



The Expanding Landscape of Road Rage: A Systematic Review of Conflicts Involving Drivers, Pedestrians, and Micromobility

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Review Article

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Abstract

Road rage, characterized by aggressive behaviours among road users, has become a significant public health concern in urban transportation. This review, which shifts from a driver-centric to a multi-modal, systemic perspective, synthesized 135 empirical studies to examine road rage across multiple user groups, while also analyzing trends, contributing factors, and mitigation strategies. Studies were sourced from Scopus and included diverse road user types and methodologies, with experimental studies being the most common (39.3%), followed by observational (24.4%) and mixed methods approaches (20.7%). The research was mainly focused on China (32 studies) and the United States (16 studies), with 116 studies (85.9%) emphasizing driver behaviour. However, pedestrian (65 studies, 48.1%) and cyclist interactions (23 studies, 17.0%) are increasingly acknowledged. Environmental factors were the most frequently examined contributors (122 studies), with substantial statistical significance noted: 59.3% of effect sizes were large (≥ 0.5). Infrastructure modifications (64 studies) and education programs (46 studies) appeared as key intervention strategies, with 30 studies reporting successful outcomes. This review highlights the need for interdisciplinary approaches that include all road users and stresses the importance of standardized reporting, cultural factors, and rigorous evaluations to improve transportation safety.

Keywords: Road Rage; Aggressive Driving; Traffic Safety; Pedestrian Safety; Cyclist Safety; Micromobility; Urban Transportation; Traffic Psychology

Abbreviations

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses; GLMs: Generalized Linear Models;

CAX: Cycling Anger Expression Inventory; AI: Artificial Intelligence, ANOVA: Analysis of Variance; LPI: Leading Pedestrian Interval.

Introduction

Road rage is a serious and growing public health issue that extends well beyond individual acts of aggression. Its impacts place a significant burden on society, directly leading to traffic crashes, injuries, and fatalities. Besides the immediate physical damage, road rage damages psychological health, causing widespread anxiety, stress, and post-traumatic stress among drivers, pedestrians, and other road users. Moreover, it erodes community bonds by reducing public trust in shared spaces, discourages active transportation such as walking and cycling, and ultimately lowers the overall quality of life and safety in communities [1-3].

As micromobility devices, such as e-scooters and e-bikes, become more common, it is essential to address the specific vulnerabilities of these users. Their speed and agility in busy urban traffic often create conflicts with both pedestrians and motorists. The lack of clear regulations for these modes of transport further increases the risk of road rage incidents, underscoring the need to better integrate micromobility into urban transportation planning.

Defining Road Rage in Multi-Modal Era

Road rage, a significant public health concern in urban transportation, is reconceptualized in this review as a spectrum of aggressive and violent behaviours exhibited by any road user within a shared transportation system. Moving beyond the traditional driver-centric paradigm, this definition explicitly encompasses the full diversity of modern road users: drivers, pedestrians, cyclists, and micromobility users [4-6].

The literature shows this phenomenon as a continuum, not a single act. On one end are aggressive behaviours that increase collision risk. For example, jaywalking, while not an act of rage itself, is a key precursor, often triggering aggressive responses from drivers [7]. Similarly, aggressive driving is defined as a conscious decision to operate a vehicle selfishly and dangerously, driven by impatience or hostility [8]. Micromobility users also display their own forms of aggression, such as risky manoeuvres, including frequent, abrupt acceleration and deceleration or sneaking through traffic gaps in an intimidating way [9,10].

At the end of the spectrum lies road rage proper, characterized by violent behaviours intended to cause physical or material harm [8]. For cyclists and micromobility users, conflicts are often defined by their subjective experience of feeling threatened or unsafe during interactions with larger vehicles, ranging from verbal aggression to collisions [11]. This inclusive, multi-modal definition provides the essential

foundation for analyzing the complex interactions and systemic causes of conflict explored in this review [12-14].

Imperative for Multi-User Perspective

The traditional approach to road rage research, which has mainly centred on the psychology and behaviour of vehicle drivers, is fundamentally inadequate for addressing the realities of modern urban transportation. Today's roads form a complex, shared environment where a variety of users must navigate a limited, often contested space. This driver-focused perspective fails to fully understand the range of conflict dynamics, overlooking the unique vulnerabilities, behaviours, and frustrations of non-driver users who can be both perpetrators and victims of aggression [15-18].

The need for this expanded perspective is heightened by two key urban trends: (a) the significant increase in micromobility options (e-scooters, e-bikes) and (b) rising urban density. These factors have fundamentally changed how people interact on city streets, creating new and frequent conflict points. Zhang, et al. [19] showed that even specific infrastructure decisions, such as bus stop design and cycleway width, greatly affect passenger-cyclist interactions, illustrating how the built environment can either reduce or provoke conflict. Moreover, policies promoting sustainable transport, such as shifting from driving to cycling, must actively address negative attitudes and aggression between user groups to be effective [20-22].

Adhering to a traditional, driver-centric view creates a significant blind spot in both research and policy. This limited perspective fails to capture the complex conflict dynamics of modern roads, overlooking how the unique vulnerabilities, behaviours, and frustrations of pedestrians, cyclists, and micromobility users contribute to aggression, whether as victims or instigators. The imperative for a multi-user perspective is undeniable, given two transformative urban trends: the explosion of micromobility and the rise in urban density. These trends have reshaped street-level interactions, creating novel conflict points. Consequently, policies aimed at promoting sustainable transport must now explicitly target inter-group aggression to succeed [20,23-25].

Study Objectives

This systematic review and meta-analysis aim to provide a comprehensive, multi-perspective understanding of road rage by systematically synthesizing global evidence on its triggers, manifestations, and impacts across the entire system of road users and to evaluate the effectiveness of proposed mitigation strategies.

The Main Objectives of this Review are:

- **Map the Research Landscape:** To identify and analyze global trends, methodological approaches, and geographic focuses in road rage research from 2019 to 2025, highlighting the evolution from a driver-centric view to a more inclusive, multi-modal perspective.
- **Characterize Road Rage by User Group:** To systematically identify, compare, and contrast the specific triggers, behavioral manifestations, and underlying psychological factors that lead to road rage for road users (drivers, pedestrians, cyclists, and micromobility users).
- **Analyze Inter-Group Conflict Dynamics:** To investigate how road rage manifests in the interactions between

different road user groups (e.g., driver vs. pedestrian, driver vs. cyclist), focusing on conflict hotspots and the escalation of aggression.

- **Assess the Robustness of the Evidence Base:** To quantitatively evaluate the statistical strength, practical significance, and methodological rigor of the existing research through meta-analysis of p-values, effect sizes, and confidence intervals.
- **Identify and Evaluate Solutions:** To catalogue and assess the proposed infrastructure, policy, educational, and technological interventions for mitigating road rage, and to synthesize reported evidence of their effectiveness.

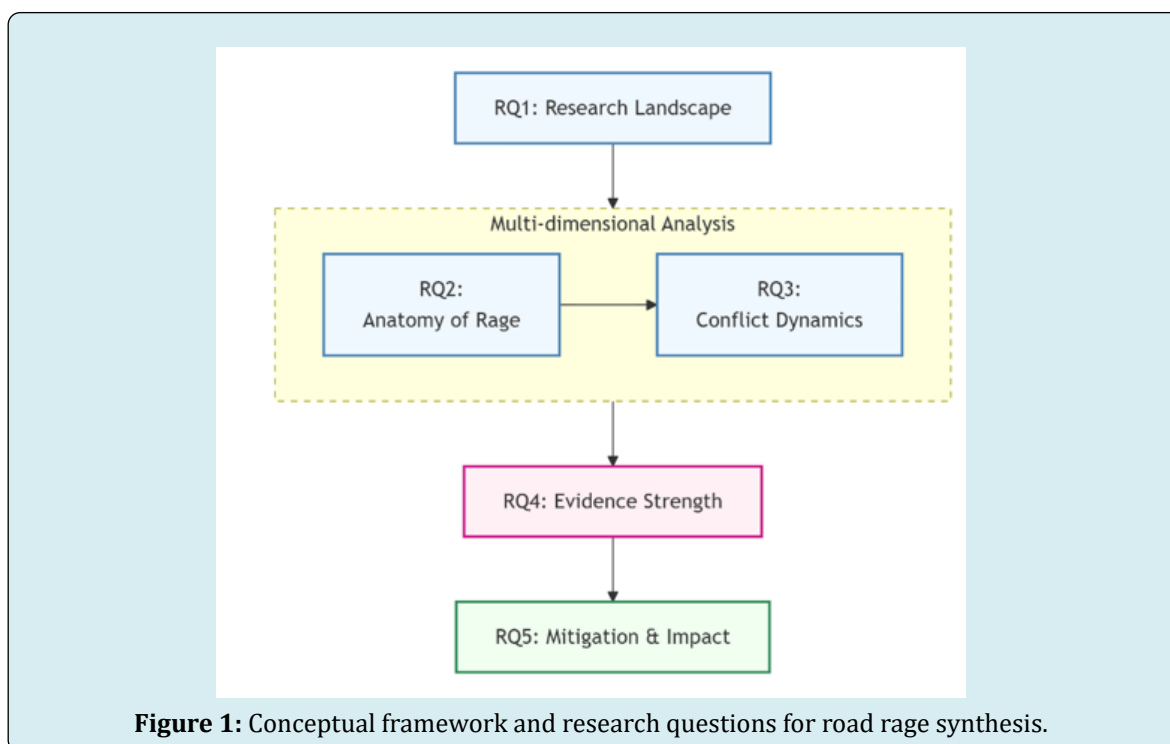


Figure 1: Conceptual framework and research questions for road rage synthesis.

