Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 272 (2025) 15–22

Procedia Computer Science

www.elsevier.com/locate/procedia

The 16th International Conference on Emerging Ubiquitous Systems and Pervasive Networks (EUSPN 2025)
October 28-30, 2025, Istanbul, Türkiye

Examining Physical Realism in Motorcycle Simulators

Wondwesen Girma Mamo[a,*], Qinaat Hussain[a], Hussain Ahamed[b], Mohamed Arbab[b], Wael K. M. Alhajyaseen[a], Kris Brijs[c], Ariane CUENEN[c], Somaya Al-maadeed[a]

[a]*College of Engineering, Qatar University, P.O. Box 2713, Doha, Qatar.*
[b]*College of Arts and Sciences, Qatar University, P.O. Box 2713, Doha, Qatar.*
[c]*UHasselt, School of Transportation Sciences, Transportation Research Institute (IMOB), Martelarenlaan 42, 3500 Hasselt, Belgium.*

Abstract

Motorcycle simulators are increasingly being used for safety research and rider training. However, replicating the physical realism found in real motorcycles poses challenges. Despite the growing interest in motorcycle simulator realism, there is a lack of comprehensive evaluations assessing the essential realistic features of the simulators currently available. This highlights the need for a thorough and updated review of simulator realism. This paper aims to provide an overview of the key aspects of physical realism in motorcycle simulators, including motion fidelity, control accuracy, sensory feedback, motion cuing and visual immersion. This paper evaluates 13 motorcycle simulators. Our evaluation shows that, although the complexity of the systems varies significantly, physical realism is consistently influenced by the convergence of a selection of key features. Advanced simulators demonstrate that the incorporation of integrated, multisensory, and dynamic features substantially enhances the perception of realism. As a result, these features may be considered as essential benchmarks for developing and validating motorcycle simulators.

Keywords: Motorcycle simulator; realism; review; motion

* Corresponding author. Tel.: +97455023607
E-mail address: w.mamo@qu.edu.qa

1877-0509 © 2025 The Authors. Published by Elsevier B.V.

10.1016/j.procs.2025.10.173

1. Introduction

Motorized Two-Wheelers (MTWs) are flexible and cost-effective modes of transportation that provide advantages in navigating congested traffic and finding parking in limited spaces [1, 2]. However, the small size and unstable nature of motorcycles [3] and their lack of physical protection [4] can make them vulnerable to crashes. Accordingly, motorcyclists typically experience higher crash severity rates than other road users [5]. A substantial body of research on motorcycle safety has emerged from crash data analyses and self-report surveys. Recently, the use of motorcycle simulators has gained traction as a valuable method in transportation research [6, 7]. These simulators offer controlled environments to examine rider behavior, evaluate safety systems, and provide targeted training, addressing key safety concerns more effectively than traditional methods [8]. A typical motorcycle simulator consists of three main subsystems: an audiovisual system, a physical interface, and a motion platform. Visual immersion is generally achieved through wide-angle projections or head-mounted displays equipped with head-tracking technology, allowing for dynamic adjustments of viewpoints that enhance the perception of realism [8]. Complementing the visual experience, the audio system reproduces engine sounds and environmental noises, which contributes to a more immersive and authentic riding experience [9]. The physical interface typically includes a full-scale motorcycle mock-up that features functional controls, such as the throttle, clutch, brakes, gear lever, handlebars, seat, and footrests. These elements can replicate the tactile and ergonomic aspects of operating a real motorcycle [10]. The motion platform (e.g., the degrees of freedom (DoF)), which facilitates the simulation of dynamic movement, varies significantly in complexity. DoF in the simulator refers to the independent movements that the simulator platform can perform [11]. DoF in a motorcycle simulator are generally classified into two main categories: rotational and translational motions. Rotational motion consists of three types: roll, which refers to the side-to-side tilting of the motorcycle during turns; pitch, forward or backward tilting that occurs during acceleration or braking; and yaw, horizontal rotation that simulates skidding or changes in direction [8]. Translational motions also include three components: heave, which represents vertical movement; sway, lateral or side-to-side motion; and surge, forward or backward shifts that replicate acceleration and deceleration [8]. Each motion type simulates a critical aspect of the real-world motorcycle dynamics. For example, roll is essential for simulating cornering, pitch mimics the dynamics of braking and acceleration, while yaw replicates the experience of rear-wheel skids [12].

