not necessarily generalizable.

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STUDYID_153	2023	Zheng et al. — Two-step design: preliminary online interviews to identify mobile phone use (MPU) behaviors while riding; then cross-sectional online questionnaire testing dual-process model links between nomophobia, attitude, self-control and MPU while riding an e-bike.	China-wide online recruitment. Formal survey hosted on Sojump; participants recruited via social networks and Baidu survey forum; consent, anonymity; ~10 min to complete; incentive 10 RMB; screening question + response-quality checks; inclusion: age >16, e-bike use ≥1/month in past 3 months, literate.	Preliminary interviews: N=24 e-bikers (online interview) to elicit MPU behavior types. Formal survey: N=563 (362M, 201F) from 28 provinces/municipalities. Age: 92.01% aged 16–50; 7.99% >50. Education: master/postgrad 52.93%; high school 30.02%; middle/primary 17.05%. Usage: 50.09% ride ≥4 times/week; 81% utilitarian; 64.13% avg trip distance <5 km.	Psychological factors (nomophobia dimensions, attitude toward MPU, self-control) predicting frequency of MPU behaviors while riding an e-bike; self-control tested as moderator of key effects.	Measures: Nomophobia via Chinese NMP-Q (4 factors); attitude measured with 3-item semantic differential (safe/dangerous, wise/unwise, good/bad; 5-point); self-control via 7-item scale; MPU frequency = mean of 7 behaviors (calls, texting, videos, music, browsing, navigation, games) over last 3 months (5-point never→always); plus demographics and e-bike usage patterns.	PCA/EFA for attitude + MPU items; reliability analyses (Cronbach's alpha); t-tests/ANOVA by demographics/usage; Pearson correlations; hierarchical multiple linear regression predicting MPU frequency; moderation analysis with interaction terms in PROCESS (bootstrapping 5000).	Regression controls included gender; predictors entered hierarchically: relevant nomophobia factors, attitude, self-control; moderation tested for (not being able to access information × self-control) and (attitude × self-control).	Limitations: self-reported MPU and online convenience sample; cross-sectional (no causal inference); potential selection bias and common-method variance; limited behavioral validation beyond self-report.

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STUDYID_164	2023	Tzouras et al. — Methodological modeling paper introducing a "Perceived Safety Choices" framework and a constrained safest-path routing model for micro-mobility first/last mile trips (e-scooter vs walking vs car). Includes scenario testing (current network vs redesigned network).	Athens city-centre road network (Greece) represented as a link-node graph (257 nodes, 400 links). Link attributes compiled from spatial data (cycle lanes, sidewalk width, speed limit, pavement condition, obstacles, pedestrian crossings) plus field photographs; organized in a GIS shapefile. Two scenarios: baseline (Scenario 0) and intervention-like redesign (Scenario 1: traffic calming/shared space + added cycle lanes).	Perceived-safety model calibration parameters taken from a prior Athens image-based double stated-preference rating experiment: 129 respondents; each rated 12 hypothetical road-environment scenarios for car driving, walking, and e-scooter riding (total 4,644 safety ratings). (No additional respondent demographics reported in this paper.)	Micro-mobility routing behaviour / choice of safer first–last-mile routes by trading off time/cost vs perceived safety; comparison across modes (walk, e-scooter, car) and across network-design scenarios.	Outcome 1: Perceived safety level (7-point Likert, ordinal) for each mode, estimated per road link from infrastructure/crossing/pavement/obstacle attributes. Outcome 2: Route selection (safest constrained path) and resulting travel distance/time/cost and safety profiles under different scenarios.	Ordered logit perceived-safety model (separate equations by mode) + shortest-path (Dijkstra) routing using a utility/cost function combining travel time, monetary cost, and a distance-referenced perceived-safety term (dmax parameter). Scenario comparison of resulting routes.	Perceived-safety covariates include: infrastructure typology (sidewalk width categories; cycle lane; shared space), pedestrian crossings (signalised vs unsignalised), pavement condition, sidewalk obstacles; plus distance terms within the routing utility.	Key assumptions/limits: constant link speeds; no congestion delays; safety parameters imported from a specific Athens stated-preference study (context/sample-specific); routing demand not modelled (all-or-nothing routing between selected zones).