The conceptual framework and research questions (RQ) of this systematic review are shown in Figure 1. The process begins with mapping the broader research landscape (RQ1) to provide context. It then proceeds to a multidimensional analysis, examining internal factors (RQ2: triggers, manifestations, psychology) and external interactions (RQ3: conflict dynamics) that comprise the phenomenon of road rage. The arrow from RQ2 to RQ3 visually indicates that internal factors of road rage directly influence and drive external conflict dynamics between user groups. The strength of the evidence gathered through this analysis is then quantitatively evaluated (RQ4). Finally, the review consolidates potential solutions and assesses their reported effectiveness (RQ5), shifting from diagnosing the issue to identifying evidence-based interventions. This structured approach ensures a thorough and logically consistent

examination of road rage among all modern road users.

Before presenting the results of this synthesis, it is helpful to outline the search method used in this review and to discuss some fundamental aspects of road rage.

Search Method

This systematic review and meta-analysis were conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 [26]. This tool was chosen for this review because it ensures that the selection and data extraction processes are transparent and reproducible. This framework supports a comprehensive synthesis of diverse studies, helping to minimize selection bias and ensuring the conclusions drawn from the review

are both reliable and valid. The study aims to synthesize and analyze existing literature on road rage among diverse road users, including drivers, pedestrians, and micromobility users. A comprehensive literature search was undertaken in the Scopus database. The search encompassed studies published between 2019 and 2025. The search terms are provided in Appendix A.

The Following Inclusion Criteria were used to Select Studies for this Review:

- Studies published in English between 2019 and 2025.
- Studies that focused on road rage or aggressive behaviour among road users.
- Studies that included data on at least one of the following road user groups: drivers, pedestrians, or micromobility users.
- Empirical studies, including experimental, observational, and survey-based research.

Exclusion Criteria were as follows:

- Studies not published in English.
- Studies published before 2019.
- Studies that did not focus on road rage or aggressive behaviour.
- Review articles, commentaries, and case reports with no empirical data.

The Following Information was Extracted from each of the 135 Studies:

- **Bibliographic Information:** Title, authors, year of publication.
- **Study Characteristics:** Study methodology, sample size, country, urban/rural setting.
- **Road User Information:** Primary Road users, user interactions, age groups, gender split.
- **Road Rage Characteristics:** Definition of road rage, triggers, manifestations, severity scale.
- **Contributing Factors:** Infrastructure, psychological, cultural, and environmental factors.
- **Outcomes:** Physical, psychological, and behavioural outcomes.
- **Mitigation Strategies:** Proposed mitigation strategies and their reported effectiveness.
- **Methodological Details:** Statistical tests used, effect sizes, p-values, confidence intervals, means/SDs, sample characteristics, key statistics, study focus, methodology, context, main findings, datasets, metrics, and metric results.
- **Study Quality:** Strengths and limitations.

The systematic literature search conducted on Scopus initially identified 317 records. After removing one duplicate, 316 records were screened, resulting in 141 reports being

sought for retrieval. Of these, 6 could not be accessed, leaving 135 studies to be assessed for eligibility. All 135 studies met the inclusion criteria and were subsequently included in the final review and meta-analysis.

Fundamental Aspects of Road Rage

Consequences of Road Rage

The most immediate consequences of road rage involve physical violence and collisions. Traffic collisions are direct outcomes of aggressive encounters. Jashami H, et al. [27] analyzed crash severity and identified factors contributing to injuries and fatalities in road rage incidents. The literature documents cases ranging from minor fender-benders caused by aggressive driving to high-speed collisions resulting from reckless maneuvers.

In extreme cases, road rage escalates to physical assaults with drivers, cyclists, and pedestrians all becoming victims of violence. The use of vehicles as weapons represents a particularly deadly form of road rage. The data suggests these incidents are not rare and represent significant threats to public safety across all road user categories. Beyond physical consequences, road rage creates profound psychological impacts. The literature shows that being a victim of road rage incidents can lead to anxiety, fear, depression, and post-traumatic stress disorder (PTSD). The constant sense of threat and hypervigilance resulting from frightening road encounters can make it challenging to drive, cycle, or walk in public spaces [28-31].

The data suggests that even witnessing road rage incidents can be traumatic, particularly for children. The psychological toll is often hidden but represents a serious consequence of aggressive road behaviour. This trauma can have lasting effects on individuals' willingness to use various transportation modes and their overall quality of life [9, 32-34].

New Challenge of Micromobility

The emergence of micromobility represents a new and significant challenge for road safety and road rage research. Micromobility users are a particularly vulnerable group, facing a unique set of risks and challenges. Micromobility users are susceptible to traffic conflicts, unpredictable events, and the aggressive behaviour of other road users. The lack of dedicated infrastructure and the ambiguity of traffic laws for these new modes of transportation further exacerbate their vulnerability [15,35-37].

Notably, road rage among micromobility users exhibits distinct patterns across vehicle types and user groups. E-scooter riders, for instance, face heightened frustration

from limited battery life (a trigger for hasty manoeuvring) and smaller vehicle size (increasing vulnerability to aggressive drivers), while e-bike users often report conflicts tied to speed mismatches with both cars and pedestrians. User demographics further shape these dynamics, e.g., on-demand delivery riders experience unique time-pressure triggers, leading to riskier overtaking or sidewalk riding-behaviors that escalate conflicts with pedestrians [38]. In contrast, casual commuters prioritize safety over speed, reporting more anger toward drivers who encroach on shared lanes. These differences highlight that micromobility is not a monolithic category, and mitigation strategies must be tailored to specific vehicle types and user needs to address their distinct road-rage experiences [39-41].

Some studies also suggest a significant lack of understanding and awareness of micromobility among other road users. This can lead to frustration, resentment, and a higher risk of conflict. The integration of micromobility into the existing transportation system will require a concerted effort to educate all road users about the rights and responsibilities of these new modes of transport. It will also require a significant investment in infrastructure capable of safely accommodating a diverse range of road users [39,42-44].

Contributing Factors to Road Rage

Design and Congestion Factors: Infrastructure design and traffic congestion play critical and often interrelated roles in shaping road user interactions and contributing to road rage incidents. Specific infrastructure factors include medians, building entrances, vegetation on medians, bus/taxi stops, lack of cross-section visibility, distance between destination and crossing point, and road geometry [7]. Their research demonstrates how poor infrastructure design creates conditions conducive to conflict and aggressive behaviour.

Chronic traffic congestion acts as a persistent environmental stressor, exacerbating the frustrations caused by flawed design. It directly contributes to time pressure, a major psychological trigger for drivers, and creates a high-density environment where conflicts between user groups are more frequent and intense. For all road users, congestion heightens frustration, reduces patience, and shortens tempers, making aggressive responses more likely.

Hasanpour M, et al. [45] examined infrastructure interventions and showed that Leading Pedestrian Interval (LPI) implementation increased vehicle delay by 26% to 349%, while achieving safety benefits, highlighting the tension between infrastructure priorities and the potential conflict between congestion concerns and safety measures. Jashami H, et al. [27] identified signalized intersections and posted speed limits as key infrastructure factors influencing

crash severity. Oikonomou A, et al. [20] emphasized the role of a lack of investments in cycling infrastructure, cycling facilities, and cycling-supportive road treatments in creating systematic conflicts.

The very design of streets, which have historically prioritized car movement over the safety and comfort of other road users, represents a fundamental source of tension. Zhang, et al. [19] demonstrated that bus stop type (curbside and floating bus stops with dedicated cycleway), road width (motorway width, cycleway width), and bus stop layout design significantly influence conflict patterns. Inadequate infrastructure fails to manage high traffic volumes, leading to congestion that, in turn, fuels the aggressive behaviours documented in this review.

Cultural and Societal Norms: Cultural and societal norms heavily shape road user behaviour and contribute to the development of road rage. The reviewed literature suggests a deeply rooted car culture that prioritizes speed and the convenience of driving above other considerations [46-48]. Dorantes-Argandar, et al. [8] examined cultural factors across Spanish-speaking countries and identified how cultural norms influence aggressive driving, rule-breaking, and driver stress.

Oikonomou, et al. [20] investigated cultural factors, including personal values (safety, equality, respect for diversity), pro-environmental beliefs, negative attitudes towards cyclists and their influence on road behaviour. The increasing pace of modern life, with an emphasis on speed and efficiency, contributes to more impatient, aggressive driving. Media portrayals that glorify speed, aggression, and disregard for traffic laws also play significant roles in shaping behavioural norms [49,50].

Stress, Anonymity, and Dehumanization: Psychological factors, including stress, anonymity, and dehumanization, are key contributors to road rage. Those psychological factors include being in a hurry, being distracted by phones or other devices, intoxication, unfamiliarity with the area, an unconcerned attitude towards jaywalking, and other personal factors related to the perception-judgement-decision-action process. [7,8,51]. The act of driving, particularly in heavy traffic, represents a significant source of stress leading to heightened arousal and greater susceptibility to anger and frustration [52,53].

Jashami H, et al. [27] documented how the driver sped too fast for conditions, did not yield right-of-way, disregarded a traffic control device, and that the driver's age and gender (male) contribute to aggressive behaviour patterns. The feeling of anonymity inside vehicles can lower inhibitions and increase the likelihood of aggressive behaviour that individuals would not consider in face-to-face interactions.

This anonymity can lead to dehumanization processes, where other road users are seen as obstacles rather than individuals [54,55].

Legal and Enforcement Gaps: Legal and enforcement gaps contribute significantly to road rage by creating environments of impunity. When traffic laws are not consistently enforced, aggressive drivers may feel they can act without consequence. The literature suggests this is particularly true for behaviours such as speeding, tailgating, and running red lights. Laws themselves can be sources of conflict when they are unclear or inadequately address the needs of all road users [56-58].

