Enhancing Perception and Interaction in Micromobility: Development of a Real-time Augmented Reality Display System*

Chinmay Sudarshan Kulkarni[1], Chokiu Leung[2], Tiago Rodrigues[3], Hitesh Pandya[3], Bruno Coelho[3], Yoshinari Kameda[4,*]

[1] *Bachelor's Program in Interdisciplinary Engineering, University of Tsukuba, 1-1-1 Tennodai Tsukuba, Ibaraki, Japan*
[2] *Institute of Systems and Information Engineering, University of Tsukuba, 1-1-1 Tennodai Tsukuba, Ibaraki, Japan*
[3] *Engineering and R&D Services, Capgemini Japan K.K, 1-23-1 Toranomon, Minato City, Tokyo, Japan*
[4] *Center for Computational Sciences, University of Tsukuba 1-1-1 Tennodai Tsukuba, Ibaraki, Japan*

Abstract

This paper details an experimental approach to enhance Personal Mobility Device (PMD) safety and user experience through a Meta Quest 3-integrated Heads-Up Display (HUD) system. Addressing risks from distracted riding and inconsistent regulations, the study evaluates real-time data display for Segway Ninebot Mini Pro 2 users. Findings indicate a statistically significant reduction in overall cognitive workload with the HUD and improved adherence to target speed. While the HUD led to slower riding and longer completion times, the research highlights a nuanced trade-off between perceived effort and riding precision. This work contributes to micromobility safety research, informing future PMD design and urban policy.

Keywords

Personal Mobility Devices (PMDs), Heads-Up Display (HUD), Micromobility, Meta Quest 3, Cognitive Workload, Road Safety, Augmented Reality

1. Introduction

Personal Mobility Devices (PMDs), including electric scooters and self-balancing transporters, have rapidly emerged as convenient and sustainable urban transportation solutions. However, their increasing prevalence introduces significant safety concerns, primarily due to distracted riding, varying user awareness, and a notable absence of standardized regulations across jurisdictions. This creates a complex challenge for municipalities, who must balance the benefits of micromobility with the imperative to ensure public safety for all.

A common issue may involve PMD users diverting their visual attention to smartphone screens for critical operational data, potentially increasing cognitive load and diminishing situational awareness. This highlights the critical importance of providing real-time information directly to the user to enhance their riding experience. The emerging landscape suggests that Head-Mounted Displays (HMDs) combined with micromobility solutions may represent a promising future direction for user interaction and information delivery in this domain.

APMAR'25: The 17th Asia-Pacific Workshop on Mixed and Augmented Reality, Sep. 26-27, 2025, Busan, South Korea

Corresponding author.
[1*] Corresponding author.
kulkarni.chinmay.sudarshan@image.iit.tsukuba.ac.jp (C. S. Kulkarni); leung@css.risk.tsukuba.ac.jp (C. Leung); tiago.rodrigues@capgemini.com (T. Rodrigues); hitesh.pandya@capgemini.com (H. Pandya); bruno.coelho@capgemini.com (B. Coelho); kameda@ccs.tsukuba.ac.jp (Y. Kameda)
0009-0004-9255-3178 (C. S. Kulkarni); 0000-0003-3336-2094 (C. Leung); 0000-0001-6776-1267 (Y. Kameda)

A key challenge in this transformative scheme is that the precise influence of such HUDs on the actual riding experience of PMD users remains largely unexplored and not fully understood. This research addresses these challenges by integrating a Heads-Up Display (HUD) system, utilizing the Meta Quest 3 augmented reality (AR) headset, to project real-time operational data directly within the rider's field of vision.

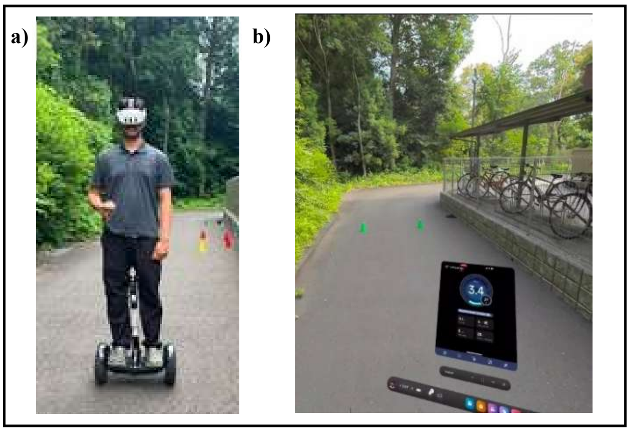


Figure 1: A subject a) wearing an AR headset rides a personal mobility device (PMD), with the perspective b) shown through the Meta Quest 3's passthrough mode.

