



GAZE PATTERNS OF E-SCOOTER RIDERS AT URBAN INTERSECTIONS: A REAL-WORLD EYE-TRACKING STUDY

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Abstract

Electric scooters have emerged as an increasingly popular means of micromobility, but their rise has sparked divided reactions from both the public and users of the transport system. There are still many challenges to the optimal use of e-scooters, related to users and infrastructure, and this is one of the reasons for a significant research gap in this area. Understanding how e-scooter riders perceive and navigate safety-critical situations is essential to improving the integration of micromobility into urban traffic environments. This study investigates gaze patterns of 28 e-scooter riders as they approach signalized intersections at varying distances from the stop line. The experiment was conducted in real-world conditions using the eye-tracking method. The results show differences in riders' visual attention between distances from the intersection, with higher fixation activity observed closer to the stop line. Heatmap analysis indicates that fixations shift from the riding path at longer distances to traffic-related areas near the intersection. Findings contribute to a better understanding of how e-scooter riders visually monitor the traffic environment as they approach intersections in urban areas.

Keywords: e-scooter, visual attention, eye-tracking, micromobility safety, urban environment

1 Introduction

The rapid development of technology, coupled with the growing need for people to move faster, more cost-effectively, and more efficiently, is driving the development of various transportation solutions [1, 2]. One such solution, primarily intended for micromobility, is the e-scooter. E-scooters have become a widespread mode of urban micro-mobility, serving both private and shared-rental purposes [3]. Although the aforementioned means of transportation have several benefits (e.g. affordability, portability, speed, small footprint, etc.), their presence in traffic has raised some challenges [4, 5]. The rapid increase in injuries and fatalities associated with e-scooter use underscores the necessity for enhanced safety measures and evidence-based urban planning to manage their expansion [6].

For example, improper or reckless use of e-scooters can lead to serious consequences in the event of a crash. Failure to comply with traffic rules and technical malfunctions of vehicles are also potential problems, in addition to the fact that younger minors often purchase e-scooters as a form of entertainment. An additional problem arises due to the often inadequate or non-existent infrastructure that would ensure the safe movement of e-scooter riders [7-9].

Previous research has primarily used emergency room records and media reports to collect crash data and conduct safety analyses [10, 11]. Badeau et al. analyzed treatment records from two emergency departments and reported that 44% of e-scooter incidents occurred on sidewalks [11].

Yang et al. examined 169 e-scooter-related crashes in the United States between 2017 and 2019 and found that most occurred on streets, at intersections, and on sidewalks (10).

Although e-scooters are increasingly common, studies utilizing naturalistic methods to evaluate their safety are scarce [12]. Cano-Moreno et al. (2022) and Ma et al. (2023) assessed the risks posed by e-scooter vibrations, which influence riding comfort based on road surface and wheel size [13, 14]. Ma et al. (2021) also investigated e-scooter interactions with urban infrastructure, concluding that vibrations, speed fluctuations, and environmental constraints elevate safety risks [15]. These findings highlight the importance of research to guide infrastructure and policy development. On the other hand, eye-tracking research has emerged as a valuable method for objectively measuring visual attention, enabling detailed analysis of how micromobility users monitor their surroundings during riding tasks [16, 17]. Pashkevich et al. (2022) used mobile eye-tracking to compare visual attention among pedestrians, cyclists, and e-scooter users, revealing that while fixation rates per minute were similar, the distribution of visual attention varied significantly between groups [18]. However, this study did not consider diverse traffic conditions.

On the other hand, intersections are widely acknowledged as problematic nodes for bicycle travel [19, 20]. In Europe, 31% of cyclist fatalities occur at junctions (21). Multiple studies have identified an elevated risk of bicycle crashes at intersections compared to other road segments [22-26]. Given the operational similarities between bicycles and e-scooters in urban traffic, intersections are also likely to represent critical risk locations for e-scooter riders. However, comparable real-world evidence focusing on e-scooter users remains limited, particularly regarding the specific intersection conditions that contribute to this increased risk, including potential physiological responses.

This paper focuses on specific parts of the urban environment. Precisely, the approach of e-scooter riders to pedestrian crossings controlled by traffic signs and traffic lights was observed. The aim was to examine the gaze behavior of e-scooter riders when approaching safety-critical elements of urban infrastructure, like intersections with pedestrian crossings. An additional objective was to explore potential gaps in hazard anticipation during the approach to pedestrian crossings and intersections, as indicated by fixation count, fixation duration, and spatial distribution of gaze.