The lack of specific road-rage legislation in many jurisdictions makes prosecution difficult and sends messages that such behaviour is not taken seriously. Inconsistent enforcement and unclear legal frameworks contribute to environments where aggressive behaviour can flourish unchecked [55,59].

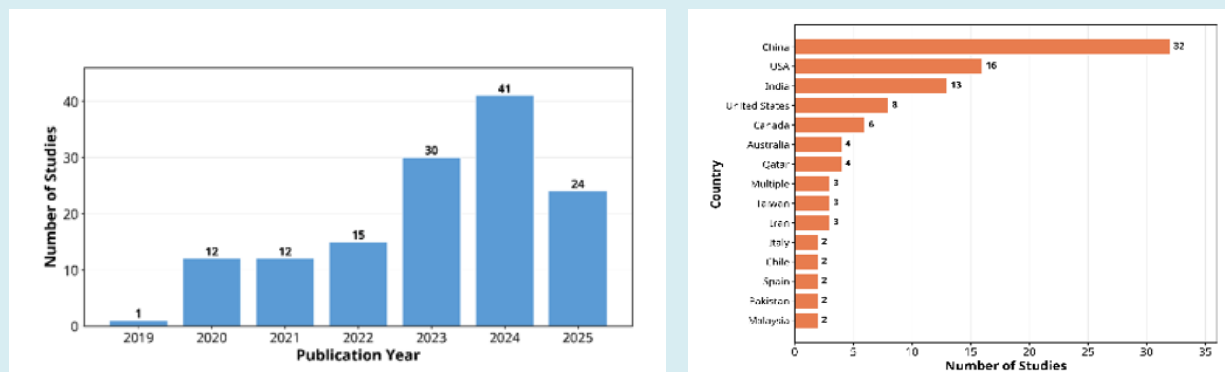
Landscape and Multi-Dimensional Analysis

Landscape of the Literature (RQ1)

Distribution by Year and Country: The temporal and geographic distribution of the 135 studies included in

this review reveals a field experiencing rapid growth and marked regional concentration. As illustrated in Figure 2a, publication output has increased exponentially since 2019, peaking at 41 studies in 2024. This sharp upward trend underscores the escalating global recognition of road rage as a critical area of academic and public policy concern, likely driven by the increasing complexity of urban transportation systems.

Geographically, the research originated from 45 countries, indicating a widespread, if uneven, interest in the phenomenon. As shown in Figure 2b, the field is dominated by studies from China (32 studies), the United States (16 studies), and India (13 studies). This concentration suggests that the current understanding of road rage is heavily influenced by the specific cultural, infrastructural, and socio-economic contexts of these three large, rapidly motorizing nations. While this provides valuable insights, it also highlights a significant gap in the literature, with many regions, particularly in Africa, South America, and parts of Europe, being substantially underrepresented. This geographic bias limits the generalizability of findings. It points to a pressing need for more culturally and contextually diverse research to build a truly global understanding of road rage dynamics [60-62].

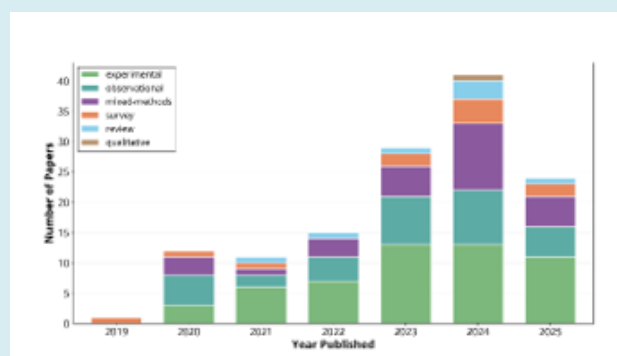


(a) By publication year (b) By countries (Top 15).

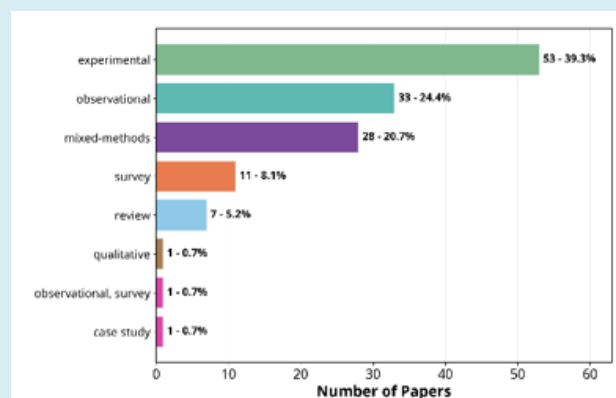
Figure 2: Distribution of road rage studies.

Methodologies Used: The methodologies used across the reviewed studies varied, including experimental, observational, and survey-based methods. The most common study methodologies are experimental (53 studies), observational (33 studies), and mixed-methods (28 studies), as shown in Figure 3. Experimental studies, the most prevalent, focus on controlled investigations of causal factors and potential interventions related to road rage. Experimental studies often use microsimulation and other modelling techniques to assess the impact of infrastructure

changes or policy interventions on road user behaviour. Microsimulation, PTV Vistro, PTV VISSIM, Surrogate Safety Assessment Model, an autoencoder neural network, and generalized linear models (GLMs) with a negative binomial error structure were used [45]. The variety of study methodologies reflects the multifaceted nature of road rage and the need for a multi-pronged research approach. The combination of experimental, observational, and qualitative methods allows researchers to explore the context of real-world traffic [63-65].



(a) By publication year.



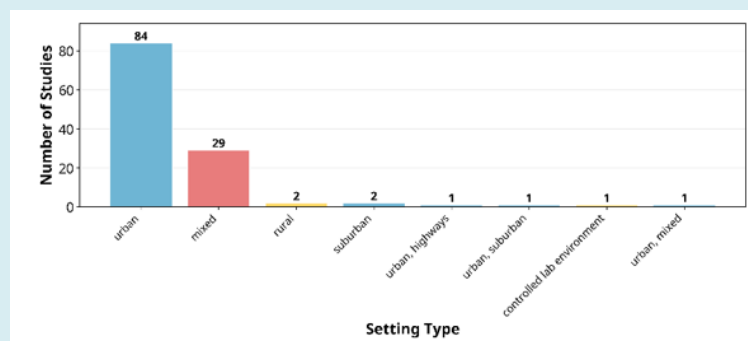
(b) By study methodology.

Figure 3: Distribution of reviewed papers by publication year and study methodology.

Observational studies rely on real-world data collection methods such as video analysis, sensor data, and on-site observation. Techniques like lidar sensor data collection, CCTV video analysis, manual counting, Pearson correlation tests, K-means clustering, and generalized linear regression models have been used [7]. Mixed-methods studies combine both quantitative and qualitative approaches, often employing surveys, interviews, and focus groups to supplement observational or experimental data. The analytical techniques are varied, including statistical

modelling, content analysis, and thematic analysis [66,67]

Urban vs. Rural Setting: A breakdown of the settings in which road rage studies were conducted (urban vs. rural) is shown in Figure 4. The bar chart clearly shows that most research has been conducted in urban environments, with 84 of 135 studies focusing on cities. This is not surprising, given that metropolitan areas are characterized by higher traffic density, greater diversity of road users, and more frequent interactions, all of which can increase the likelihood of road rage incidents [68-70].

**Figure 4:** Urban vs rural settings in road rage studies.

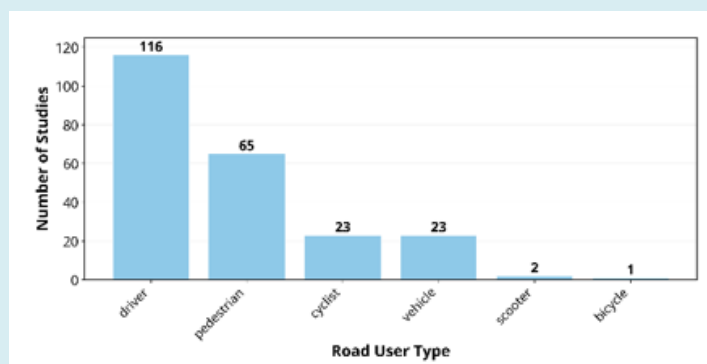
The focus on urban environments emphasizes the urgent need to tackle road rage, where the impacts of aggressive behaviour can be severe.

The results of these studies can offer valuable insights for urban planners and policymakers seeking to create safer, more efficient transportation systems. While emphasizing urban areas is understandable, the relatively few studies conducted in rural and suburban settings suggest a potential gap in the research.

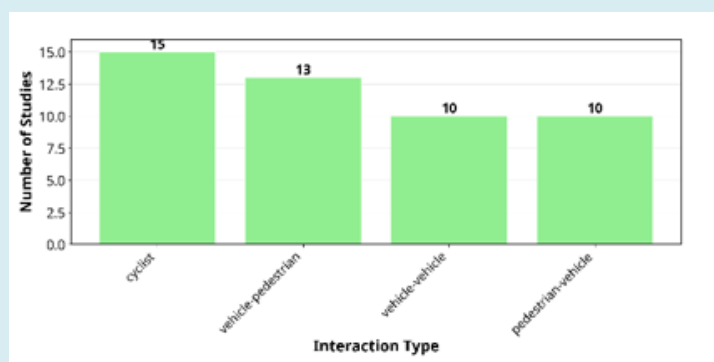
Road rage can also occur in these environments, and its triggers and expression may differ from those in cities. Future research could investigate these differences in more detail to develop a more complete understanding of road rage across all settings [71-73].