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STUDYID_166	2023	Bishop et al. — Cross-sectional online survey of experienced cyclists; tested a theoretically specified model linking attentional control (distraction control), cycling experience and cycling self-efficacy with on-road cycling behaviours and negative cycling experiences using path analysis.	United Kingdom; participants recruited via UK cycling-club mailing lists and online fora. Online questionnaire (self-report) administered via a web survey platform.	N=191 experienced cyclists (155 men; 36 women). Age 18–80 (mean 57.03, SD 13.97). Ethnicity: 98% White UK (others: Asian British n=1; Black British n=2; Hispanic n=1). 70% cycling-club members. Formal cycle training: 53.4% (beginner 37.7%; intermediate 4.71%; advanced 11.0%). Analysis conducted on 185 cases after excluding 6 missing.	Psychological/exposure variables: attentional style (internal/external distraction control), cycling self-efficacy, cycling experience (weekly cycling volume; years of urban cycling) as predictors of cycling behaviour patterns and negative experiences.	Self-reported outcomes via validated/adapted scales: - Cycling Behaviour Questionnaire (CBQ) subscales: Errors, Violations, Positive Behaviours. - Negative experiences while cycling (frequency-based items). Key predictors measured via: - Adapted Attentional Style Questionnaire (ASQ) -> Internal vs External Distraction Control factors. - Bespoke cycling self-efficacy measure.	Item-level psychometrics and scale construction: MIRT for ASQ item fit (yielding a 12-item 2-factor version) and PCA using polychoric correlations. Main analysis: path model fitted in R (lavaan SEM function), allowing exogenous predictors to covary; model fit reported (e.g., CFI, RMSEA, SRMR).	Model included (as predictors): Internal Distraction Control, External Distraction Control, cycling self-efficacy, weekly cycling volume (ongoing experience), years of urban cycling (historical experience).	Limitations/notes: self-report measures and cross-sectional design (no causal inference); sample heavily male and predominantly White UK; older mean age; small amount of missing data handled via casewise exclusion (final n=185).

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STUDYID_175	2023	Cubells et al. — Observational GPS-tracking study + intercept survey; analysed speed and route choice of bike-share cyclists vs private e-scooter riders through an intersectionality lens (gender × age × parenthood) using multilevel mixed-effects modelling.	Barcelona (Spain). NEWMOB project: street intercept survey (CAPI) of 902 micromobility users; subset asked to wear GPS logger (QStarz BT-Q1000XT) for 1 week. GPS logging every 15 s; trips identified with HABITUS software; travel diary used to distinguish bicycle vs e-scooter trips; GPS tracks map-matched to street network to link infrastructure context.	GPS panel initially: 70 bike-share cyclists + 65 e-scooter riders invited; after wear-time criterion (>=8 h on >=1 day), 93 valid users. Final analytic dataset: 911 GPS-tracked micromobility trips across 283 days by 89 participants (55 cyclists; 34 e-scooter riders). Participant profile: 56% men; 62% <35 years; 58% university graduates; 79% employed; 76% childless.	Exposure/context: cycling-facility typology along routes (bicycle lanes, bicycle sharrows, pedestrianised streets, unprotected streets) and other street/temporal attributes; intersectionality variables (gender, age, parenthood) interacting with mode (bike-share vs e-scooter).	Outcomes: - Trip characteristics (duration, distance, daily frequency, time-of-day). - Route choice / infrastructure use (% of trip in each facility type, derived via map-matching). - Riding speed (km/h) derived from GPS points and mapped street segments (speed model outcome).	Descriptive and bivariate comparisons + multilevel linear mixed-effects model for speed (participant-level clustering), including built-environment variables and interaction terms to test intersecting identities (e.g., mode×gender×parenthood).	Key covariates in modelling included: facility type, intersections, traffic lights; plus slope and time-of-day variables; sociodemographics (gender, age, parenthood) and mode (bike-share vs e-scooter).	Notes/limits: sample not fully representative (over-represents young adults/men); private e-scooters only (no shared e-scooters allowed in Barcelona at the time); diary-based mode labelling may introduce reporting error; filtering rules removed implausible trips/speeds.

