Watch Out! E-scooter Coming Through!: Multimodal Sensing of Mixed Traffic Use and Conflicts Through Riders' Ego-centric Views

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E-scooters are becoming a popular means of urban transportation. However, this increased popularity brings challenges, such as road accidents and conflicts when sharing space with traditional transport modes. An in-depth understanding of e-scooter rider behaviour is crucial for ensuring rider safety, guiding infrastructure planning, and enforcing traffic rules. In this paper, we investigated the riding behaviours of e-scooter users through a naturalistic study. We recruited 23 participants, equipped with a bike computer, eye-tracking glasses and cameras, who traversed a pre-determined route, enabling the collection of multi-modal data. We analysed and compared gaze movements, continuous speed, and video feeds across three different transport infrastructure types: a pedestrian-shared path, a cycle lane and a roadway. Our findings reveal that e-scooter riders face unique challenges, including difficulty keeping up with faster-moving cyclists and motor vehicles due to the capped speed limit on shared e-scooters, issues in safely signalling turns due to the risks of losing control when using hand signals, and limited acceptance from other road users in mixed-use spaces. Additionally, we observed that the cycle lane has the highest average speed, the least frequency of speed change points, and the least head movements, supporting the suitability of dedicated cycle lanes – separated from motor vehicles and pedestrians – for e-scooters. These findings are facilitated through multimodal sensing and analysing the e-scooter riders' ego-centric view, which show the efficacy of our method in discovering the behavioural dynamics of the riders in the wild. Our study highlights the critical need to align infrastructure with user behaviour to improve safety and emphasises the importance of targeted safety measures and regulations, especially when e-scooter riders share spaces with pedestrians or motor vehicles. The dataset and analysis code are available at https://github.com/HiruniNuwanthika/Electric-Scooter-Riders-Multi-Modal-Data-Analysis.git.

Additional Key Words and Phrases: micro-mobility, e-scooter, rider behaviour, road users, eye-tracking, video analysis, speed variations

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1 INTRODUCTION

Micro-mobility is emerging as a significant mode of urban transport due to its various benefits. Micro-mobility promotes environmental sustainability, mitigates traffic congestion, and fosters healthier lifestyles [53, 68]. With

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the proliferation of micro-mobility solutions, there is a critical need for an in-depth understanding of rider behaviour as a way to address road safety issues. Previous research shows the importance of examining rider behaviour to ensure rider safety [10], improve infrastructure [80], adopt practices [14], and enforce traffic rules [69]. E-scooters have become a prominent area of research for several reasons: (1) They introduce a novel experience for both riders and other road users who interact with them, presenting unique challenges and dynamics within public spaces [66]. (2) They are permitted on multiple transport infrastructure, that are allocated for traditional transport modes [50, 66]. (3) Although e-scooters are often considered similar to bicycles, they differ in terms of usage patterns and social acceptance [4, 50]. It is evidenced by recent discussions at UBICOMP [62, 63] and CHI [31, 50, 66].

Traditional methods such as interviews [29], survey [43], and observations [6] have been commonly employed for the analysis of rider behaviour. However, these approaches are subject to limitations, including potential recall bias and subjectivity in responses [15]. By integrating real-time speed, gaze behaviour data and ego-centric video analysis with traditional methods, we aim to obtain a more accurate and comprehensive understanding of rider behaviour. Although previous research has successfully used multi-modal data collection methods, such as video feeds, accelerometer and eye-tracking data [22, 37, 58, 82] to analyse cyclists' behaviour, these studies primarily focused on bicycles.

Cities adopt different infrastructure policies for e-scooters, allowing them to operate on various types of transport infrastructure [7, 24]. Given the novelty of e-scooters, there is still uncertainty surrounding optimal infrastructure adaptation and rider integration. This variation in infrastructure influences rider behaviour, infrastructure adaptability, and interactions with other road users. However, studies on e-scooter rider behaviour across various types of infrastructure remain limited. To address this gap, we conduct a comparative analysis of rider behaviour across three different infrastructure types.

Inspired by existing naturalistic studies on cycling behaviour, we conducted a study to investigate the variations in e-scooter rider behaviour across different transport infrastructures. Our approach combined quantitative and qualitative analyses to examine various aspects of e-scooter rider behaviour. Specifically, we compared continuous speed, gaze movements, head movements, and fixated Areas of Interest (AOIs) of e-scooter riders when navigating three distinct types of transport infrastructure: pedestrian-shared paths, cycle lanes, and roadways. We used Tobii Pro 3 Glasses, Garmin Edge 130 Plus bike computer, Insta 360 camera, and GoPro HERO 10 Camera for data collection. The main contributions of our work include:

- We collected a multi-modal dataset through a naturalistic study converging various mobility infrastructures. The features characterising rider behaviour (e.g., speed, eye movement, head movements, gestures) were identified from the literature and appropriate devices to capture each of these were selected. To ensure reproducibility and support future micro-mobility modeling, we have made the dataset (excluding collected videos due to privacy concerns) and analysis code publicly available[1].
- We applied a combination of multi-modal data analysis methods, established in the literature, to the novel context of e-scooter use. This approach enabled us to derive valuable insights into e-scooter rider behaviour, interactions, conflicts, and responses of other road users.

The rest of the paper is structured as follows. Section 2 distinguishes e-scooter riding behaviour from cycling and reviews the existing literature. In Section 3, we present the naturalistic study design followed by the data analysis process. The results of our study are presented in Section 4. Section 5 offers a discussion of the findings. In Section 6, limitations and future work are discussed. Finally, we conclude the paper in Section 7.

[1] https://github.com/HiruniNuwanthika/Electric-Scooter-Riders-Multi-Modal-Data-Analysis.git