Focus on Road Users and Their Interactions (RQ1, RQ3)

Road User Types Studied: The frequency with which different road user types are mentioned in the reviewed studies is shown in Figure 5a. As noted, drivers are by far the most studied group, appearing in 116 of the 135 papers. This reflects the traditional focus of road rage research on driver behaviour. However, the figure also highlights the growing attention being paid to other road users, particularly pedestrians and cyclists. The ever-increasing number of studies that include these vulnerable road users is a positive development, reflecting a more inclusive and holistic approach to road safety. The mention of scooters and bicycles, although less frequent, indicates an emerging interest in the role of micromobility in road rage incidents [15,74,75].



(a) Road user type



(b) Type of user Interactions

Figure 5: Distribution of reviewed papers by road user type and type of user interactions.

The analysis of road user types is crucial for understanding the complex dynamics of multi-user road environments. By examining interactions among different user groups, researchers can identify specific conflict points and develop targeted interventions to improve safety for all [76,77].

Types of User Interactions: Figure 5b breaks down the types of road user interactions reviewed, showing that cyclist-related interactions are the most frequently studied, followed by vehicle-pedestrian and vehicle-vehicle interactions. This highlights the growing recognition of the unique challenges and vulnerabilities cyclists face in today's urban transportation systems.

The growing popularity of cycling likely drives a focus on cyclist-related interactions as a mode of transportation and, in turn, increases conflicts between cyclists and other road users. Research in this area is crucial to developing safer infrastructure and promoting a culture of mutual respect on the roads. The continued attention to vehicle-pedestrian and vehicle-vehicle interactions is also essential, as these remain primary sources of conflict and collisions. By understanding the dynamics of these interactions, we can develop more effective strategies to prevent aggressive behaviour and improve road safety for all [78-80].

Anatomy of Road Rage (RQ2)

Road Rage Factors Studied: Various factors have been investigated as possible contributors to road rage across the studies, as shown in Figure 6. The bar chart displays the number of studies examining each of the six main categories: infrastructure, psychological, environmental, cultural, triggers-reported, and manifestations-reported.

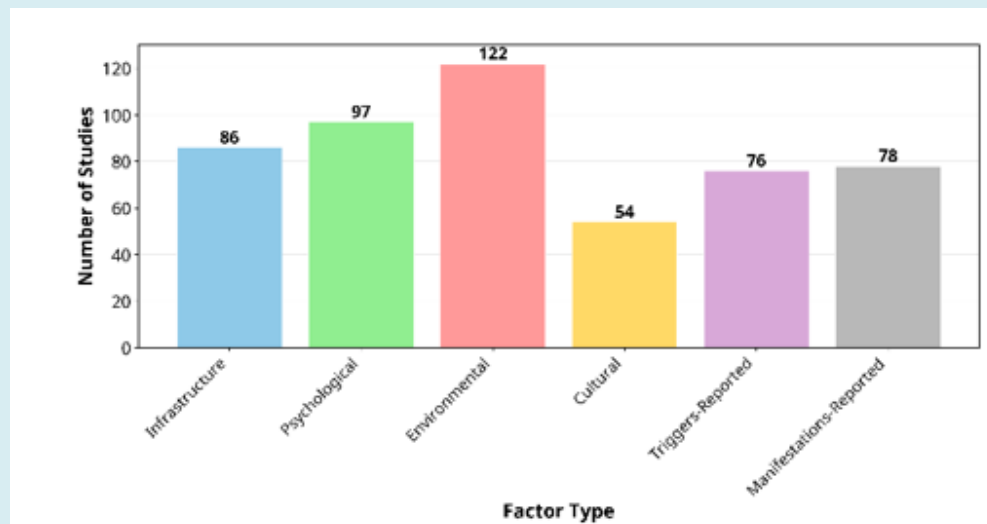


Figure 6: Road rage factors studied in the reviewed papers.

Road Rage Triggers, Manifestations, and Psychological Factors: To further examine the nuances of road rage among different user groups, a quantitative synthesis of the top five triggers, manifestations, and psychological factors for drivers, pedestrians, cyclists, and micromobility users was conducted. The results are summarised in Table 1. The analysis reveals both commonalities and differences in the triggers of road rage across user groups. Traffic congestion emerged as a universal trigger, affecting all road user groups. However, other triggers were more specific to each group's experiences. For example, drivers were more likely to be triggered by time pressure and aggressive driving by others, while pedestrians were more affected by the distance between crosswalks and their destination. Cyclists and micromobility users were susceptible to traffic conflicts

trigger-related, and manifestation-related. The figure indicates that environmental factors are the most frequently studied (122 studies), followed by psychological factors (97 studies) and infrastructure factors (86 studies). This highlights that while individual psychological factors and infrastructure challenges play significant roles, the broader environmental context, such as urban congestion and traffic design, has the greatest impact on road rage incidents. Understanding these factors is essential for developing effective interventions that address both individual behavior and systemic issues. The relatively smaller number of studies on cultural factors (54 studies) may point to a gap in the literature that future research could address [81-83].

Analyzing these factors is essential for creating a comprehensive model of road rage. By understanding how individual, situational, and societal factors interact, we can develop more effective and targeted interventions to prevent and reduce aggressive behaviour [84].

and unpredictable events, highlighting their vulnerability in mixed-traffic environments [85-87].

In analyzing manifestations of road rage, the analysis highlights how it is expressed across user groups. Drivers are more likely to engage in aggressive driving behaviours such as speeding and tailgating, while pedestrians' manifestations are more related to crossing behaviours. Cyclists and micromobility users exhibit more subtle forms of aggression, such as frequent acceleration and deceleration, which may be a response to the perceived need to maintain momentum and navigate through traffic. The manifestations of micromobility users reflect their unique mode of transport, characterized by high manoeuvrability and the ability to exploit small gaps in traffic [88-90].

For psychological factors, the analysis reveals that stress and anonymity are common psychological factors that contribute to road rage across all user groups. However, there are notable differences as well. For drivers and cyclists, anger, frustration, and personality traits are more prominent, suggesting that individual emotional and dispositional factors play a significant role in their aggressive behaviour. For cyclists, the experience and expression of anger are themselves key psychological factors. Zheng, et al. [4] further validated the Cycling Anger Expression Inventory (CAX) in China, underscoring that cycling anger is a measurable psychological construct with distinct expressive pathways, including verbal aggression, physical aggression, and the

use of a bicycle to express anger. For pedestrians, perceived risk and driver distraction are more salient, reflecting their vulnerability and reliance on others' safe behaviour. For micromobility users, risk-taking attitudes and unawareness of traffic laws are more pronounced, which may be related to the novelty of these modes of transport and the lack of established norms and regulations [91-95].

While traffic congestion is a universal trigger, it manifests as time pressure for drivers and as impeded crossing opportunities for pedestrians. This mismatch can escalate conflicts at intersections, where a driver's hurry directly contests a pedestrian's attempt to cross.

Road User	Top Five
(a) Triggers	
Drivers	Traffic congestion, time pressure, aggressive driving, hostility, and the distance between the crosswalk and the destination
Pedestrians	Traffic congestion, the distance between the crosswalk and the destination, being in a hurry, being drunk, and poor road design
Cyclists	Traffic congestion, traffic conflicts, vehicle interactions, unpredictable traffic events, and sudden situations like conflicts or road irregularities
Micromobility	Higher heterogeneity in traffic composition, especially higher composition of motorized two-wheelers (2W) and motorized three-wheelers (3W) vehicle classes, congested conditions, fluctuations in lateral movement, and reckless/aggressive driving and riding
(b) Manifestations	
Drivers	Speeding, tailgating, running red lights, aggressive driving, and honking
Pedestrians	Aggressive driving, emergency braking, changing lanes, speeding, and crossing streets illegally
Cyclists	Speeding, frequent acceleration, frequent deceleration, sudden accelerations, and abrupt changes in speed
Micromobility	Higher lateral velocity, increased lateral movement, seeping through available lateral gaps, traversing laterally to overtake vehicles, and gaining the desired longitudinal positions or speeds
(c) Psychological Factors	
Drivers	Personality traits, anger, frustration, stress, and anonymity
Pedestrians	Stress, anonymity, driver age, perceived risk, and driver distraction
Cyclists	Stress, anonymity, frustration, anger, and personality traits
Micromobility	Reckless/aggressive driving, risk-taking attitudes, unawareness of traffic laws, fatigue, and alcohol use

Table 1: Top five triggers, manifestations, and psychological factors of road rage among different road user groups.

Statistical Analysis

Quantitative Synthesis Methods and Metrics

The statistical robustness of the evidence base, as detailed in the following section, is supported by specific quantitative models and safety metrics commonly employed in the reviewed literature. Presenting these foundational equations provides clarity on how the synthesized findings were derived initially and measured.

A key methodological challenge in road rage research is the reliance on conflicts or near-misses as proxies for actual crashes, given the relative rarity of the latter. A standard metric for quantifying the severity of these interactions is the Post Encroachment Time (PET). It measures the time difference between the moment one road user clears a potential point of collision and the moment another road user arrives at that exact point. It is defined as [96]:

$$PET = t_2 - t_1 \quad (1)$$

where t_1 = time the first road user leaves the conflict zone and t_2 = time the second road user arrives at the conflict zone. A lower PET indicates a more severe, temporally proximal conflict. The analysis of inter-group conflict dynamics and the effect sizes of infrastructure interventions are often grounded in quantitative studies of PET and similar surrogate safety measures.