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STUDYID_183	2022	Chouhan et al. — Quantitative; cross-sectional self-report survey. MRBQ-based assessment of risky riding behaviours linked to self-reported crash frequency.	Online questionnaire (snowball via social media + email). India; survey window: 1 Dec 2020 – 29 Feb 2021.	N=392 PTW riders (≥18 years); 426 responses collected, 34 incomplete removed. Gender: 91.84% male; 8.16% female. Age: 18–30 (69.13%); 31–40 (18.88%); 41–50 (11.99%). Marital status: 79.08% married; 20.92% unmarried. Education: High school 41.20%; Bachelor 51.53%; Postgrad/PhD 7.27%. Holding license: 83.16% yes. Own PTW: 85.20% yes. Crash (last 2y): none 69.13%; 1 crash 18.88%; ≥2 crashes 11.99%. Near-crash (last 2y): none 46.17%; 1–2 30.10%; 3–5 14.03%; 6–10 6.12%; ≥10 3.58%.	Aberrant riding behaviours measured using modified MRBQ (36 items; 6-point frequency scale). Latent behaviour factors derived via EFA: traffic errors; control errors; speed violations; stunt performance.	Primary outcome: self-reported crash frequency (count over past 2 years). Secondary: near-crash involvement (past 2 years) + riding exposure variables (km/day, years riding, license years, etc.).	Descriptive statistics + Spearman correlations. EFA (Principal Axis Factoring; direct oblimin; KMO/Bartlett; Cronbach's alpha) to extract MRBQ factors. Crash-frequency modelling: Random-parameter Negative Binomial (RPNB) to account for unobserved heterogeneity; compared with fixed-parameter NB (log-likelihood, AIC).	Gender; marital status; years riding; riding exposure (km/day); MRBQ factor scores (traffic/control errors, speed violations, stunts).	Non-probability snowball sample; online self-report (social desirability + recall bias). Cross-sectional design (associations, not causal). Two-year crash/near-crash recall window.

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STUDYID_201	2022	Huang — Quantitative; cross-sectional survey. Tests relationships between perceived task difficulty (mental workload), feeling of risk, UX, speed, and self-reported e-bike crashes.	Paper-and-pencil survey administered at 16 e-bike repair stations. Taiwan; ethics approval: NTHU IRB 11002EC017.	273 completed surveys; 220 valid questionnaires used (80.5% fully complete). Gender: 99 female (45%); 121 male (55%). Age: <20 (4.1%); 20–29 (19.5%); 30–39 (15.0%); 40–49 (20.0%); 50–59 (21.4%); 60–69 (16.4%); >70 (3.6%). Occupation (selected): culinary/personal services 32.7%; retired/homemaker 20.5%; engineering 17.3%; other categories reported in Table 1.	Perceived mental workload: DALI (6 subscales) + RSME. Subjective risk: anxiety + arousal (10-point scales). User experience (UX): attractiveness + pragmatic/hedonic qualities. Riding characteristics: e-bike style, riding experience, frequency, daily distance, speed.	Traffic crash experience (self-report): number of crashes, locations, cause, and injuries. Additional outcomes: behavioural intention/satisfaction; associations between workload/risk/UX and crash involvement.	SPSS v22; chi-square, t-test, Mann–Whitney U, ANOVA, correlation analysis. Ordinal logistic regression (predictors of crash involvement) + multiple regression (predictors of riding speed).	Gender; riding speed level; e-bike style; riding experience and exposure variables; possession of Taiwanese scooter driver's license; age/occupation.	Convenience sample from repair stations (selection bias). Self-reported crashes and perceptions. Cross-sectional.