Realism in simulators involves how precisely a simulation mirrors real-world physical motorcycle, environments, tasks, and experiences across physical, functional, and psychological dimensions [13]. Physical realism in a motorcycle simulator refers to how accurately it replicates real-world motorcycle dynamics [e.g., 6, 7]. The physical aspects of simulators including motion platforms, sensory feedback, visual immersion, control system, and motion cueing contribute to realistic riding experiences [8]. For example, motion cues can significantly impact rider performance and perception of simulator realism [8]. A realistic control system, especially with realistic steering torque and reverse steering, is essential for ensuring simulator realism [7]. Sensory feedback, including realistic sound and environmental cues, enhances speed perception and immersion, often more effectively than motion feedback alone [3]. The motion factor, represented by DoF, is crucial for accurately replicating the complex dynamics of motorcycle riding and enhancing realism for the rider [11]. Previous studies indicated that increasing the number of DoFs enhances realism by more accurately replicating the complex dynamics of real-world riding [e.g., 12, 14]. High-DoF simulators, especially those based on parallel or serial mechanical platforms, have shown superior performance in simulating rider lean and enabling smoother transitions between positive and counter steering, thereby offering higher dynamic fidelity [10]. These configurations allow for more precise behavioral replication, making them ideal for advanced training and research applications [10]. In sum, the most realistic motorcycle simulators combine high-quality motion, precise control systems, immersive sensory feedback, and engaging visuals [3, 8].

Despite the growing interest in simulator realism, there is a lack of comprehensive evaluations of key physical realism features—such as motion platforms, visualization systems, motion cueing algorithms, and sensory feedback—in the currently available motorcycle simulators. Although Wildner and Diermeyer [15] provided a systematic overview of powered two-wheeler simulators, they focused on a general description of each simulator rather than specifically highlighting and rating the features of realism. Moreover, most existing studies focus on the realism of individual simulators, leading to a fragmented understanding of the overall picture. Additionally, the absence of rating metrics may lead the comparison and assessment of simulator realism vague. This highlights the need for an updated, integrated review of simulator realism features. This review paper aims to: (1) Identify the key features of physical realism in the currently available motorcycle simulators utilized in research-based simulation studies. (2) Evaluate the level of physical realism these simulators achieve across five core aspects: motion fidelity, control interface, sensory feedback, motion cueing, and visual immersion.

2. Methodology

To identify relevant studies for this review, a search was conducted between December 2024 and May 2025 using the SCOPUS, Web of Science, and PubMed databases, focusing on research related to motorcycle simulators. These databases were chosen for their extensive coverage of scientific publications, which includes both journal articles and conference proceedings. To ensure comprehensive results, broad search terms were utilized: (motorcycl OR motorbik OR scooter* OR two-wheel* OR 2-wheel* OR motorized-bik* OR e-bik* OR electr*-bik*) AND (simulat*) AND (valid*). No restrictions were placed on language, region, or publication year. After removing duplicates, 1,277 records were screened based on their titles and abstracts. From these, 48 full-text articles were reviewed. Studies were included if they involved physical motorcycle simulators. Based on the exclusion criteria, which focused on vehicle simulators other than two-wheeler/motorcycle simulators, and simulators other than commercial ones, only studies utilizing simulators for academic or experimental research and two-wheeler motorcycle simulators were included in this review. Non-two-wheeler motorcycle simulators and commercial simulators were excluded. This decision to exclude commercial simulators was based on their lack of research orientation, insufficient technical transparency, and absence of publicly available validation data [9]. In total, 13 studies were identified, and accordingly, 13 simulators mentioned in these papers were considered.