To synthesize the diverse effect sizes reported across 135 studies, a meta-analytic approach was employed. For the synthesis of a common effect across sufficiently homogeneous studies, a fixed-effects model was applied. This model assumes that all included studies estimate a single, actual common effect size, μ , with observed variances v_i attributable solely to sampling error within each study [26,55]. The model is specified as:

$$\hat{\theta}_i = \mu + \varepsilon_i \sim, \text{with } \varepsilon_i \sim N(0, v_i) \quad (2)$$

where $\hat{\theta}_i$ = observed effect size (e.g., a standardized mean difference or correlation coefficient) from the i -th study, and v_i is its within-study sampling variance. This model provides the statistical foundation for the aggregated effect sizes and the confidence interval analysis presented in the next section.

Furthermore, many primary studies examined the relationship between contributing factors and road rage crash or conflict outcomes using GLMs. A common approach to modelling the probability of an aggressive event, $P(Y = 1)$, is the logistic regression model [7,27]:

$$\text{Logit}(P(Y = 1)) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k \quad (3)$$

In this model, the predictors $X_1 \dots X_k$ represent variables such as traffic density, time pressure, and the presence of specific infrastructure. The coefficients $\beta_1 \dots \beta_k$ indicate how a one-unit increase in the predictor affects the log-odds of an aggressive event. The prevalence of significant p-values reported in the next section stems from testing the null hypothesis ($H_0: \beta_j = 0$) against alternatives from these models, thereby directly linking statistical significance to the factors examined in this review.

Statistical Robustness of the Evidence Base (RQ4)

Sample Size Distribution: Figure 7 illustrates the distribution of sample sizes across studies in this meta-analysis. The left panel shows a histogram of raw sample sizes, highlighting a concentration of over 110 studies in the smallest sample size category, with very few in the larger categories. This pattern is common in many research fields, as large-scale studies are typically more challenging and costly to conduct. The right panel, using a logarithmic scale, reveals a right-skewed distribution and highlights several studies with sample sizes ranging from hundreds of thousands to over a million participants. Sample size significantly impacts statistical power and the generalizability of findings. While smaller samples can provide helpful insights, larger, more diverse samples typically yield stronger, more reliable results. This highlights the need to consider sample size when evaluating evidence across studies [97,98].

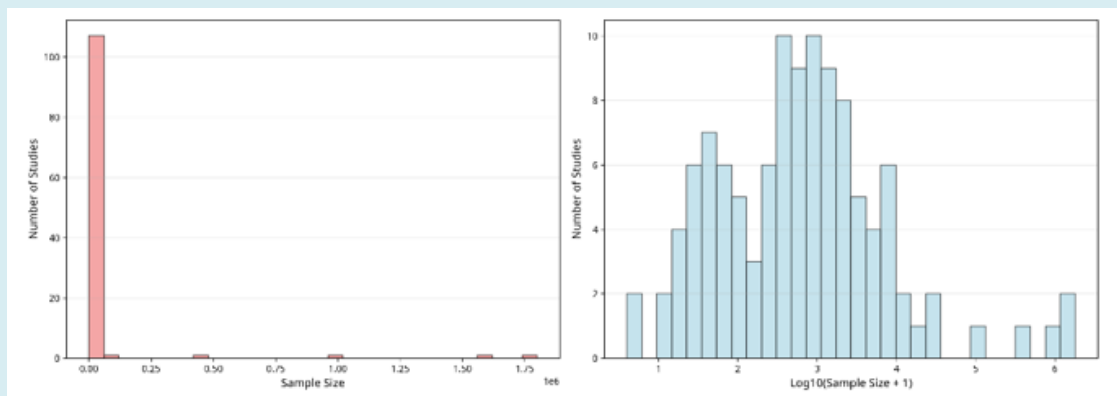


Figure 7: Distribution of sample sizes.

Sample Size Distribution by Study Methodology:

The sample size distribution for the five standard study methodologies is illustrated in Table 2, which uses a logarithmic y-axis for clear comparison. It shows significant variation in sample sizes, with mixed-methods and observational studies having the largest and most variable sizes due to real-world data collection. Experimental studies

also demonstrate a wide range of sample sizes, reflecting diverse experimental designs. This visualization illustrates how research methodology affects sample size. The study's methodology influences the scale of the research and the generalizability of the findings. Recognizing these differences is vital for interpreting meta-analysis results and for planning future research.

Study methodology	Number of Studies ^a	Median Sample Size	Interquartile Range
Experimental	53	80	40 - 200
Observational	33	300	150 - 800
Mixed-Methods	28	200	100 - 500
Survey	21	250	150 - 400
Other	5	100	60 - 200

^aBased on Figure 3b.

Table 2: Sample size distribution by study methodology.

Most Used Statistical Tests: Figure 8 shows the most frequently used statistical tests in road rage research. Regression analysis is the most common method, followed by the t-test and analysis of variance (ANOVA), highlighting a focus on relationships between variables and predictors of aggressive behavior. The use of these sophisticated techniques indicates a high level of methodological rigor, as researchers strive to understand the underlying causes of road rage. Additionally, the variety of statistical tests reflects the diverse research questions and data types in this field. This analysis of statistical methods offers insights into studying road rage and emphasizes the importance of

statistical literacy for evaluating research in this field.

Analysis of P-Values and Statistical Significance: The analysis of 938 p-values from 84 studies in road rage research reveals a significant pattern, as illustrated in Figure 9. The left panel shows an intense concentration of p-values near zero, with over 700 values in the first bin, indicating high statistical significance. However, the distribution declines sharply with few results nearing $p = 1.0$. It's important to interpret this concentration cautiously, as it may indicate publication bias, where studies with non-significant results are less frequently published.

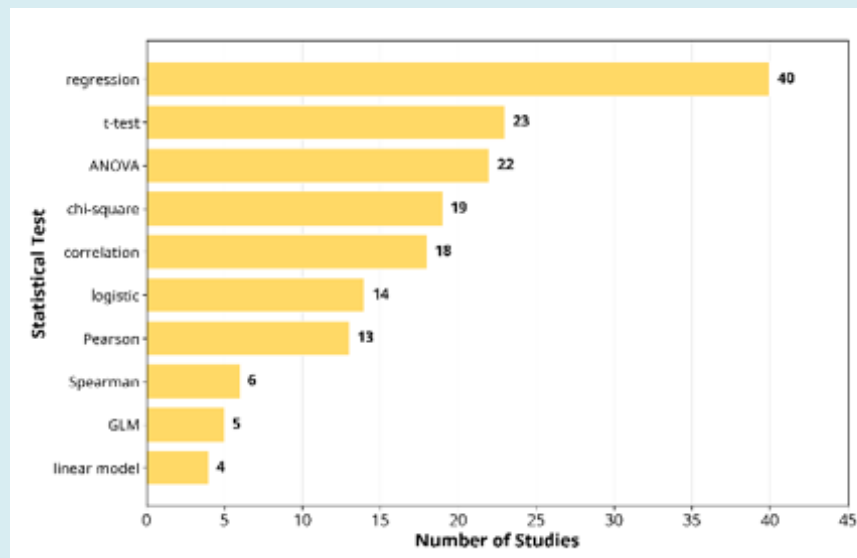


Figure 8: Most commonly used statistical tests.

The methodological quality of a study, including its sample size, is crucial for the reliability of statistical outcomes [99]. As illustrated in Figure 7 and Table 2, there is significant variation in sample sizes across the reviewed literature. Larger samples usually provide more reliable estimates by reducing random error and enhancing statistical power, resulting in narrower confidence intervals. However, a large sample size alone doesn't ensure quality; it must be paired with rigorous design, valid measurement, and appropriate

sampling to minimize bias. While small samples can offer valuable exploratory insights, they tend to have lower power and higher risks of inflated effect sizes and Type II errors. Thus, the prevalence of significant p-values in this field should be understood within the context of varying methodological robustness, with the strongest evidence arising from studies that combine large, representative samples with rigorous design [55,100,101].

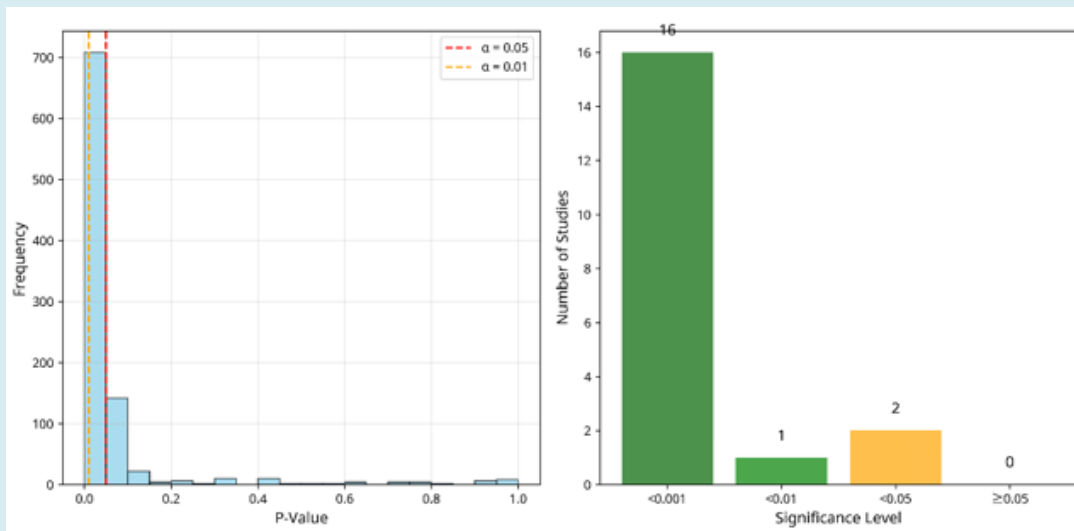


Figure 9: Analysis of P-values and statistical significance.