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STUDYID_207	2022	Šraml et al. — Quantitative; real-world experimental eye-tracking study. Compares gaze behaviour of motorcycle riders vs car drivers across different urban road environments.	Field experiment in Maribor, Slovenia. Defined 11.7 km route with 4 areas (speed limits 70/40/100/30 km/h; different intersection/road layouts).	N=10 volunteers: 5 car drivers + 5 motorcycle riders. Gender: 6 male; 4 female; participants in their 50s. Inclusion: ≥15 years driving experience; class B and A licences; own vehicle. Exclusion/controls: no glasses/eye correction (etc.); limited helmet types for riders (modular/half/open-face).	Road layout / traffic environment effects on visual attention. Comparison between rider vs driver gaze allocation to road elements (infrastructure, hazards, distractions).	Eye-tracking metrics: raw gaze points mapped to predefined areas of interest (AOIs). Counts and duration of fixations on road elements (e.g., carriageway, roadside, signs, markings, mirrors/other vehicles) by route area. Supplemented with synchronized video review.	Wearable eye-tracker: Tobii Pro Glasses 2; per-participant calibration/validation. Manual/automatic mapping of gaze points to AOIs; descriptive comparisons. No inferential statistical testing reported (limited sample).	Route and timing controlled (weekdays outside rush hours; similar weather). Participant experience/licensing criteria; helmet restrictions; own vehicles to reduce novelty effects.	Small sample size; results exploratory and not statistically generalizable. Potential observer/learning effects (single run on defined route; ~20 min per participant).

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STUDYID_208	2022	Zhou et al. — Cross-sectional questionnaire survey; aims to relate safety knowledge and safety attitudes to risky riding behaviours of urban e-bike drivers; combines regression modelling and group comparisons by personal characteristics.	Guilin (China); survey conducted across five main urban areas; 500 e-bike drivers randomly sampled; 411 valid questionnaires analysed.	N=411 valid. Gender: 223 male (54.26%), 188 female (45.74%). Age: <18 (54; 13.14%), 19–25 (100; 24.33%), 26–45 (201; 48.91%), >46 (56; 13.62%). Education: below junior high 128 (31.15%), high school 139 (33.82%), above college 144 (35.04%). Driving age (e-bike): 1–3y 200 (48.66%), 4–7y 151 (36.74%), >8y 60 (14.59%). Use frequency: 1–5/wk 169 (41.12%), 6–10/wk 200 (48.66%), >11/wk 42 (10.22%). Travel distance: <4 km 125 (30.41%), 5–10 km 169 (41.12%), >10 km 117 (28.47%). Other: license (have 169; 41.12%), vehicle type (pedal 107; 26.03% / motorcycle type 304; 73.97%), accident experience (yes 21; 5.11%).	Risky riding behaviour of e-bike drivers (aggressive, negligent, violations) and how it relates to safety knowledge, safety attitudes and personal characteristics.	Tools/scales: - Safety knowledge: 8 single-choice items (traffic signs, right-of-way, defensive/polite driving), scored 0–8. - Traffic safety attitudes: 11 Likert items (responsibility attitude, violation attitude, group behaviour attitude). - Risky driving behaviour: adapted DBQ + aggressive behaviour; 3 dimensions (aggressive, negligent, violation) on 5-point frequency scale. - Personal info: demographics, experience, frequency/distance, violations, crash experience.	Statistical modelling uses multiple regression analyses to explain each risky behaviour dimension; includes comparisons by personal characteristics (e.g., age, gender, accident experience).	Predictors include safety knowledge + attitude subscales; personal characteristics (age, gender, education, licence, experience, etc.).	Self-reported behaviours and attitudes; single-city sample; cross-sectional design limits causality; questionnaire-based measures may be subject to recall/social desirability.

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STUDYID_212	2022	Akgün-Tanbay et al. — Face-to-face survey at a shared street; models road-user perceptions (safety, comfort, chaos) for walking/cycling/micro mobility and determinants of perceived infrastructure quality using ordered logit models.	Via Maqueda, Palermo (Italy); 15 working days starting 22 May 2020; intercept interviews (10–15 min). 653 approached → 457 agreed; analysis restricted to respondents with experience of all three modes in the area (walking, cycling, micromobility): n=200.	N=200. Gender: 94 female (47%), 106 male (53%). Age groups: 18–24 (11; 5.5%), 25–39 (53; 26.5%), 40–54 (72; 36%), 55–65 (42; 21.5%), >65 (21; 10.5%). Profession: student 29 (14.5%), full-time working 112 (56%), retired 51 (25.5%), others 8 (4%). Road-use frequency: rarely 4 (2%), once/week 12 (6%), 2–3x/week 29 (14.5%), 4x/week 74 (37%), every day 81 (40.5%).	Perceptions of shared-space performance: safety, comfort and "chaos" (disorganization) for walking/cycling/micro mobility; role of infrastructure perception and socio-demographics.	Measures: - Perception of infrastructure (LOS A–F). - Safety/comfort/chaos perceptions for each mode (Likert 1–5). - Predictors: gender, age group, profession, road-use frequency.	Descriptive statistics + ordered logit regression models (STATA) for: (1) safety perception by mode, (2) comfort perception by mode, (3) chaos perception by mode, (4) perception of infrastructure as outcome.	Predictors in ordered-logit models include perception of infrastructure, gender, age groups, and road-use frequency (depending on model).	Intercept sample; restricted to users experienced in all 3 modes (may bias toward more multimodal/active travelers); COVID-19 context affected refusal rates; cross-sectional perceptions.

