E-Scooter Dynamics: Unveiling Rider Behaviours and Interactions with Road Users through Multi-Modal Data Analysis

Hiruni Kegalle
RMIT University
Melbourne, Australia

Danula Hettiachchi
RMIT University
Melbourne, Australia

Jeffrey Chan
RMIT University
Melbourne, Australia

Flora Salim
University of New South Wales
Sydney, Australia

Mark Sanderson
RMIT University
Melbourne, Australia

ABSTRACT

Electric scooters (e-scooters), characterised by their small size and lightweight design, have revolutionised urban commuting experiences. Their adaptability to multiple mobility infrastructures introduces advantages for users, enhancing the efficiency and flexibility of urban transit. However, this versatility also causes potential challenges, including increased interactions and conflicts with other road users. Previous research has primarily focused on historical trip data, leaving a gap in our understanding of real-time e-scooter user behaviours and interactions. To bridge this gap, we propose a novel multi-modal data collection and integrated data analysis methodology, aimed at capturing the dynamic behaviours of e-scooter riders and their interactions with other road users in real-world settings. We present the study setup and the analysis approach we used for an *in the wild* study with 15 participants, each traversing a pre-determined route equipped with off-the-shelf commercially available devices (e.g., cameras, bike computers) and eye-tracking glasses.

KEYWORDS

Micro-mobility, E-scooter, Road User Interaction, Eye-tracking, Speed, Video Analysis

ACM Reference Format:
Hiruni Kegalle, Danula Hettiachchi, Jeffrey Chan, Flora Salim, and Mark Sanderson. 2024. E-Scooter Dynamics: Unveiling Rider Behaviours and Interactions with Road Users through Multi-Modal Data Analysis. In *The Augmented Humans International Conference (AHs 2024), April 04–06, 2024, Melbourne, VIC, Australia.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3652920.3653056

1 INTRODUCTION

Micro-mobility has emerged as a prevalent mode of urban transportation, offering a sustainable alternative to conventional vehicles by mitigating traffic congestion and promoting active lifestyles [23, 31]. Particularly, e-scooters are rapidly adopted both as personal and rental vehicles for several reasons, including their efficient electric propulsion system, versatility in navigating various transport infrastructures [3, 29], and the convenience of parking them without the need for specific parking spaces. However, their proliferation has led to safety concerns and conflicts in shared spaces with traditional transportation methods. Problems such as blocking walkways [7], disruption of parking arrangements [19], and an increase in accidents [28, 34] underscore the need for technological solutions and regulatory frameworks.

To develop effective policies or technological interventions, it is important to thoroughly understand the behaviours of e-scooter riders and their interactions with other road users within real-world environments. Nonetheless, the acquisition and analysis of such data present considerable challenges. These include ethical concerns [12, 15], the unpredictability inherent in natural settings, the need to maintain consistent data quality [11, 22], and technical limitations such as device battery life and internet connectivity. Furthermore, data gathered from real-world environments tend to be more heterogeneous and complex compared to those obtained from controlled experimental settings.

Addressing these challenges, we designed a study aimed at understanding the usage patterns of e-scooters across various mobility infrastructures. Our research investigates the behaviours of riders and their interaction dynamics with other road users in natural settings. We developed an experimental setup that involves collecting data from a range of off-the-shelf devices, followed by an integrated analysis of data.

2 RELATED WORKS

As e-scooters gain popularity in urban areas, quantitative studies based on historical trip data were used for demand forecasting [10, 27], usage patterns identification [4, 13, 14], and measuring the infrastructure utilisation [17, 35–37]. Another line of work looked at accident reports to determine the injury patterns after e-scooter incidents [20, 24, 28]. Although these studies offer measurable data on e-scooter utilisation, they do not effectively capture the nuances and complexities of real-world interactions between riders and other road users.