2 Research methodology

2.1 Participants

A sample of 28 adults (average age: 30.0 ± 5.1 years) took part in the study. The group comprised 21 males and 7 females. Before the test drive began, participants had to read and sign a consent form for participation in the study. All of them were volunteers, not compensated in any way for their efforts. Participants were given verbal instructions describing the experimental procedure and the intended riding route. They were instructed to follow the predefined route, obey traffic rules, ride safely, and behave as they normally would during everyday e-scooter use. Ethical and data security guidelines set by University of Zagreb Faculty of Transport and Traffic Sciences were followed at all times and appropriate consent was signed.

2.2 Equipment and experiment setup

A typical e-scooter was provided for each subject, along with a reflective vest, helmet, and knee and elbow pads. Gaze behavior was recorded using Tobii Pro Eye Tracking Glasses 2. The collected data was processed using Tobii Pro Lab software. For each participant, eye tracking glasses were calibrated prior to the experiment.

Each participant completed a ride of an approximate length of 0.9 km between August and November 2025. For this paper, typical conflict situations were selected, focusing on the approach to signalized intersections with a single traffic light controlling traffic that continues straight or turns left. Figure 1 illustrates the experimental route, including the start point and the signalized intersections (micro-locations ML1 and ML2) selected as test locations for the intersection approach analysis. All participants rode the same route where two signalized intersections were taken as examination MLs: at one, they continued straight (ML1), and at the other, they turned left (ML2). At each ML, there were two examination points – 30 meters and 10 meters prior to the intersection stop line.

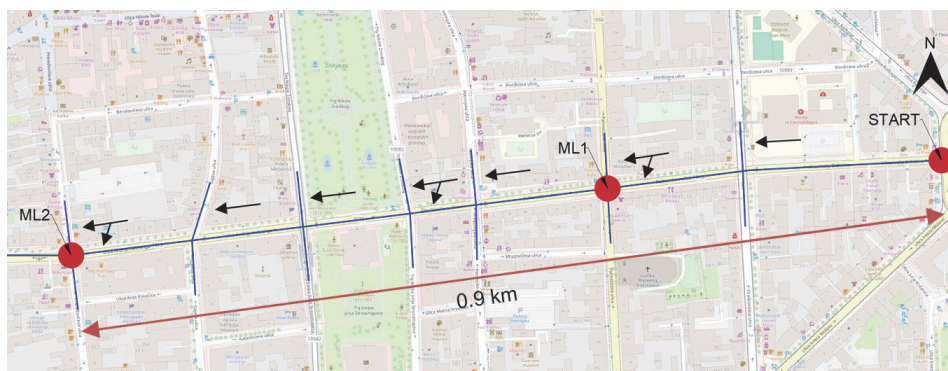


Figure 1 Experimental route showing the start point and the selected signalized intersection test locations (ML1 and ML2)

In all situations, the movement of e-scooter riders was observed during the green light at the traffic light, to ensure uniform conditions for comparison and free-flow traffic. The intersection approach test points were located along a route where the bike lane was marked on the roadway (left-most) in the direction of motor vehicle traffic (one-way multi-lane street).

2.3 Data analysis

The first part of the analysis was conducted using the aforementioned Tobii Pro Lab software. On each recording in the software, event tags were placed 30 and 10 meters in front of the stop line, thereby creating the desired Time of Interest (TOI) interval (average TOI duration: 0.78 ± 0.27 sec), to assess gaze behavior in the intersection-approaching zones. Fixation and saccade rates were computed as the count of events overlapping the time-of-interest window, normalized by the duration of the TOI (events per second).

Basic gaze metric data (fixations, saccades) were extracted for each TOI and each participant. After that, the mapping of the view to the screenshot was carried out (the screenshot was made from the recording). For each TOI, a representative screenshot was selected from the recording at approximately 10 m and 30 m before the stop line. These data were further used to create heatmaps, which visually represent the distribution of riders' gaze. A linear mixed-effects model (LLM) (fixation-rate \sim distance \times maneuver + (1 | participant)) was used to examine the effects of distance and maneuvers on fixation rate. Significance was evaluated using Wald z-tests and p-values.