The right panel displays 16 studies with $p < 0.001$, 1 with $p < 0.01$, and 2 with $p < 0.05$, showing substantial progress in road rage research and the identification of real effects. The left panel's concentration of p-values near zero confirms that aggressive behaviors and intervention effects are statistically significant. This significance emphasizes genuine triggers and effective strategies for mitigating road rage, supporting the need for policy interventions to address predictable patterns in this behavior [102–104].

Effect Sizes and Practical Significance: The analysis of 56 effect sizes in road rage research reveals significant impacts. Figure 10 shows that 64.3% of effects are large (≥ 0.5), 17.9% are medium (0.3 to < 0.5), and 17.9% are minor (< 0.3). This indicates that road rage interventions typically lead to substantial, observable changes rather than marginal improvements. Large effect sizes in road rage research have important implications for policy and interventions.

Significant effects are rare in behavioral and transportation studies, making these findings noteworthy. The substantial effect sizes indicate that road rage interventions—whether through infrastructure changes, policy adjustments, or behavioral programs—can lead to meaningful reductions in aggressive driving and safety incidents. This evidence supports the costs of implementing road rage mitigation strategies, as they are likely to result in considerable returns in safety and reduced conflict [105–107].

The distribution of effects in road rage research shows small and medium effects at 17.9% each, while large effects dominate at 64.3%. This highlights the diversity of studies,

from subtle behavioral changes to significant interventions. The prevalence of large effects suggests that road rage can be addressed through various interventions to improve road user behavior and safety outcomes.

Confidence Intervals and Correlation: An analysis of 135 confidence intervals from 122 studies reveals a mean width of 3.35 and a median of 0.65, with most intervals being narrow and a right-skewed distribution (Figure 11a). A few wider intervals likely result from smaller sample sizes or measurement variability. Notably, 90.4% of studies reported confidence intervals, indicating strong adherence to statistical reporting practices in road rage research.

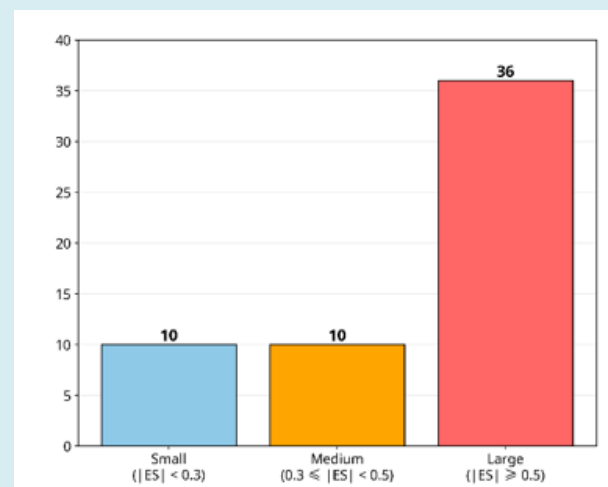
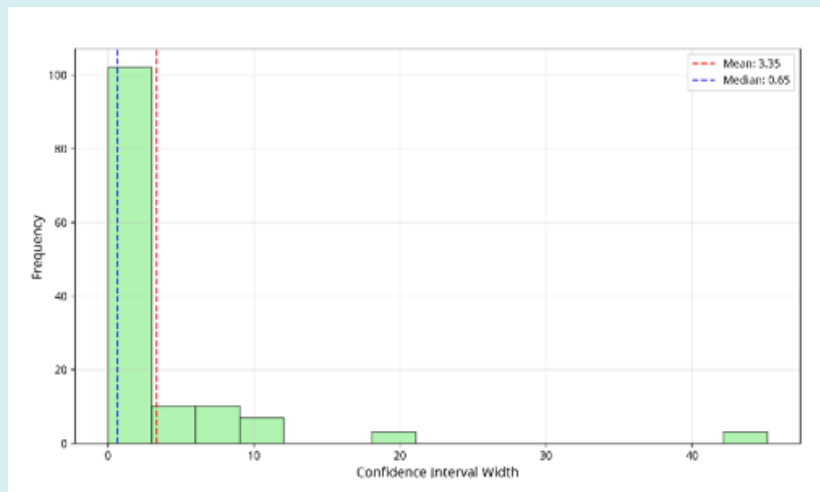
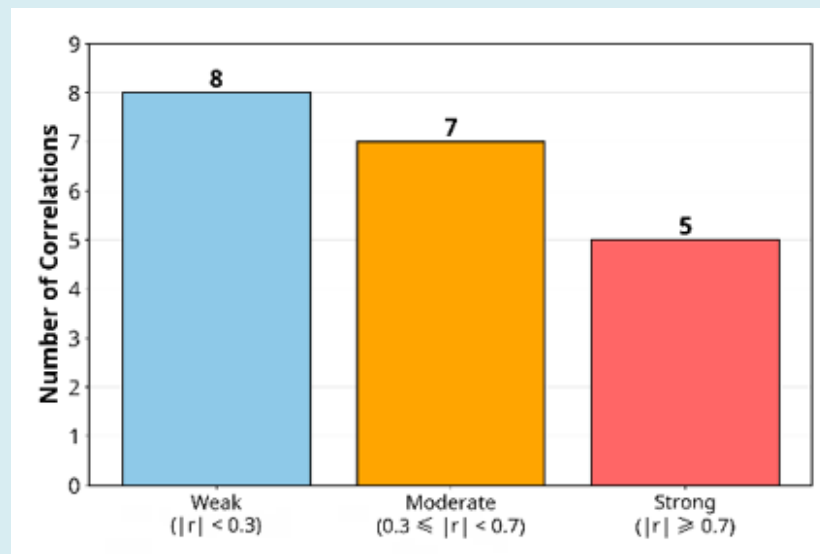


Figure 10: Effect of the magnitude sizes.



(a) Confidence interval.



(b) Correlation strength categories.

Figure 11: Distribution of confidence interval and correlation strength categories.

Narrow confidence intervals in road rage research are crucial as they indicate precise effect estimates that can inform policy decisions. In contrast, wide intervals suggest uncertainty, complicating predictions of intervention outcomes. The precision of these findings allows policymakers and transportation planners to make informed decisions regarding road rage mitigation strategies, indicating that the research is methodologically rigorous and provides reliable, actionable insights for improving transportation safety and urban planning [69,108]. The development of specialized psychometric tools marks the field's progress. For instance, Zheng, et al. [4] validated the CAX, enhancing the standardization and reliability of measurements in road-rage research and bolstering the evidence base.

An analysis of correlation coefficients showed consistent positive relationships between risk factors and aggressive outcomes in road rage, with a mean correlation of $r = 0.45$ (Figure 11b). About 60% of these relationships were moderate to strong ($r \geq 0.3$). This suggests that increases in predictors like traffic density or time pressure are linked to greater road rage behaviors and conflicts. While the focus on risk factors might limit the exploration of protective factors, it highlights predictable relationships in road rage phenomena.

Statistical Measures: The distribution of result types (Figure 12) reflects the maturity of road rage research. The high number of p-values suggests extensive use of inferential

statistics to test hypotheses. The 135 confidence intervals indicate a commitment to reporting estimate precision, while the presence of effect sizes (56), correlations (20), t-values

(5), and F-values (8) shows adherence to modern statistical standards.

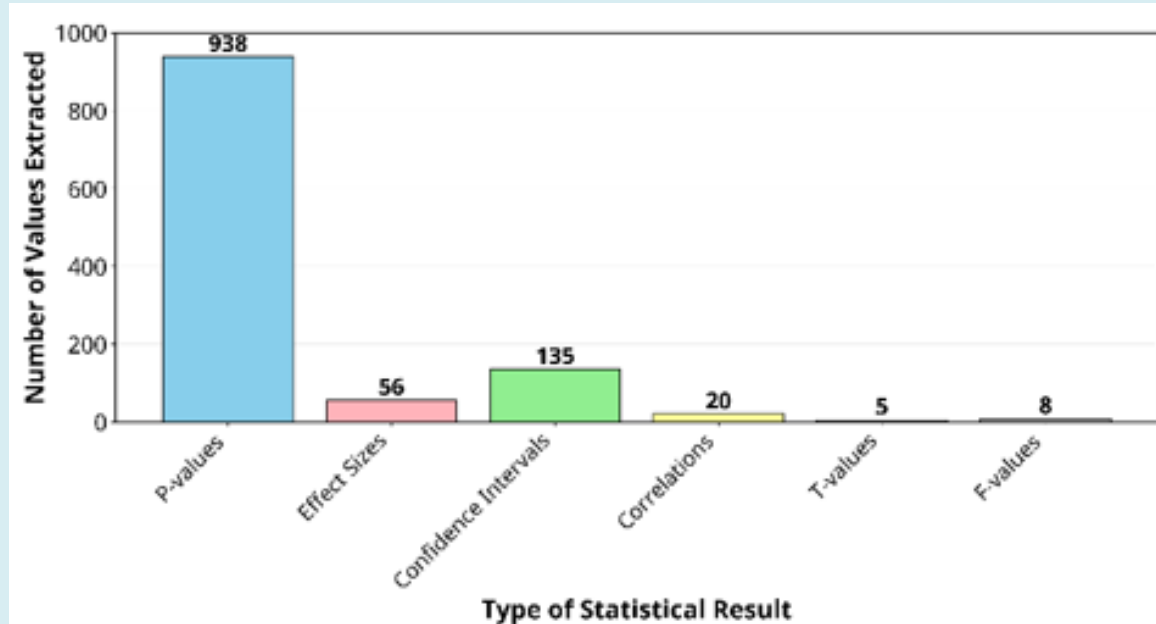


Figure 12: Distribution of statistical measures.