This project addresses the challenges on integrating a Heads-Up Display (HUD) system using the Meta Quest 3 augmented reality (AR) headset to provide real-time operational data directly within the rider's field of vision (Figure 1). The core objective is to assess how HUD technology can enhance PMD user safety by mitigating the cognitive load associated with glancing at mobile screens for critical information. Concurrently, this study explores the technical and practical challenges of integrating real-time data from the Segway application onto the Meta Quest 3. By investigating these aspects, this paper aims to contribute to the discourse on micromobility safety, advocating for a dual approach of technological innovation and regulatory harmonization.

2. Related Works

The emergence of micromobility devices has provided a valuable solution for urban transportation, but their widespread adoption has highlighted significant safety challenges [1]. A key concern is the cognitive load and distraction riders experience, which often stems from the need to interact with external devices like smartphones for navigation or speed monitoring [2]. Research has shown that these distractions can lead to a decrease in situational awareness and an increase in accident risk. For instance, a study by Qawasmeh et al. found that improper lane use and other hazardous rider behaviors are a significant factor in micromobility crash severity [3]. Similarly, Pashkevich's eye-tracking study demonstrated that e-scooter riders can experience notable attention lapses, for example, 2.3-second durations, when checking handlebar-mounted displays for vital information [4]. This underscores the critical need for an interface that can present information to the rider without diverting their gaze and attention from the road [5].

To address similar issues in other domains, Heads-Up Displays (HUDs) and Augmented Reality Heads-Up Displays (AR HUDs) have been developed and studied extensively. In the automotive industry, AR HUDs have proven effective at reducing driver cognitive load and improving safety by projecting information directly onto the windshield, thus allowing drivers to maintain their focus on the road [6]. Winkler et al. suggest that AR HUDs can enhance a driver's situational awareness and improve reaction times to potential hazards. The technology has also been adapted for two-wheeled vehicles, with companies developing HUD systems for motorcycle and bicycle helmets that display information such as speed and navigation [8], [9]. These systems are designed to keep the user's eyes forward, as research shows this improves reaction times and aids in obstacle detection [10]. However, a major technical challenge for these systems is ensuring low-latency projections to prevent motion sickness and maintaining display visibility under varying light conditions [11], [12].

Despite the substantial body of work on micromobility safety and the proven benefits of AR HUDs in other transportation contexts, a critical research gap exists concerning their comprehensive application to self-balancing personal mobility devices. A key limitation in existing AR HUD research is a "stable platform bias," as much of the work has been conducted on vehicles where balance is not a primary cognitive demand, such as cars or even conventional bicycles [13]. As explained by Billinghurst et al., this is a crucial distinction, as operating a self-balancing PMD imposes a continuous and dominant cognitive load for postural control, fundamentally differentiating it from other modes of transport [13], [14]. Therefore, simply adapting an AR HUD from a car or bicycle is insufficient, as the interface could inadvertently increase the already high cognitive demands of the rider [14], [15]. While some related research has explored the use of AR for balance training and rehabilitation [16], [17], these applications do not address the real-time perceptual and interactive needs of an individual operating a device in a dynamic urban environment.

This lack of dedicated research highlights a pressing need to develop and evaluate AR HUD systems specifically designed for the unique human-factors challenges of self-balancing PMDs. This research gap represents a significant opportunity to fundamentally improve the safety and user experience of this unique form of personal mobility by creating an interface that is sensitive to the rider's cognitive demands for both navigation and balance.

3. Benefits of Real-Time AR-HUD

PMD adoption has surged, but safety measures lag. Nearly half of PMD accidents involve self-inflicted injuries, and 40% result in head trauma, yet only 10-15% of riders wear helmets[18]. This highlights the urgent need for better safety solutions.

Augmented reality (AR) could improve road safety by providing real-time hazard alerts without distracting users—a concept known as "Heads-Up computing." Studies show AR warnings enhance reaction times, but their effectiveness depends on clear information design[6]. Poorly designed displays increase cognitive load, worsening distraction. Optimizing UI elements, like size and placement, is crucial to reducing mental and physical strain in safety-critical systems.

The design of information displays significantly influences user experience and cognitive load. In-vehicle information systems (IVIS) with touch screens can induce higher visual, manual, and cognitive distraction compared to physical buttons[6]. Assessing and predicting cognitive performance is paramount in safety-critical contexts, as mental workload directly links to performance efficacy. Furthermore, VR interface design principles, such as element size and distance, can impact physical effort and mental demand, emphasizing the need for meticulous UI optimization to minimize cognitive and physical strain.

4. Evaluation of AR-HUD

The primary purpose of this research is to experimentally evaluate the tangible efficacy of an AR HUD system, specifically utilizing the Meta Quest 3 headset, in directly enhancing both the safety and overall user experience for individuals operating a Segway Ninebot Mini Pro 2. This evaluation is achieved through a rigorous quantification of the system's impact on subjective cognitive workload and objective riding performance. A secondary, yet equally important, purpose is to identify and analyze any potential trade-offs in performance or significant individual differences in user response that may arise from the introduction of this AR interface.