3 Results

Gaze behavior outcomes are reported across the two examination points (ML1 and ML2). Table 1 presents the eye-tracking measures for the different maneuver types and distances. The results show variations in both fixation rate and saccade rate across the experimental conditions. For the straight maneuver (ML1), the mean fixation rate increased from 2.62 at 30 m to 3.62 at 10 m before the intersection. A similar pattern was observed for saccade rate, which increased from 3.16 at 30 m to 5.07 at 10 m before the intersection. On the other hand, for the left maneuver (ML2), the mean fixation rate decreased slightly from 3.72 at 30 m to 3.19 at 10 m. In contrast, the mean saccade rate increased from 4.18 at 30 m to 4.91 at 10 m. Overall, higher fixation and saccade rates were observed at the 10 m distance compared with the 30 m distance for the straight maneuver (ML1). The highest mean saccade rate (5.07) was measured at ML1 at 10 m, while the lowest (3.16) was at ML1 at 30 m examination point.

Table 1 Descriptive statistics of fixation and saccade rates by maneuver type and distance

Micro-location	Maneuver Type	Distance [m]	Mean Fixation Rate	Mean Saccade Rate	SD Fixation Rate	SD Saccade Rate
ML1	Straight	30	2.62	3.16	1.00	2.18
ML1	Straight	10	3.62	5.07	1.48	2.99
ML2	Left	30	3.72	4.18	1.82	3.14
ML2	Left	10	3.19	4.91	1.16	3.10

Despite the descriptive differences shown in table 1, a significant distance × maneuver interaction was observed for fixation rate ($p = 0.003$). Specifically, for straight riding (ML1), fixation rate was lower at 30 m than at 10 m, whereas no comparable distance-related change was observed for left turns. The statement indicates that riders exhibited more frequent fixation events when approaching the intersection during straight maneuvers, which is sound, as they needed to be more cautious due to the potential for collisions with left-turning vehicles. For saccade rate, no significant effects were observed (all $p > 0.21$). Consistent with previous eye-tracking research, fixation-based measures were considered the primary indicators of visual attention in this study [9, 18, 27].

Figure 2 presents gaze heatmaps extracted from Tobii Pro Lab software, illustrating riders' visual attention while approaching an intersection at different distances and movement conditions (figures 2a and 2b representing ML2; figures 2c and 2b representing ML1). In (a), approximately 30 m before the intersection, riders mainly focused on the forward riding path, indicating general visual scanning. In (b), at 10 m before the intersection, riders showed more concentrated fixations near the intersection area and toward the turning direction. However, the visualization also indicates that riders were quickly checking their right side, where there is a lane from which motor vehicles can also make a left turn. In (c), approximately 30 m before the intersection, riders focused primarily on the forward path. In (d), at 10 m before the intersection, riders showed dense fixations in the immediate forward area near the intersection, but also showing some caution regarding the traffic on their right side. The heatmaps also highlight several high-attention areas near the intersection, particularly the conflict zone between the cycling path and motor traffic, the turning area, and the adjacent vehicle lane.



Figure 2 Gaze heatmaps showing riders' visual attention when approaching the intersection

The visualizations are consistent with the previous metric analysis. Mean fixation rates were similar at both ML2 examination points (where riders turned left), indicating that they became cautious earlier, or they were preparing for the upcoming turning. On the other hand, fixation rates were significantly lower at the more distant examination point where riders continued straight (ML1) than at the point closer to the intersection, where fixation rates increased (with more fixations around the environment).

4 Discussion and conclusion

This study examined the visual attention patterns of e-scooter riders at different distances (30 m and 10 m) from signalized intersections during straight and left-turn movements. The linear mixed-effects model showed a significant interaction between distance and maneuver type. For straight maneuvers, riders made more fixations at shorter distances from the intersection than at longer distances. This indicates that riders observed the traffic environment more frequently when they were closer to the stop line. This pattern is consistent with previous eye-tracking studies on cyclists, which also reported increased fixation activity near intersections [27]. The heatmaps analysis supports these results by showing that gaze distribution changed with distance from the intersection. At longer distances, riders mainly directed their gaze along the riding path, whereas closer to the stop line their fixations were concentrated near the intersection area, particularly the conflict zone and adjacent vehicle lane. Previous studies have reported a similar pattern, with riders demonstrating more forward-directed gaze at longer distances and increasingly concentrated fixations near intersections [9, 27]. These patterns suggest that riders observe the traffic environment more carefully near the intersection. This interpretation is consistent with eye-tracking studies of road users, which indicate increased visual attention to key elements such as traffic signals and oncoming vehicles when approaching intersections, although the distribution of attention may vary depending on intersection design [28]. The generalizability of the findings is constrained by the limited participant sample size, which should be considered when interpreting the results. In addition, the study focused on a limited set of intersection conditions. Future research should include larger samples and examine a wider range of infrastructure types and traffic environments to better understand visual behavior in urban micromobility.