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STUDYID_221	2021	Ragot-Court et al. — Instrument development/validation study: created A-TRIBE self-reported risky riding behaviour inventory applicable to all two-wheelers; tested psychometric structure and criterion validity.	Shanghai (China); self-administered online questionnaire via private internet survey company; IRB approval; anonymous responses; no compensation. Stratified recruitment: 80 participants in each of 5 primary vehicle groups (bicycle, bicycle-type e-bike, scooter-type e-bike, non-electric engine scooter, motorcycle).	N=400. Age 18–65 (M=31.7, SD=7.9; median 31). Occupation: 92% working population. Gender by group: bicycle 50% male; bicycle-type e-bike 55% male; scooter-type e-bike 62.5% male; engine scooter 50% male; motorcycle 72.5% male. Overall ≈232 men / 168 women (computed from group proportions).	Measurement of risky riding behaviours across two-wheelers to enable comparative research (bicycles, e-bikes, scooters, motorcycles).	A-TRIBE item pool: 16 items (frequency over last 6 months; 0–5 scale) describing hazardous riding behaviours (overtaking, lane filtering, red-light behaviours, close following, intersection/pedestrian crossing behaviours). External markers for validity: previous accidents (last 3 years), primary vehicle type, max speed categories, riding/driving experience variables, socio-demographics.	Psychometrics in SPSS/AMOS: - Exploratory factor analysis (principal axis factoring) + item reduction to 12-item single-factor structure (52.81% variance; factor loadings >0.57; KMO=0.941; Bartlett χ^2 significant). - Reliability tests (split-half; Cronbach's alpha reported). - Confirmatory factor analysis (ULS estimation) with fit indices. - Criterion validity using eta (η) correlation ratio and F-ratios vs external variables (accidents, vehicle type, speed, experience).	Not a causal model; criterion variables include accident history, experience indicators, max speed, and primary vehicle type; socio-demographics explored.	Online panel in one city; self-report behaviours/accidents; translation/cross-cultural adaptation addressed via translation/back-translation and clarity testing.

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STUDYID_224	2021	Wang et al. — Sociotechnical systems analysis using Rasmussen's Risk Management Framework (RMF) and Accimap; mixed-methods (structured review of collision reports + directed study of delivery couriers + expert validation).	China. Online media reports of e-bike collisions (Jan 2017–Jan 2018) retrieved via Baidu keyword searches; courier-company documentation (7 delivery companies) + on-site courier interviews at local restaurants; Accimap revised/validated through expert workshops.	Collision cases: selected media-reported e-bike collisions with sufficiently detailed descriptions (number of cases not reported). Couriers: n=17 (all male; mean age 24.8±3.5; full-time), interviewed at 8 randomly selected restaurants. Experts (validation): Workshop 1 n=6 (3 authors + 3 external experts); Workshop 2 same participants; Workshop 3 n=13 (first author + 11 local-government experts + 1 meeting secretary).	System-level factors (actors, policies, environment, equipment, behaviors) contributing to e-bike collisions; courier-specific mechanisms (bonus-based pay, time pressure, management rules) influencing riding behavior.	Crash-case coding: involved road-user types, weather (e.g., night/rain), road equipment (lights/signs/turns/lanes), and pre-crash actions/status (e.g., speeding, phone use, wrong-way riding). Courier data: document review (contracts, salary/bonus, promotion, insurance, safety education) + semi-structured interviews on work pressure and safety behavior. Main output: generic Accimap model (nodes/links across RMF levels).	Qualitative synthesis to build Accimap bottom-up from an actor map (135 actors); iterative identification of contributory factors and links; internal author verification; expert review and revision via three workshops.	Not applicable (systems model; no inferential statistical controls).	Heavy reliance on media reports for collision detail (selection/reporting bias likely). Official collision data difficult to obtain and may miss minor crashes/near-misses; authors note the collision-data collection mechanism is flawed in China. Timeframe: collision reports Jan 2017–Jan 2018; courier interviews during study period.