4.1. Hypothesis for Solving the Issue(s)

As previously articulated in the introduction, the central tenet of this research is grounded in the primary hypothesis: that the Meta Quest 3-integrated AR HUD system will result in a statistically significant reduction in the overall perceived cognitive workload, as measured by the Weighted NASA-TLX Score, for PMD users. Complementing this, the secondary hypotheses anticipate quantifiable improvements in objective performance metrics, specifically predicting a reduction in deviation from requested speed (smaller margin), an increase in sampled speed, and a decrease in overall task completion time, all indicative of a safer and more efficient riding experience.

4.2. Verification

This study employed a robust within-subjects experimental design to rigorously evaluate the hypotheses, involving a cohort of 20 first-time Segway users. The within-subjects approach was chosen to minimize inter-individual variability, as each participant served as their own control by completing both experimental conditions.

5. Experiment and Results

5.1. Hardware and Setup

The primary Personal Mobility Device utilized was a Segway Ninebot Mini Pro 2, selected for its integrated sensors and robust connectivity capabilities. The Augmented Reality display was provided by a Meta Quest 3 headset. The Segway's proprietary application was mirrored onto the Meta Quest 3 (Figure 2(c)), enabling the projection of real-time operational data (e.g., current speed, battery life, tilt angles) directly into the rider's field of vision via the headset's Passthrough mode (Figure 1(b), 2(a)). This setup aimed to create an immersive experience wherein critical information was seamlessly integrated into the rider's natural visual field without requiring overt attention shifts.

5.2. Experimental Procedure

The study protocol was meticulously structures to ensure consistency and control:

1. Comprehensive Briefing: Prior to any practical trials, all participants received a detailed briefing outlining the study's objectives, the operational principles of the PMD, and the functionalities of the AR HUD system.

2. Training Session: A dedicated training session was conducted in a safe, enclosed environment. This allowed participants to familiarize themselves with the Segway's controls and, for the headset condition, to acclimate to the AR interface and the overlaid information.

3. Test Ride: Following training, participants navigated a standardized rectangular obstacle course (12.5m x 2m) designed to simulate typical urban riding challenges (Figure 3). The course included various turns and a zig-zag segment, specifically crafted to challenge aspects of rider control, motor skills, and cognitive functions. The order of conditions (with or without HUD) was counterbalanced across participants to mitigate order effects.

4. Data Collection: Both subjective and objective data were systematically collected to provide a holistic evaluation:

   - Subjective Workload: After completing each riding condition, participants completed the NASA-TLX (National Aeronautics and Space Administration Task Load Index) questionnaire. This tool measured perceived workload across six core subscales: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration.

These individual ratings were then combined to calculate a comprehensive Weighted Score, representing overall cognitive burden.

- Objective Performance: Quantitative metrics of riding performance were recorded throughout the trials. These included: Requested Speed (the target speed for the segment from green to orange cones), Sampled Speed (km/h, the actual average speed maintained), and Margin (km/h, the absolute deviation from the requested speed, indicating precision). Additionally, the total Timestamp (completion time in seconds) for navigating the course was recorded. For the headset condition, any time spent explicitly reading a distinct text or logo (an incidental task) was subtracted from the total Timestamp to derive an Adjusted Completion Time, ensuring a purer measure of task duration.

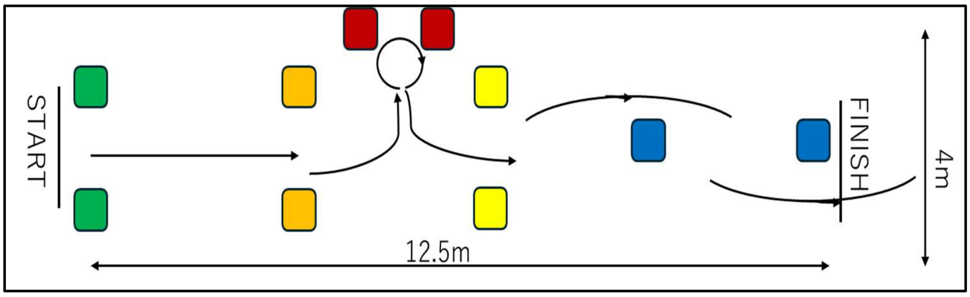


Figure 2: Test course layout with and without headset. Riders observed their request speed limit between the Green and Orange cones, as marked by squares in the figure.

5.3. Statistical analysis methods

All collected data underwent rigorous statistical analysis as follows:

- **Descriptive Statistics**: For every measured metric and condition, the **Mean** (1) and **Standard Deviations** (2) were calculated to summarize central tendency and data dispersion**.**

$$\bar{x} = \frac{\sum xi}{n}, \tag{1}$$

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} \tag{2}$$

- **Inferential Statistics:** To determine if observed differences between the "no headset" and "with headset" conditions were statistically significant, **Paired t-tests** were employed. This test is specifically suited for within-subjects designs, comparing the means of two related samples.