To explore the dynamics of e-scooter riders, researchers have employed a range of other methodologies, such as interviews [7, 19, 29], surveys [8, 21], media report analysis [9], and observations [1, 5, 29, 30]. While these approaches provide valuable insights, they may be subject to personal biases or inaccuracies inherent in self-reporting [33]. Contrarily, the use of sensors and cameras offers a more objective record of events, capturing the details of user

AHs 2024, April 04–06, 2024, Melbourne, VIC, Australia

ACM ISBN 979-8-4007-0980-7/24/04
https://doi.org/10.1145/3652920.3653056

behaviour (e.g., reaction times) that individuals may not consciously acknowledge. Additionally, studies conducted *in the wild* reveal complex and unpredictable interactions, that might not be fully remembered or reported by participants in interviews or surveys.

3 METHOD

Our study employed the Naturalistic Observation approach [2] to examine the interactions between e-scooter riders and other road users in their natural environment. Participants navigated a pre-determined route equipped with various devices, such as eye-tracking glasses and a helmet-mounted 360-view camera. Additionally, the riding behaviour of each participant was recorded using a chest-mounted camera worn by another following rider (e.g., researcher). This study design was chosen to ensure that participants exhibit their natural riding behaviour and genuine interaction patterns.

3.1 Devices

Referring to Figure 1, the Tobii Pro Glasses 3 eye-tracker was used to record gaze movements from a first-person viewpoint. The device's lightweight design and the convenience provided by its portable control unit were key factors in its selection, ensuring its usability during riding scenarios. Participants were also equipped with a helmet-mounted Insta360 X3 camera, chosen for its capability to capture a comprehensive 360-degree view. The participant's e-scooter was embedded with a Garmin Edge 130 Plus bike computer for gathering GPS and speed data. Its lightweight and compact design was chosen to ensure it did not inconvenience the rider. This bike computer features an extended battery life, and its collected data can be conveniently exported via a web portal. The behavior of the participant was recorded by a trailing researcher using a chest-mounted GoPro HERO 10 camera.

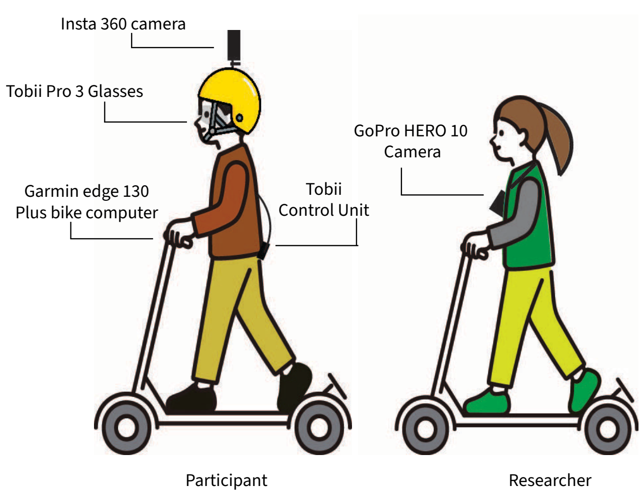

Figure 1: Participant equipped with Insta 360 camera, Tobii Pro 3 Glasses, Garmin edge 130 Plus bike computer and a following rider equipped with GoPro HERO 10 Camera.

3.2 Procedure

We started with an introductory session where we outlined the study goals, equipment to be used, and data that would be collected. Participants were also provided with a document detailing the local traffic laws pertaining to e-scooter usage. We then confirmed the participant's age and received their verbal acknowledgement of previous e-scooter experience. Following this, we helped the participants put on the helmet-mounted camera and eye-tracking glasses, and performed standard calibration of the eye tracker. A safety officer from our team inspected the equipment setup for compliance and safety.

After ensuring everything was correctly set up, we mounted the bike computer on the participant's e-scooter. Then we provided a brief period for participants to acclimate themselves by riding the e-scooter in a secure test area. Before proceeding with the study, we confirmed verbally that the participants felt comfortable and confident using the e-scooter while equipped with the study devices.

With the preparatory steps completed, we began to record data simultaneously from all devices. Upon the completion of each participant's ride, we conducted a brief interview to gather their feedback on the study experience and discuss any significant interactions they had during their ride.