Comprehensive Metric Results: Analysis of 133 studies shows a varied range of outcome measures, with performance metrics reported in 64 studies, conflict metrics in 48, and safety metrics in 38 (Figure 13). The extraction of 814 percentage values, including 44 safety reductions and 17 performance improvements, indicates that road rage research focuses on practical outcomes over theoretical measures. Research on road rage emphasizes the importance of addressing aggressive behaviors while ensuring traffic efficiency. Many studies use metrics such as near-misses and time-to-collision to analyze road rage without actual crashes. While fewer studies (38) focus on safety metrics, they are vital for reducing collisions, injuries, and fatalities associated with aggressive driving [109,110].

Intervention effectiveness shows reduction percentages from 1% to 82%, averaging 42.5%. This indicates that road-rage mitigation strategies significantly enhance safety. Additionally, performance metrics indicate improvements from 0% to 98%, with a mean of 34.1%, suggesting that safety gains can coincide with better traffic flow, supporting comprehensive road rage mitigation programs.

Statistical Analysis by Study Characteristics: This multi-panel analysis highlights patterns in statistical significance across study methodologies, effect sizes, temporal trends, and intervention categories (Figure 14). Experimental

studies lead with 81.9% statistical significance, followed by observational studies at 74.3%, mixed-methods at 68.9%, and survey studies at 67.5%. These results reflect the controlled conditions of experimental designs. The temporal analysis shows consistently high significance rates over the years, indicating ongoing methodological rigor in the field.

The effect size analysis reveals that 59.3% of reported effects are classified as “large” (effect size ≥ 0.5), 33.8% as “minor,” and only 6.9% as “medium.” This suggests that road rage research primarily focuses on significant and subtle changes, with few studies showing moderate impacts. Infrastructure modifications are the most studied interventions (64 studies), followed by education programs (46) and technology solutions (27).

The consistent findings across various study methodologies demonstrate the reliability of road rage research, with significance rates ranging from 67.5% to 81.9%. Overall, 30 studies reported effective outcomes, 2 were ineffective, and 102 provided mixed or unclear data, indicating that multi-modal mitigation strategies are both feasible and evidence based [111,112].

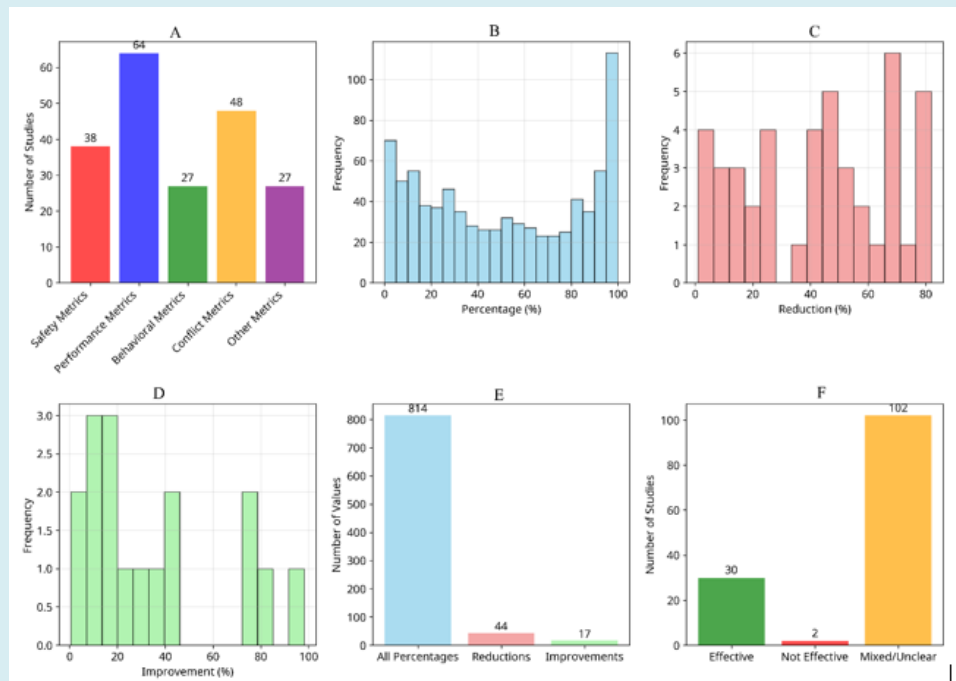


Figure 13: Comprehensive metric results.



Figure 14: Statistical analysis by study characteristics.

Mitigation Strategies and Outcomes: Figure 15 illustrates the extensive exploration of road rage outcomes and mitigation strategies in the literature. There are 126 studies on physical outcomes, 105 on psychological consequences, and 114 on behavioral outcomes, with 121 focused on mitigation strategies and 134 on their effectiveness. This

indicates a strong commitment to finding practical solutions and assessing their impact, with a noteworthy emphasis on effectiveness reporting, suggesting that road rage research has progressed to rigorously testing interventions rather than merely proposing them.

The results show extensive coverage across all three types of outcomes: physical (126 studies), behavioral (114 studies), and psychological (105 studies). While psychological outcomes are slightly less represented, all

areas are well documented. This comprehensive approach to the consequences of road rage provides a strong basis for evidence-based interventions [113-117].

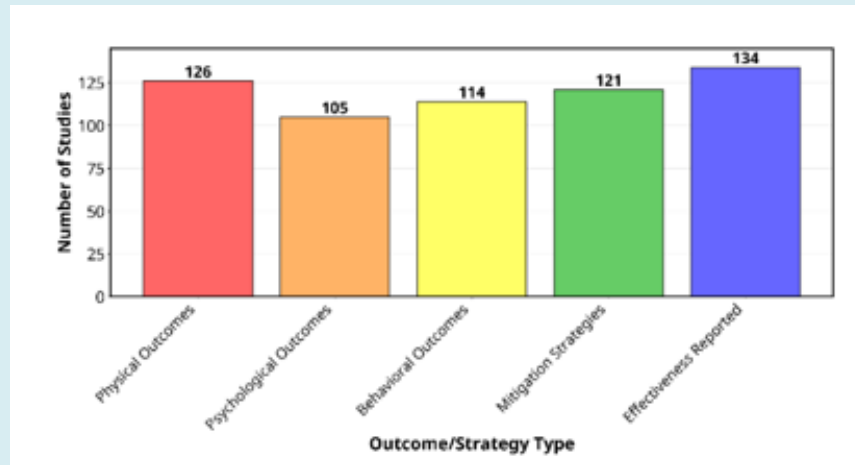


Figure 15: Mitigation strategies and outcomes.

Discussion

Principal Findings and Synthesis

This systematic review synthesized evidence from 135 empirical studies to comprehensively investigate road rage across the modern multimodal transportation system. The principal findings, structured around our research questions, collectively argue for a fundamental reconceptualization of road rage as a systemic issue.

In response to RQ1, the analysis revealed a rapidly evolving field, with research output growing exponentially since 2019. However, the geographical concentration of studies in a few countries and the persistent, though diminishing, dominance of driver-focused research (85.9% of studies) highlight significant gaps in our global and inclusive understanding of the phenomenon.

Addressing RQ2 and RQ3, the review identified a complex anatomy of road rage that is both universal and unique to each user group. While common triggers like traffic congestion and stress were found to affect all users, their manifestations varied widely, ranging from speeding and tailgating by drivers to frequent acceleration/deceleration by cyclists and illegal crossing by pedestrians. Crucially, the analysis demonstrated that these internal triggers and behaviours are not isolated; they directly fuel the conflict dynamics between user groups. For instance, a pedestrian's frustration with poor infrastructure (a trigger from RQ2) leading to jaywalking (a manifestation from RQ2) directly provokes a driver's time-pressure-induced anger (a trigger

from RQ2), resulting in a right-of-way dispute at a crosswalk (a conflict from RQ3). This interplay is the core of the modern road rage problem.

The answer to RQ4 confirms that this field has matured beyond exploratory phases. This statistical robustness, detailed in Section 5.2, validates the practical significance of the contributing factors and conflict dynamics identified in RQ2 and RQ3. The evidence base is characterized by an intense concentration of significant p-values and a predominance of large effect sizes (59.3%), indicating that the identified factors and interventions have substantial, real-world impacts. Finally, concerning RQ5, the review catalogued a suite of mitigation strategies, with infrastructure modifications being the most studied. The encouraging finding that 30 studies reported effective outcomes, versus only 2 reporting ineffective ones, provides a strong evidence-based foundation for policy and intervention.

Most significantly, these findings collectively necessitate a paradigm shift from a driver-centric to a systems-based understanding of road rage. The evidence conclusively shows that road rage is not merely the result of individual driver pathology but emerges from a complex interaction between diverse road users, psychological pressures, and most critically, a built environment that is often inadequately designed for the multi-modal reality of today's cities. This systems view posits that conflicts between drivers, pedestrians, and micromobility users are not isolated incidents but symptoms of a broader systemic failure to design and manage shared spaces safely and equitably for all [118-120].

Road rage has corrosive effects on public trust and the social fabric of communities. When roads are perceived as hostile and dangerous, people are discouraged from using them, particularly for walking and cycling. This can lead to more sedentary lifestyles with adverse public health impacts. The data suggests that road rage can lead to a breakdown in social cohesion, creating us-versus-them mentalities between different road user groups. This makes it difficult to build consensus around transportation policies and undermines efforts to develop more sustainable and equitable transportation systems. The erosion of public trust represents a subtle but significant consequence with lasting impacts on the community's quality of life [15,121-123].