  - Paired T-statistic:

$$t = \frac{\bar{d}}{s_d/\sqrt{n}}, \tag{3}$$

where $\bar{d}$ is the mean of the differences between paired observations, s_d is the standard deviation of these differences, and n is the number of paired observations (participants). The p-value derived from this t-statistic indicates the probability of observing such a difference if no true effect existed

- **Correlational Analysis:** To explore the intricate relationships between the *changes* (i.e., the difference between the "no headset" and "with headset" conditions) in subjective and objective metrics, **Pearson correlation coefficients (r)** were calculated. This approach allowed for a direct assessment of how the *impact* of the headset on one variable related to its *impact* on another for the same individual.

  - Pearson Correlation Coefficient:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}}, \tag{4}$$

where P-values were concurrently derived for all t-tests and Pearson correlations to ascertain statistical significance.

5.4. Results

The comprehensive analysis of the full 20-participant dataset provides robust empirical evidence regarding the AR HUD's impact on PMD user experience and performance.

5.4.1. Cognitive Workload (NASA-TLX):

The primary hypothesis, predicting a significant reduction in overall cognitive workload with the AR-HUD, was strongly supported:

- Overall Weighted Score: A statistically significant reduction in the overall perceived cognitive workload was observed when participants utilized the AR HUD. The mean Weighted Score decreased from $\bar{x}$=51.45±24.37 (no headset) to $\bar{x}$=43.03±19.82 (with headset), with a t-statistic of t(19)=2.121 and a p-value of p=0.047. This finding suggests that the AR HUD successfully alleviated the perceived mental burden on riders.

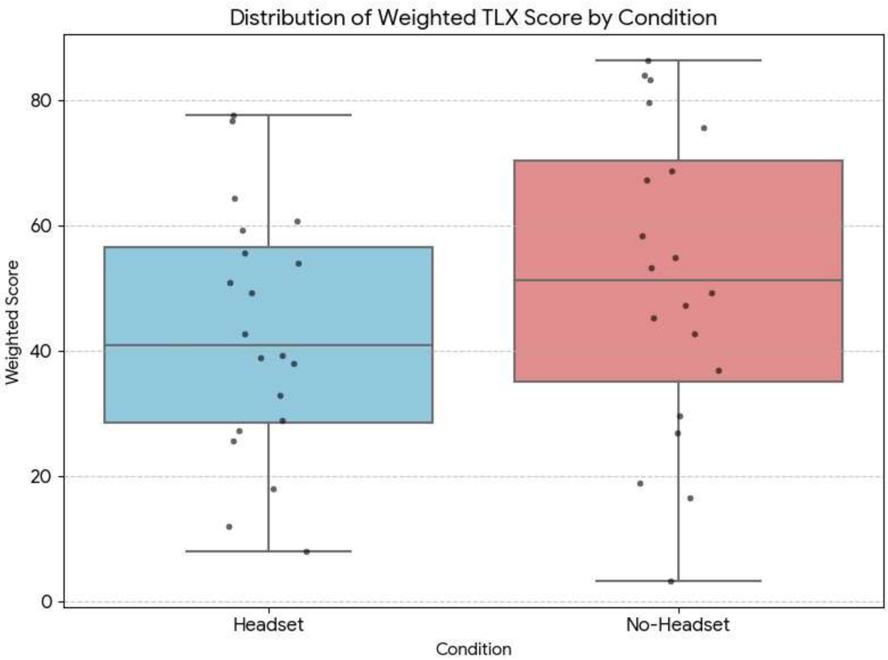


Figure 3: Whisker plot for Distribution of Weighted TLX scores by condition (Headset/No-Headset)

- Temporal Demand: A statistically significant reduction was specifically noted in the Temporal Demand subscale. Participants reported feeling less time pressure or a less frantic pace with the headset ($\bar{x}=35.25\pm23.65$) compared to the no-headset condition ($\bar{x}=53.25\pm24.78$). This finding ($t(19)=2.902$, $p=0.009$) was even more statistically significant with the expanded dataset, reinforcing that the immediate and integrated information delivery of the HUD allowed riders to perceive the task as less hurried, suggesting a more comfortable and potentially safer experience.

- Effort: While the mean perceived Effort showed a reduction (from $\bar{x}=53.75\pm29.46$ to $\bar{x}=45.00\pm29.60$), this change was not statistically significant ($t(19)=1.322$, $p=0.202$) in the full dataset.

- Other NASA-TLX subscales (Mental Demand, Physical Demand, Performance, and Frustration) consistently showed non-significant trends towards reduction.

5.4.2. Objective performance metrics

As for the objective Performance Metrics, the analysis of objective performance metrics revealed consistent adaptive changes in riding behavior, suggesting a nuanced impact beyond simple speed or efficiency gains:

- **Sampled Speed (km/h):** A **statistically significant decrease** in sampled speed was observed when participants used the AR HUD. The mean sampled speed was $\bar{x}=5.36\pm1.76$ km/h without the headset, which reduced to $\bar{x}=4.48\pm1.37$ km/h with the headset ($t(19)=3.423$, $p=0.003$).