To describe the features of motorcycle simulators used in research-based riding simulation studies, we reviewed key physical aspects such as motion fidelity, sensory feedback, visual immersion, control system, and motion cueing quality. To quantify simulators' physical realism based on these aspects, we developed a scoring scale. This scale was developed by referring to previous related studies [9, 16-18]. A study by Wynne et al. [16] utilized a comprehensive framework to assess simulator fidelity, facilitating comparisons across different platforms. They evaluated simulators in three domains—visual, motion, and physical fidelity—using a 5-point scale, resulting in total scores ranging from 3 to 15, with higher scores indicating greater fidelity. For example, visual fidelity was rated from 1, representing a single PC screen, to 5, representing a field of view exceeding 270° with projector screens. In our review, we modified this methodology by employing a 0–2 scale across the domains, yielding a maximum possible realism score of 10 per simulator (Table 1). We selected a 0–2 scale because certain simulators clearly met a "zero" criterion (e.g., absence of motion fidelity). Additionally, setting the upper limit at 2 was pragmatic, as certain domains, such as control system fidelity and motion cueing system, comprised only three definable criteria. Employing a broader scale (e.g., 5- or 7-point) would have resulted in unused categories, thereby diminishing clarity and comparability.

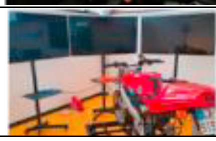
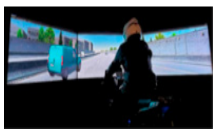
Table 1. Scoring scale for the physical realism features of the motorcycle simulators

No	Factor	Scoring Criteria
1	Motion Fidelity	0 = No motion, 0.5 = 1–2 DoF, 1 = 3 DoF, 1.5 = 4–5 DoF, 2 = Full 6 DoF
2	Sensory Feedback	0 = None, 0.5 = Audio only, 1 = Audio + 1 feature, 1.5 = Audio + 2 features, 2 = Audio + 3 features (e.g., vibration, wind, helmet haptics)
3	Visual Immersion	0 = single/static screen, 1 = triple screen or limited FOV, 1.5 = FOV > 180° or HMD, 2 = HMD + tracking or immersive dome
4	Control System Fidelity	0 = Steering only, 1 = Steering + throttle or brake, 2 = Full set (steering, brakes, clutch, gear) with feedback
5	Motion Cueing System	0 = No cueing, 1 = Basic motion translation, 2 = Advanced logic (e.g., washout filters, blended axis mapping)

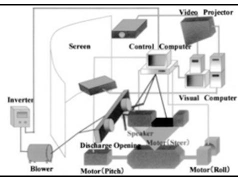
3. Synthesis of findings

Table 2 presents a list of thirteen simulators, highlighting their physical realism features, including motion fidelity, sensory feedback, visual immersion, control system, and motion cueing systems. These motorcycle simulators differ significantly in terms of complexity, but they share some core features, such as motion fidelity, sensory feedback, and control inputs. High-end simulators like Cruden and UNIPD offer up to six DoFs, while simpler options like MOVING provides minimal or passive motion. Audio feedback is the most common sensory feature, although some simulators also include elements like wind, vibration, and haptic cues. Visual systems vary widely, ranging from basic screens to immersive multi-display setups or virtual reality (VR) environments. Most simulators come equipped with full motorcycle controls, with some even incorporating force feedback. The motion cueing systems also differ, from basic tilting to advance washout filters.

Table 2. Summary of motorcycle simulators and their key physical realism features

Motorcycle simulators with realism features	**Simulators Pictures**
Cruden Simulator: It provides motion fidelity via a 6-DoF Stewart platform (surge, sway, heave, roll, pitch, yaw). Sensory feedback is audio only. Visual immersion is achieved through an Oculus Rift Head Mounted Display with 6-DoF tracking. Control system fidelity includes full motorcycle inputs. The motion cueing system uses a classical washout filter with Direct Workspace Management **[**8**].**	
DESMORI Simulator: It gives the motion fidelity via a 6-DoF hydraulic Stewart platform. Sensory feedback includes audio, seat vibration, and simulated wind drag/longitudinal using rope-towing mechanism. Visual immersion is delivered through a 220° cylindrical screen with TFT displays. Control system fidelity includes full motorcycle inputs. The motion cueing system is based on basic motion translation **[**19**].**	
UNIPD Simulator: It makes motion fidelity through a 4-DoF platform (Yaw, roll, pitch, lateral position). Sensory feedback is limited to 5.1 surround audio. Visual immersion uses three angled screens for a 180° view. Control system fidelity includes full motorcycle inputs. The motion cueing system uses an empirically tuned washout filter [20].	
IFSTTAR Simulator: The motion fidelity is provided through a 3-DoF platform (pitch, row, yaw). Sensory feedback is limited to 4.1 audio. Visual immersion uses a single front-facing screen with a 60° × 40° view. Control system fidelity includes full motorcycle inputs. The motion cueing system uses a simplistic visual-physical lean split with direct actuator output [10].	
MUARC Simulator: It produces motion fidelity through a 3-DoF platform (pitch, roll). Sensory feedback includes audio and a seat-mounted bass shaker for engine vibration. Visual immersion is achieved using three forward-surround screens. Control system fidelity includes full motorcycle inputs with elastic force feedback via helical springs. The motion cueing system relies on basic physical motion translation without advanced cueing logic [21].	
MOVING Simulator: It provides motion fidelity through a passive platform with a single roll DoF. Sensory feedback includes audio only. Visual immersion is limited to a static monitor setup. Control system fidelity includes steering, throttle, and brake inputs. Motion cueing system is absent, relying entirely on rider-induced roll [6].	
IMACOM Simulator: It gives motion fidelity through a 3-DoF dynamic platform supporting roll, pitch, and yaw. Sensory feedback includes a 5.1 audio system and motorized handlebars for haptic cues. Visual immersion is achieved using three 55-inch screens arranged for a 130° field of view. Control system fidelity includes full motorcycle inputs with force-feedback handlebars. The motion cueing system is simplistic, relying on synchronized actuator output without advanced filtering [22].	