3.3 Analysis

Data collected from distinct devices required a specific method of analysis as depicted in Figure 2. For eye movement data, we applied the fixation-by-fixation approach [25, 32], using the Tobii Pro Lab software. Since the automated object detection with a pre-trained Region-Based Convolutional Neural Network (R-CNN) model [26] showed limited accuracy (mean pedestrian detection recall = 10.5%, mean car detection recall = 15.1%), we performed manual annotation- assigning each fixation to its corresponding Area of Interest (AOI).

The speed data analysis commenced with pre-processing, and we used a Python script to identify speed change points, implementing the Pruned Exact Linear Time (PELT) algorithm [6] (optimal penalty using Akaike Information Criterion). To validate the speed change points detected, we used data visualisation. The causes behind speed alterations, were revealed by reviewing GoPro footage corresponding to these timestamps. The methodology of combining automated anomaly detection with manual review, is often embraced in pervasive computing studies [16, 18].

The manual analysis of GoPro and Insta360 videos aimed to discover the navigational methods of riders and other road users' responses during encounters.

4 RESULTS

Based on the data collected from 15 participants, we conducted a quantitative comparison of speed, gaze fixations, and encounters across three types of infrastructure (e.g., pedestrian-cycle shared paths, designated cycle lanes, motor vehicle-cycle shared lanes). The findings revealed that designated cycle lane provided a more efficient and safer riding experience, evidenced by higher average speeds with fewer interruptions. Conversely, lanes shared with motor vehicles were associated with the lowest average speeds and

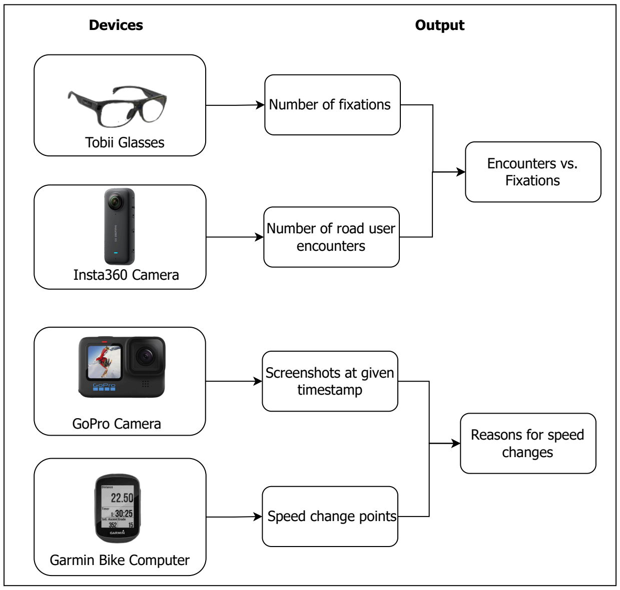

Figure 2: Data analysis workflow.

a higher frequency of fixations, indicating an increased perception of risk and a need for continuous vigilance. Additionally, our results showed that riders tended to reduce their speed on pedestrian-cycle shared paths, likely as a precautionary measure to safely coexist with pedestrian traffic. Further, our study uncovered challenges riders faced when navigating through groups of pedestrians, compared to manoeuvring around individual pedestrians and noted various strategies employed by riders to negotiate their way, through mixed traffic environments, including the use of bells, off-road movements, hand signals, head movements, and verbal interactions.

5 CONCLUSION

With the prevalent use of e-scooters in urban areas, interactions and conflicts between riders and other road users are becoming more frequent. Our novel approach of *in the wild* multi-modal data collection and integrative data analysis can offer insights that are crucial for urban infrastructure planning and policy formulation. Moreover, the findings hold significant value for the design of technological interventions, including sensor-based collision avoidance systems and AI-enhanced micro-mobility solutions, aimed at enhancing the safety of both riders and other road users.

ACKNOWLEDGMENTS

This research was conducted by the ARC Centre of Excellence for Automated Decision-Making and Society (project number CE200100005), and funded by the Australian Government through the Australian Research Council. We gratefully acknowledge the City of Melbourne and Lime Mobility for supporting us.

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