- **Margin (km/h):** The **Margin from requested speed** showed a **statistically significant reduction**, decreasing from $\bar{x}=2.01\pm1.33$ km/h (no headset) to $\bar{x}=1.13\pm0.82$ km/h (with headset) ($t(19)=3.423$, $p=0.003$). This indicates **improved precision**.

5.4.3. Individual differences and correlations

Analysis of individual participant data indicated variability in responses, complementing the group-level findings. For instance, while a majority (14 out of 20) of participants experienced a reduction in their Weighted NASA-TLX Score with the HUD, 6 participants reported an increase. This highlights the importance of individual user characteristics in AR adoption. Similarly, 16 riders demonstrated improved precision (smaller margin) with the headset, while 4 showed worsened precision. In terms of speed, 16 riders were slower, and 4 were faster with the headset. These individual patterns suggest diverse strategies or adaptation rates among users when interacting with the AR HUD.

To further explore the relationships between these observed changes, Pearson correlation coefficients were calculated between the differences (No Headset - With Headset) for various subjective and objective metrics. A **statistically significant negative correlation** ($r=-0.479$, $p=0.033$) was identified between a reduction in **perceived Physical Demand** (i.e., the headset made the task feel physically easier) and an increase in **Adjusted Completion Time** (i.e., the participant took longer to complete the course). This intriguing relationship may suggest a potential trade-off: when the AR HUD alleviated physical exertion, riders might have adopted a more relaxed pace, leading to a longer, less hurried completion. This could indicate that reduced physical strain, facilitated by the HUD, may allow users to prioritize comfort and a deliberate pace over raw speed. Other strong internal correlations within TLX subscales were also observed, such as between the change in Effort and the change in Frustration ($r=0.824$, $p<0.001$), and between the change in Effort and the change in Weighted Score ($r=0.819$, $p<0.001$). These robust internal correlations may suggest that improvements in perceived effort and frustration are tightly linked and collectively contribute to the overall reduction in cognitive workload experienced by the rider.

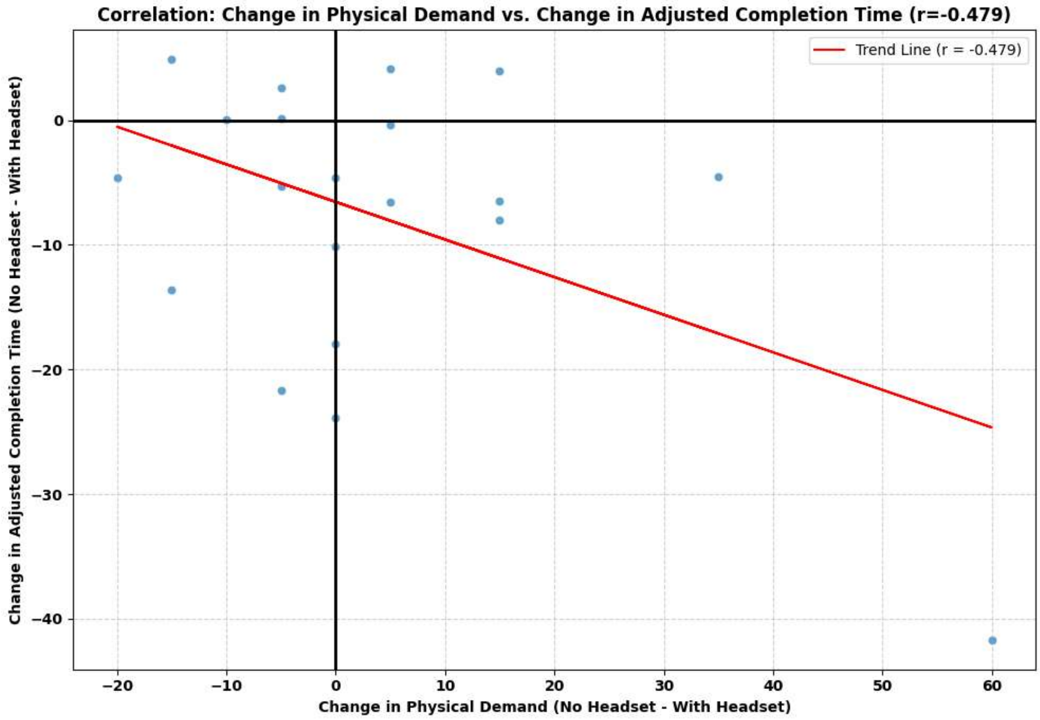


Figure 4: Correlation of Physical Demand change, and Timestamp Difference between two Headset and No-Headset conditions.

5.5 Discussion

The empirical evidence from this study suggests that the Meta Quest 3-integrated AR HUD system may influence PMD user experience and performance in complex ways. The data appears to indicate a statistically significant reduction in overall perceived cognitive workload, particularly concerning temporal demand, which could imply a more comfortable and less stressful riding experience.