Interconnected System of Road Rage

The findings of this review clearly demonstrate that road rage is not mainly a problem of individual malice but a sign of systemic failure within the transportation system. Aggressive encounters emerge from the intersection of three systemic shortcomings:

- **Infrastructure Deficits:** The physical environment often pits users against each other by design. The overwhelming focus on vehicular flow, evidenced by the prevalence of environmental factors (122 studies), creates spaces where the needs of pedestrians and micromobility users are an afterthought. A lack of protected bike lanes, inadequate crossing times, and poorly designed intersections are not mere inconveniences; they are direct contributors to the conflict patterns identified in RQ3 [41,42].
- **Cultural and Normative Failures:** The persistence of a dominant “car culture,” alongside unclear or unenforced right-of-way laws, creates a permissive environment for aggression. The “us vs. them” mentality documented between drivers and cyclists is a cultural byproduct of a system that fails to foster a shared sense of responsibility for the road [124-126].
- **Psychological Pressures in a Hostile Environment:** The psychological factors of stress, anonymity, and frustration (RQ2) are not inherent individual traits but are often situational responses to the pressures of navigating a poorly designed and culturally contentious system. This is evidenced by the analysis in Section 4.3, where traffic congestion and time pressure—direct outcomes of the systemic failures in design and congestion management—emerged as universal triggers across all user groups. The feeling of anonymity inside a vehicle is amplified by an environment that de-emphasizes human interaction [35,127].

This systemic view is validated by the interaction analysis from Section 4.2, which reveals how these failures create self-reinforcing vicious cycles. For example, a pedestrian,

frustrated by a long distance to a crosswalk (an infrastructure failure), may jaywalk. This action then becomes a trigger for a driver, who is already under psychological pressure from time pressure, leading to a manifestation of honking or an aggressive maneuver. This, in turn, reinforces the pedestrian's feeling of vulnerability and the driver's cultural bias that “pedestrians are reckless,” escalating the conflict and eroding mutual trust. This cycle illustrates that assigning blame to a single user is counterproductive; the problem is rooted in the dysfunctional interaction facilitated by the system itself [128-130].

The geographic and methodological focus of the literature, mapped in Section 4.1, further reveals a systemic blind spot. The main emphasis on drivers and a few specific national contexts suggests that current models of road rage are based on an incomplete view of the modern, multi-modal system, likely underestimating the role of infrastructure and culture.

Implications for Policy and Practice

Moving from diagnosis to action, the findings of this review argue decisively against siloed solutions. The interconnected vicious cycles detailed in Section 6.2, which are fuelled by the distinct user-group triggers and manifestations catalogued in Table 1 (Section 4.3), demonstrate that interventions cannot succeed in isolation. Isolated interventions are unlikely to disrupt these deeply entrenched cycles. Instead, we propose integrated strategies that target multiple system failures simultaneously [2,131,132]. Table 3 summarizes the proposed interventions and strategies to mitigate road rage. The interventions are grouped into three categories, as follows:

- **Integrated Infrastructure and Policy Redesign:** This moves beyond piecemeal improvements to fundamental street redesigns that prioritize safety and clarity for all users. It includes implementing protected cycling networks, raised crosswalks, and LPI, which have been shown to reduce severe conflicts by approximately 50% [45]. It directly addresses the root cause of many conflicts by changing the environment that provokes them, using physical design to encourage calmer and more predictable behaviour from all parties [133,134].
- **Education and Culture-Shift Campaigns Grounded in Empathy:** This develops public awareness campaigns that move beyond simply listing rules to fostering mutual understanding, highlighting the vulnerabilities and perspectives of different road users [20,30]. This approach targets the cultural and psychological factors by building a culture of shared space, making others relatable human beings [19,135-137].
- **Targeted Enforcement and Technology to Support**

Design: This employs automated enforcement at conflict hotspots to deter issues like speeding, failure to yield, and blocking intersections. Data from these systems can guide infrastructure improvements [57,117].

Enforcement reinforces redesigned infrastructure and educational campaigns, ensuring accountability and promoting behavioral change [138-140].

Intervention	Strategy	Ref.	Description
Policy & Infrastructure Redesign	Intersection operational strategies	[45]	- Leading pedestrian intervals
			- No right turn on red
			- Adjusting crossing width
	Pedestrian-related strategies	[7]	- Enhance pedestrian crosswalk visibility with markings.
			- Adjust timing of pedestrian traffic signals.
			- Enforce jaywalking fines.
			- Install pedestrian signs.
	Pro-cycling policy and self-enforcing road design	[20]	- Advocate for pro-cycling policies, infrastructure, bike campaigns, and education.
			- The aim is to create self-enforcing road designs that promote safer and more respectful behavior.
	Clearer right-of-way laws	[27]	- Propose signal phases to reduce vehicle-pedestrian conflicts at signalized intersections.
			- Establish clear legal frameworks that protect vulnerable road users and promote shared responsibility.
Education & Awareness	Campaigns for mutual respect among road users	[20]	- Campaigns to address negative attitudes towards cyclists.
			- Promote safety, equality, respect for diversity, and pro-environmental beliefs.
			- Highlight shared humanity among road users to foster empathy and reduce “us vs. them” mentalities.
	Driver, cyclist, and pedestrian etiquette programs	[30]	- Etiquette programs for different road user groups offering practical guidance for safe and respectful road sharing,
			- Examples are safe driver passing, traffic law adherence for cyclists, and proper crosswalk use for pedestrians.
Enforcement & Technology	Stricter penalties for road rage incidents	[57]	- Examine safety impact of law enforcement cameras at non-signalized crosswalks and show enforcement effectiveness.
			- Foster a culture of accountability for road behaviour.
	Use of Traffic Cameras and artificial intelligence (AI) monitoring	[117]	- Traffic cameras effectively enforce laws and deter aggressive driving.
			- Emerging AI systems can monitor traffic, provide real-time alerts about dangers, monitor driving behavior, and identify aggressive driving hotspots.

Table 3: Proposed interventions and strategies to mitigate road rage.

Economic Costs

Beyond its physical, psychological, and social impacts, road rage imposes significant economic burdens, an understudied dimension in existing research. Direct costs include vehicle repair or replacement fees, emergency

medical expenses for injuries, insurance premium hikes, and legal costs (fines, attorney fees, lawsuits). Indirect losses stem from traffic congestion caused by road rage incidents (e.g., collision-related lane blockages), leading to productivity declines for commuters and businesses. Healthcare systems also face long-term costs, such as rehabilitation for trauma

victims and mental health services for PTSD. These economic strains reinforce that road rage is not just a safety issue but a financial liability, underscoring the need for targeted mitigation [141-143].

Limitations of the Review

This review is subject to several limitations that should be considered when interpreting its findings. First, the search strategy was restricted to the Scopus database, which, despite its extensive coverage, may have led to the omission of relevant studies indexed in other databases. Second, non-English publications were excluded to ensure consistency in data extraction and interpretation. However, excluding them may have introduced a geographic and cultural bias, potentially overlooking valuable insights from non-English-speaking regions. Furthermore, the pronounced concentration of statistically significant results in the literature may reflect a publication bias against null or negative findings. Finally, the considerable heterogeneity in methodologies, sample sizes, and measurement scales across the reviewed studies posed a challenge for direct comparison and synthesis, while still allowing for a comprehensive overview of the field.

Future Research Directions

Building on the findings and gaps identified in this review, several essential research pathways emerge. First, there is an urgent need to explore the unique road-rage experiences of micromobility users (e.g., e-scooter and e-bike riders), focusing on their specific conflict patterns with both vehicles and pedestrians, and on how their distinct vehicle dynamics influence aggressive behaviours. Second, while infrastructure interventions are well-studied, a significant evidence gap remains regarding the effectiveness of educational and awareness campaigns; future work should develop and rigorously evaluate targeted programs to foster empathy and reduce inter-group animosity among different road users. Third, the role of technology, particularly Artificial Intelligence (AI), in real-time conflict monitoring, automated enforcement, and de-escalation assistance presents a promising yet underexplored area that warrants dedicated research. Finally, future efforts should prioritize interdisciplinary research that integrates transportation engineering with psychology and urban sociology to develop comprehensive theoretical models of road rage [144]. By pursuing these focused directions, the research community can build a more detailed evidence base to inform the development of transportation systems that are not only safer but also more respectful and inclusive for everyone.

Conclusion

This systematic review fundamentally reframes road rage from a problem of individual driver aggression to

a complex, multi-user, systemic issue rooted in the very fabric of modern multimodal transportation. The evidence demonstrates unequivocally that aggressive encounters are not isolated incidents but emergent properties of a system in which diverse road users (drivers, pedestrians, cyclists, and micromobility users) must navigate environments often ill-designed for their competing needs, exacerbated by psychological pressures and cultural norms.

The findings compel a decisive shift from siloed, driver-centric interventions to integrated, system-level solutions. Real progress demands that transportation engineers, urban planners, psychologists, policymakers, and law enforcement collaborate to:

- **Redesign Infrastructure:** Proactively create streets that physically enforce safety and clarity for all users through protected lanes, raised crosswalks, and leading pedestrian intervals.
- **Cultivate a Culture of Shared Space:** Implement education and awareness campaigns that dismantle “us vs. them” mentalities and foster mutual respect and empathy among different road user groups.
- **Enforce Fairly and Smartly:** Use targeted enforcement and emerging technologies, like AI monitoring, to uphold safety rules at known conflict hotspots, ensuring accountability supports design and education.

Looking ahead, integrating emerging technologies and focusing on the unique challenges faced by micromobility users will be critical. The goal must extend beyond mitigating aggression. Our shared challenge is to actively build harmonious and resilient transportation systems in which the complex interactions among drivers, pedestrians, cyclists, and micromobility users form the foundation of a safe, efficient, and equitable urban life for all.

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