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STUDYID_250	2021	Twisk et al. — Naturalistic cycling study with instrumented conventional bicycles, pedelecs, and speed pedelecs (s-pedelecs) to compare speed-related riding behavior in everyday traffic; plus brief questionnaires on preference, risk-taking and sensation-seeking.	Netherlands (The Hague area). Commuter trips in daily traffic; riders used an assigned bicycle type for ~2 weeks. Data collected Apr–Nov 2016; sections classified as urban vs rural using a digital topography map.	N=46 commuter cyclists (age 25–56; mean 43.7±9.4). By bicycle type: conventional n=14 (women 71%); pedelec n=12 (women 67%); s-pedelec n=20 (women 25%).	Bicycle type (conventional vs pedelec vs s-pedelec), road context (urban vs rural sections), and rider differences (gender; age; risk-taking; sensation-seeking) in relation to speed behavior.	GPS (5 Hz) + IMU (100 Hz) measured speed/acceleration. Outcomes: mean speed (urban/rural), speed variability (SD), harsh braking events (deceleration >2 m/s^2), and for s-pedelecs MSAL (% road sections with mean speed >25 km/h).	Mixed-effects modeling in R (lme4): LME for mean speed and speed variability; GLMM Poisson for harsh braking; GLMM binomial-logit for MSAL; participant random intercept; Bonferroni-corrected post-hoc comparisons.	Fixed effects included bicycle type, area (urban/rural) and gender; age, risk-taking and sensation-seeking as covariates. For harsh braking, trip distance used as covariate.	Bicycle type self-selected (participant-preference bias). Mostly commuter/rush-hour riding. At the time, legal maximum for s-pedelecs was 25 km/h; MSAL used to quantify mean-speed exceedance.

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STUDYID_298	2019	Zhuo Wang et al. — Cross-sectional investigation with two components: (1) in-person street-intercept field survey and (2) online survey via WeChat to assess awareness, self-reported behavior, and regulatory attitudes regarding e-bike safety.	Tianjin, China. Field survey (2015–2017) in 9 districts (4 urban, 5 rural) using street intercept at transport hubs/streets/near supermarkets/parking areas. Online survey distributed via Tianjin CDC WeChat official account and released on a local portal website.	Total N=16,859 adult respondents (>=18). Field survey: n=1,653 (819 male, 834 female): e-bike users n=794 (788 drivers, 6 passengers) and non-e-bike road users n=859. Online survey: n=15,206 (8,982 male, 6,224 female): e-bike users n=4,426 (3,661 drivers, 765 passengers) and non-e-bike road users n=10,780.	Awareness and practice of traffic-violation/unsafe behaviors among e-bike users vs other road users; attitudes toward special e-bike regulations (e.g., helmet use).	Awareness: participants rated each behavior as right/wrong/don't care (correct awareness = rating as wrong). Practice (field survey): usually (>3 times/week), occasionally (1–2/week), never (correct practice = never). Attitudes: support for special regulations (very supportive/supportive/don't care/oppose). Demographics (gender, age, education, occupation, income, road-user type) collected.	Group comparisons using Pearson's chi-square tests (frequency data) and t-tests (quantitative data); analyses performed in SPSS v19; significance threshold $p<0.05$.	Primary grouping: e-bike users vs non-e-bike road users; field survey sampling targeted near-even splits by gender and road-user type; no multivariable adjustment reported (bivariate tests).	Cross-sectional and largely self-reported (social desirability/recall bias possible). Online survey is a convenience sample via WeChat (selection bias likely). Field and online components differ in focus (field includes both awareness and practice; online focuses on broader attitudes).