However, the objective performance metrics suggest a nuanced trade-off. While the HUD was associated with a statistically significant reduction in sampled speed and an increase in completion time, there was also a statistically significant improvement in precision, as indicated by a smaller margin from the requested speed. This observed relationship between subjective workload reduction and altered objective performance may suggest that the HUD could encourage a more controlled and deliberate riding style, potentially prioritizing precision over raw speed, especially for users new to such interfaces. This interpretation is further supported by the correlation between reduced physical demand and increased completion time, where a less strenuous task might lead to a more relaxed pace. The identified individual variability in responses may also highlight the importance of personalized AR experiences in future designs, as not all users responded identically to the intervention.

These findings take on particular significance when viewed through the lens of a self-balancing PMD's unique cognitive demands. Unlike more stable vehicles, operating a Segway requires a continuous and dominant cognitive load for postural control. The statistically significant reduction in overall perceived cognitive workload, especially the reduction in temporal demand, suggests that the AR HUD successfully offloaded some of this cognitive burden by making critical operational data more accessible. This points to a key design insight; for devices where rider balance is a primary concern, an AR HUD is not merely a convenience but a potential safety-critical tool that can free up mental resources. Future interface designs for PMDs should, therefore, prioritize the heads-up display of information essential for safety and control, such as speed and battery life, to mitigate the cognitive friction associated with looking down at a mobile screen. This approach allows riders to maintain a continuous, forward-facing visual field, directly addressing a core challenge of micromobility safety.

6. Conclusion

Building upon these insights and addressing the inherent limitations of the current study (e.g., sample size, first-time users, simulated environment), several promising avenues for future research may emerge. These include conducting longitudinal studies to investigate the effects of prolonged use and extensive training with the AR HUD, and expanding participant cohorts to include individuals with varying levels of PMD experience and diverse demographics for more comprehensive insights.

Future work could also involve real-world trials in authentic, uncontrolled urban environments, alongside the integration of advanced data collection methods, such as eye-tracking technology, to precisely measure visual attention shifts, gaze patterns, and cognitive tunneling with and without the HUD. Furthermore, exploring the development of adaptive HUD designs that can intelligently adjust information density, presentation modality, and visual saliency based on real-time factors like rider proficiency or environmental complexity may be beneficial. Finally, engaging proactively with urban planners, policymakers, and PMD manufacturers could advocate for the development of harmonized regulatory frameworks that support the safe and effective integration of advanced safety-enhancing technologies like AR HUDs into micromobility ecosystems.

Declaration on Generative AI

During the preparation of this work, the author(s) used Grammarly in order to: Grammar and Spelling check, Paraphrase and Reword. Further, the author used Google Gemini 2.5 Pro in order to: Improve Writing Style, Peer review simulation. After using these tools and services, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

References

[1] National Transportation Safety Board, MICROMOBILITY: DATA CHALLENGES ASSOCIATED WITH ASSESSING THE PREVALENCE AND RISK OF ELECTRIC SCOOTER AND ELECTRIC BICYCLE FATALITIES AND INJURIES, Safety Research Report SRR-22-01, National Transportation Safety Board, Washington, DC, 2022.

[2] National Transport Commission, DRIVER DISTRACTION: A REVIEW OF SCIENTIFIC LITERATURE, National Transport Commission, Melbourne, VIC, 2022.

[3] B. Qawasmeh, J.-S. Oh, V. Kwigizile, Micro-Mobility Safety Assessment: Analyzing Factors Influencing the Micro-Mobility Injuries in Michigan by Mining Crash Reports, Future Transportation 4 (2024) 1580–1601. doi:10.3390/futuretransp4040076.

[4] A. Pashkevich, T. Burghardt, S. Pulawska-Obiedowska, M. Sucha, 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). doi:10.1016/j.cstp.2022.01.015.

[5] D. L. Strayer, J. Turrill, J. M. Cooper, J. R. Coleman, N. Medeiros-Ward, F. Biondi, Assessing Cognitive Distraction in the Automobile, Human Factors 57 (2015) 1300–24. doi:10.1177/0018720815575149.

[6] M. Winkler, M. Soleimani, A Review of Augmented Reality Heads Up Display in Vehicles: Effectiveness, Application, and Safety, International Journal of Human-Computer Interaction 2025 (2025) 1–16. doi:10.1080/10447318.2024.2443252.

[7] CrossHelmet, CrossHelmet X1 features: HUD, Noise Cancellation & much more. (2024). URL: https://www.crosshelmet.com/features/.

[8] Renfrew Group Design, Digilens Motorcycle Helmet HUD. (2024). URL: https://renfrewgroup.com/portfolio/digilens-motorcycle-helmet-hud/.

[9] M. Taha, S.M.S. Ahmed, A. Aziz, M.A. Bari, Smart HUD Helmet, International Journal of Emerging Technologies and Innovative Research (JETIR) 8 (2021) a947–a953.