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References

- [1] Mouratidis, K., Peters, S., van Wee, B.: Transportation technologies, sharing economy, and teleactivities: Implications for built environment and travel, *Transportation Research Part D: Transport and Environment*, 92 (2021), 102716, DOI: 10.1016/j.trd.2021.102716
- [2] Elassy, M., Al-Hattab, M., Takruri, M., Badawi, S.: Intelligent transportation systems for sustainable smart cities, *Transportation Engineering*, 16, 100252, 2024, DOI: 10.1016/j.treng.2024.100252
- [3] Huang, F.H.: Factors Influencing Sustained Use of Shared E-Scooter Services in Urban Taiwan, *Promet - Traffic & Transportation*, 36 (2024) 5, pp. 902-921, 2024, DOI: 10.7307/ptt.v36i5.616
- [4] Tuncer, S., Brown, B.: E-scooters on the Ground: Lessons for Redesigning Urban Micro-Mobility, *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, ACM, New York, NY, USA, 2020., DOI: 10.1145/3313831.3376499
- [5] Anke, J., Ringhand, M., Petzoldt, T., Gehlert, T.: Micro-mobility and road safety: Why do e-scooter riders use the sidewalk? Evidence from a German field study, *European Transport Research Review*, 15 (2023) 1, pp. 29, DOI: 10.1186/s12544-023-00607-z
- [6] Tark, J.: Micromobility products-related deaths, injuries, and hazard patterns, report, 2024.
- [7] Tian, D., Ryan, A.D., Craig, C. M., Sievert, K., Morris, N.L.: Characteristics and risk factors for electric scooter-related crashes and injury crashes among scooter riders: A two-phase survey study, *International Journal of Environmental Research and Public Health*, 19 (2022) 16, 10129, DOI: 10.3390/ijerph191610129
- [8] Scquizzato, T., Gamberini, L., Stella, F., Paoli, A., Gazzato, A., Forti, A., et al.: Analysis of road traffic accidents involving standing electric scooters reported in newspapers in Italy, *Clinical and Experimental Emergency Medicine*, 9 (2022) 1, pp. 36–40, DOI: 10.15441/ceem.21.078
- [9] Chen, D., Hosseini, A., Smith, A., Zheng, Z., Xiang, D., Heydarian, A., et al.: Impact of road infrastructure and traffic scenarios on e-scooterists’ riding and gaze behavior, *International Conference on Transportation and Development 2025*, American Society of Civil Engineers, Reston, VA, pp. 373–383, 2025., DOI: 10.1061/9780784486207.032
- [10] Yang, H., Ma, Q., Wang, Z., Cai, Q., Xie, K., Yang, D.: Safety of micro-mobility: Analysis of E-scooter crashes by mining news reports, *Accident Analysis and Prevention*, 143 (2020), 105608, DOI: 10.1016/j.aap.2020.105608
- [11] Badeau, A., Carman, C., Newman, M., Steenblik, J., Carlson, M., Madsen, T.: Emergency department visits for electric scooter-related injuries after introduction of an urban rental program, *American Journal of Emergency Medicine*, 37 (2019) 8, pp. 1531–1533
- [12] Janikian, G.S., Caird, J.K., Hagel, B., Reay, G.: A scoping review of E-scooter safety: Delightful urban slalom or injury epidemic, *Transportation Research Part F: Traffic Psychology and Behaviour*, 101 (2024), pp. 33–58, DOI: 10.1016/j.trf.2023.12.015
- [13] Cano-Moreno, J.D., Cabanellas Becerra, J.M., Arenas Reina, J.M., Islán Marcos, M.E.: Analysis of E-Scooter vibrations risks for riding comfort based on real measurements, *Machines*, 10 (2022) 8, DOI: 10.3390/machines10080688