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STUDYID_304	2018	Hertach et al. — Cross-sectional survey of e-cyclists with retrospective self-report of single-vehicle crashes; weighted analyses to improve representativeness; logistic regression models for crash risk and injury severity.	German-speaking Switzerland; Sep–Nov 2016. Recruitment via: - active: letters to 2,400 registered owners of fast e-bikes (support up to 45 km/h) + 484 participants of e-bike training courses, - passive: channels of Swiss Council for Accident Prevention and partner organisations (web/newsletter/social media). Online survey; training-course participants could also complete paper questionnaire.	Completed questionnaires: 4,044. Final analytic sample (active & regular e-cyclists, "Sample A"): N=3,658. Mean age 54.4 (SD 12.8); age groups: 14–34 (6%), 35–49 (24%), 50–64 (42%), 65+ (27%). Gender: 48% male (n=1,771), 51% female (n=1,883). E-bike type: 32% e-bike45 (support up to 45 km/h), 68% e-bike25. Crash-experienced subset ("Sample B"): N=638 single-vehicle crash cases.	Exposure: e-bike riding exposure index (duration of e-bike use × frequency); additional factors: main purpose of use (work/school vs leisure/errands), self-rated safety in challenging situations, prior two-wheeler experience, training-course participation, e-bike technical characteristics (type, motor/battery position).	Outcomes: 1) Ever experienced a single-vehicle crash in road traffic (yes/no). 2) Injury severity in single-vehicle crash (no/minor vs moderate/serious). Also descriptive distributions of crash mechanisms and perceived crash causes (multiple-choice + optional open text).	Weighted analyses (weights for e-bike type and training-course participation derived from passively recruited sample). Logistic regression for crash risk and for injury severity (stepwise approach: bivariate screening p≤0.2 → multivariable model with backward elimination). Software: SPSS 24 and STATA 14.	Candidate covariates tested include: gender, age, education, e-bike type/geometry, exposure index, prior two-wheeler use, main purpose of e-bike use, participation in training course, and "general feeling of safety" composite (mean of 5 situation-specific items).	Notes/limits: self-report (recall/social desirability) though most crashes occurred within previous 3 years; selection bias possible despite multi-channel recruitment and weighting; police reporting low for minor injuries. Crash mechanisms validated by two researchers cross-checking closed vs open responses; some recoding + 4 new mechanism categories created from narratives.

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STUDYID_347	2014	Sgarra et al. — Methodology/case-study on using an ITS passive in-vehicle telematics system to improve powered two-wheeler (PTW) safety analysis and black-spot ranking through enriched crash data and indicator computation.	Rome (Italy). Integrates: - RMAD (Rome Municipality Accidents Database), collecting city crash records since 2004 (ID, time, severity counts, vehicles, location), and - ITS provider database (Octo-Telematics) from a 2011 trial on PTWs. GIS + GPS-based data merged to compute indicators at 23 PTW crash locations (local/district roads).	ITS telematics sample: N=240 PTWs (volunteer/undisclosed selection due to privacy). Trial duration: 1 year. Recorded events: 23 PTW crashes across 23 locations. (No rider demographic breakdown reported.)	Exposure/context: implementation of collision-detection telematics (GPS+GSM/GPRS + 3-axis crash accelerometer) enabling capture of crash dynamics (e.g., crash instant speed, max speed, acceleration) and linking to road geometry/traffic attributes in a GIS environment.	Outcomes/measures: Computed PTW safety indicators to rank/diagnose unsafe links/sections: - Hazard Indicator (HI) (modified for urban context by replacing length parameter with crash instant speed from telematics), - Accident Density Index (ADI), - Safety Potential Indicator (SAPO, k€/km·year) per Italian regulation.	Indicator computation workflow: literature review → ITS tool selection → site selection → test data collection → calculation of HI/ADI/SAPO. Uses merged RMAD + telematics parameters (e.g., crash speed) to improve indicator quality and identify critical sub-sections between street numbers.	Indicator inputs include traffic index (TI), gradient (G), horizontal alignment (HP), lane parameter (LP), crash instant speed (Si), plus accident-cost components for SAPO (fatalities/severe/light injuries and corresponding costs; ADT/ACR terms).	Notes/limits: pilot scale (23 crashes) and telematics sample not representative; acceleration data not used (vehicle/pavement dependent and insufficient metadata); authors note need for qualitative indicators capturing riders' needs/behaviours beyond quantitative metrics.