[10] Rinf.tech, AR-HUD Development Challenges, Approaches, and Benefits. (2024). URL: https://www.rinf.tech/ar-hud-development-challenges-approaches-and-benefits%E2%80%8B/.

[11] A. Hazarika, M. Rahmati, Towards an Evolved Immersive Experience: Exploring 5G- and Beyond-Enabled Ultra-Low-Latency Communications for Augmented and Virtual Reality, Sensors 23 (2023) 3682. doi:10.3390/s23073682.

[12] DiSTI, Augmented Reality HUD, (2021), URL: https://disti.com/wp-content/uploads/2021/05/AugmentedRealityHUD-DiSTI-English.pdf.

[13] M. Billinghurst, A. Clark, G. Lee, A Survey of Augmented Reality, volume 8 of Foundations and Trends® in Human-Computer Interaction: Vol. 8; No. 2-3, pp 73-272. doi:10.1561/1100000049

[14] Z. G. Gursoy, U. Yilmaz, H. Celik, P. Arpinar-Avsar, S. Kirazci, Effect of Individualized Cognitive and Postural Task Difficulty Levels on Postural Control during Dual Task Condition, Gait & Posture 96 (2022) 1–8. doi:10.1016/j.gaitpost.2022.05.001.

[15] G. Andersson, J. Hagman, R. Talianzadeh, A. Svedberg, H. C. Larsen, Effect of Cognitive Load on Postural Control, Brain Research Bulletin 58 (2002) 135–139. doi:10.1016/s0361-9230(02)00770-0.

[16] S. Blomqvist, S. Seipel, M. Engström, Using Augmented Reality Technology for Balance Training in the Older Adults: a Feasibility Pilot Study, BMC Geriatr 21 (2021) 144. doi:10.1186/s12877-021-02061-9.

[17] A. Etaat, N. Haghbin, M. Kersten-Oertel, An Online Balance Training Application using Pose Estimation and Augmented Reality, in: Proceedings of the 8th International Conference on Information and Communication Technologies for Ageing Well and e-Health, SciTePress (2022), pp. 168-176. doi:10.5220/0010973800003188.

[18] European Commission, Road safety thematic report –Personal Mobility Devices. (2021). URL: https://road-safety.transport.ec.europa.eu/document/download/6f698f20-f43f-4066-816a-d1db217b3bc4_en?filename=road_safety_thematic_report_personal_mobility_devices_tc_final.pdf.