- [14] Ma, Q., Yang, H., Yan, Z.: Use of mobile sensing data for assessing vibration impact of E-scooters with different wheel sizes, *Transportation Research Record: Journal of the Transportation Research Board*, 2677 (2023) 8, pp. 388–399, DOI: 10.1177/03611981231156586
- [15] Ma, Q., Yang, H., Mayhue, A., Sun, Y., Huang, Z., Ma, Y.: E-Scooter safety: The riding risk analysis based on mobile sensing data, *Accident Analysis and Prevention*, 151 (2021), 105954, DOI: 10.1016/j.aap.2020.105954
- [16] Guo, X., Tavakoli, A., Robartes, E., Angulo, A., Chen, T.D., Heydarian, A.: Roadway design matters: Variation in bicyclists' psycho-physiological responses in different urban roadway designs, preprint, 2022.
- [17] Shiferaw, B., Downey, L., Crewther, D.: A review of gaze entropy as a measure of visual scanning efficiency, *Neuroscience and Biobehavioral Reviews*, 96 (2019), pp. 353–366, DOI: 10.1016/j.neubiorev.2018.12.007
- [18] Pashkevich, A., Burghardt, T.E., Puławska-Obiedowska, S., Šucha, M.: Visual attention and speeds of pedestrians, cyclists, and electric scooter riders when using shared road – a field eye tracker experiment, *Case Studies on Transport Policy*, 10 (2022) 1, pp. 549–558, DOI: 10.1016/j.cstp.2022.01.015
- [19] Caviedes, A., Figliozzi, M.: Modeling the impact of traffic conditions and bicycle facilities on cyclists' on-road stress levels, *Transportation Research Part F: Traffic Psychology and Behaviour*, 58 (2018), pp. 488–499, DOI: 10.1016/j.trf.2018.06.032
- [20] Zhang, H., Peng, D., Shi, X.: Evaluation of cognitive load differences between elderly and young pedestrians at the signalised intersection, *Promet - Traffic & Transportation*, 36 (2024) 4, pp. 704–716, DOI: 10.7307/ptt.v36i4.519
- [21] Pedestrians and Cyclists 2015, Report, European Commission, https://road-safety.transport.ec.europa.eu/system/files/2021-07/ersosynthesis2015-pedestrianscyclists25_en.pdf
- [22] Prati, G., De Angelis, M., Marín Puchades, V., Fraboni, F., Pietrantonio, L.: Characteristics of cyclist crashes in Italy using latent class analysis and association rule mining, *PLoS One*, 12 (2017) 2, e0171484, DOI: 10.1371/journal.pone.0171484
- [23] Wei, F., Lovegrove, G.: An empirical tool to evaluate the safety of cyclists: Community based, macro-level collision prediction models using negative binomial regression, *Accident Analysis and Prevention*, 61 (2013), pp. 129–137, DOI: 10.1016/j.aap.2012.05.018
- [24] Stone, M., Broughton, J.: Getting off your bike: Cycling accidents in Great Britain in 1990–1999, *Accident Analysis and Prevention*, 35 (2003) 4, pp. 549–556, DOI: 10.1016/S0001-4575(02)00032-5
- [25] Chen, L., Chen, C., Srinivasan, R., McKnight, C.E., Ewing, R., Roe, M.: Evaluating the safety effects of bicycle lanes in New York City, *American Journal of Public Health*, 102 (2012) 6, pp. 1120–1127, DOI: 10.2105/AJPH.2011.300319
- [26] Kaplan, S., Prato, C.G.: A spatial analysis of land use and network effects on frequency and severity of cyclist–motorist crashes in the Copenhagen region, *Traffic Injury Prevention*, 16 (2015) 7, pp. 724–731, DOI: 10.1080/15389588.2014.1003818
- [27] Rupi, F., Krizek, K.J.: Visual eye gaze while cycling: Analyzing eye tracking at signalized intersections in urban conditions, *Sustainability*, 11 (2019) 21, pp. 6089, DOI: 10.3390/su11216089
- [28] Gruden, C., Ištoka Otković, I., Šraml, M.: An eye-tracking study on the effect of different signalized intersection typologies on pedestrian performance, *Sustainability*, 14 (2022) 4, 2112, DOI: 10.3390/su14042112