A. Supplementary Graphs

Figure A.1: Mean NASA-TLX weighted scores by condition

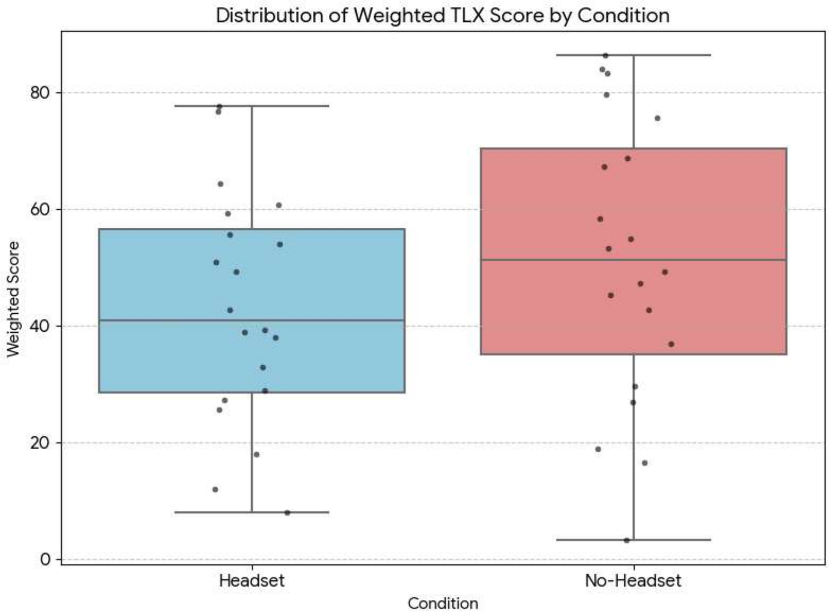


Figure A.2: Mean Sampled Speed and Margin by condition

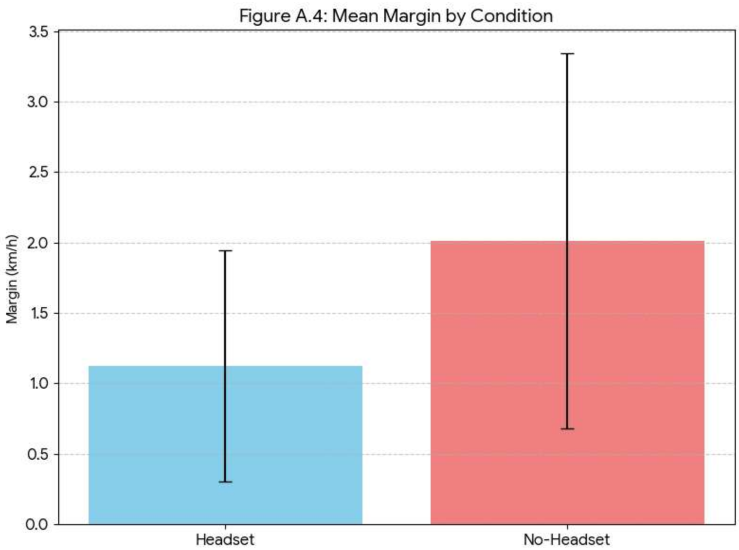
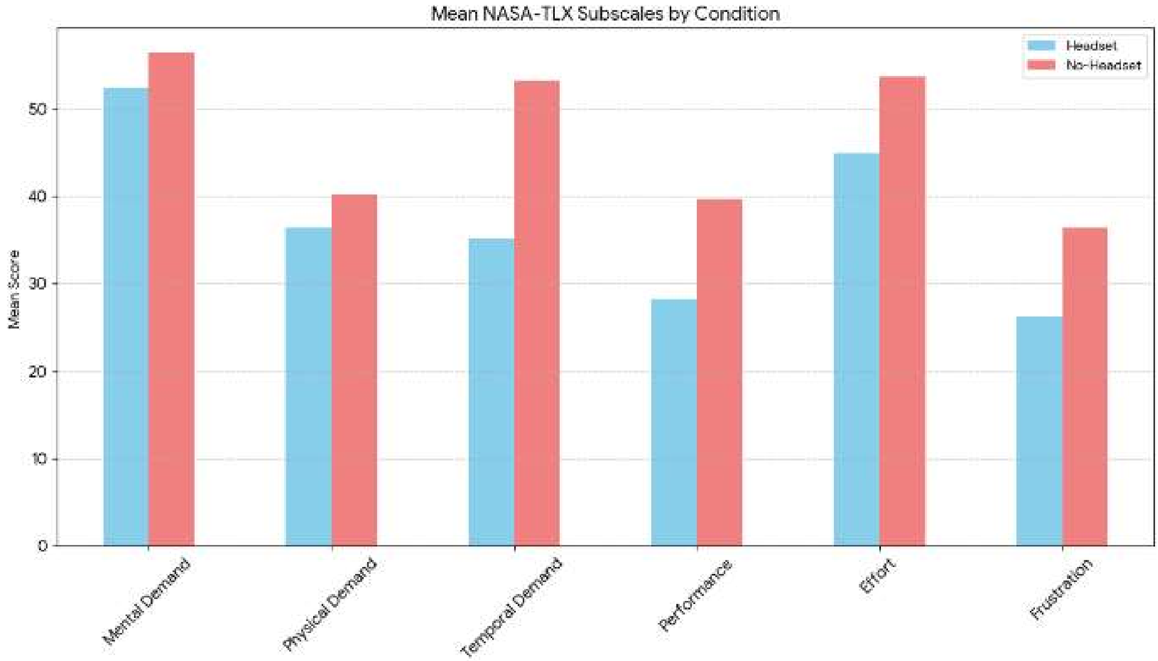


Figure A.3: Individual Changed in Weighted NASA-TLX score by condition



B. Supplementary Tables and Charts

Table B.1: Full descriptive statistics by condition with standard deviation

Metric	Condition	Mean	Std Dev
Mental Demand	No Headset	56.50	30.18
	With Headset	52.50	29.49
Physical Demand	No Headset	40.25	30.80
	With Headset	36.50	30.14
Temporal Demand	No Headset	53.25	24.78
	With Headset	35.25	23.65
Performance	No Headset	39.75	26.28
	With Headset	28.25	21.48
Effort	No Headset	53.75	29.46
	With Headset	45.00	29.60
Frustration	No Headset	36.50	29.07
	With Headset	26.25	24.11
Weighted Score	No Headset	51.45	24.37
	With Headset	43.03	19.82
Requested Speed	No Headset	3.35	0.81
	With Headset	3.35	0.81
Sampled Speed (km/h)	No Headset	5.36	1.76
	With Headset	4.48	1.37
Margin (km/h)	No Headset	2.01	1.33
	With Headset	1.13	0.82
Timestamp	No Headset	26.37	6.65
	With Headset	34.06	14.12

Table B.2: Full paired T-Test results

Metric	T-statistic	P-value	Significant (p<0.05)
Mental Demand	0.574	0.572	False
Physical Demand	0.918	0.370	False
Temporal Demand	2.902	0.009	True
Performance	1.891	0.074	False
Effort	1.322	0.202	False
Frustration	1.447	0.164	False
Weighted Score	2.121	0.047	True
Requested Speed	NaN	NaN	False
Sampled Speed (km/h)	3.423	0.003	True
Margin (km/h)	3.423	0.003	True
Timestamp	−2.987	0.008	True

Table B.3: Pearson Correlation Heatmap for Differences (No Headset-Headset)