NIHON Simulator: It involves motion fidelity produced by a 2-DoF platform (pitch and roll) driven by AC servomotors. Sensory feedback includes engine sound, wind simulation, and haptic handlebar response. Visual immersion is achieved via a front-facing projection system with a 150° lateral and 35° vertical field of view. Control system fidelity includes full motorcycle inputs with monitoring of handle torque, brake forces, throttle, and foot pressure. The motion cueing system is simplistic, using direct actuator output without advanced filtering or blending [23].



MotorcycleSim: It produces motion fidelity through a 1-DoF pneumatic system that controls lean angle up to ±25°. Sensory feedback includes engine sound and environmental audio via surround speakers. Visual immersion uses a large front-facing flat screen (~2.5 m²). Control system fidelity includes full motorcycle inputs integrated into a real Triumph Daytona 675 chassis. The motion cueing system is simplistic, relying on pneumatic actuator responses without advanced filtering or cueing logic [9].

WIVW Static Simulator: Tt involves 0 DoF with no active platform motion, allowing only passive roll via rider weight shifting. Sensory feedback includes engine, roll, wind, and surrounding traffic sounds. Visual immersion is provided by a 2 m × 1.7 m screen offering a 60° horizontal and 42° vertical field of view. Control system fidelity comprises full motorcycle controls with simplified positive steering, substituting physically correct counter-steering. The motion cueing system is absent, relying entirely on rider-induced passive motion [24].

MTW Simulator: It provides motion fidelity through a 3-DoF platform enabling vertical translation, roll, and pitch. Sensory feedback includes audio cues simulating engine, wind, and traffic sounds. Visual immersion uses a curved screen offering a 180° field of view. Control system fidelity features full motorcycle controls including clutch, throttle, brakes, and gear. The motion cueing system is simplistic, providing basic physical motion translation without advanced filtering [3].

Enhanced Postura Motergo: It involves a motion system providing 2 DoF, roll and pitch, with a single DC motor controlling roll. Sensory feedback includes engine, wind, and traffic sounds. Visual immersion was improved by upgrading from a single flat screen to a 180° curved projection screen with multiple projectors. Control system fidelity now incorporates full motorcycle inputs via a custom HS1 Full throttle controller. The motion cueing system is basic, providing physical roll and pitch motion without advanced cueing algorithms [25].

INRETS-UEVE Simulator: It uses a 3-DoF platform for roll, pitch, and yaw, with sensory feedback from sounds and dual haptic handlebars simulating inertia and tire forces. Visual immersion is provided by three projection screens. It features full motorcycle controls with handlebar force feedback, and an advanced motion cueing system using washout filters with tilt coordination [26].

Table 3 and Fig. 1 present an evaluation of the thirteen motorcycle simulators based on physical realism, highlighting how their technical complexity contributes to the overall realism of each simulator.

Table 3. Physical realism scores for motorcycle simulators

No	Simulator	Motion Fidelity	Sensory Feedback	Visual Immersion	Control Fidelity	Motion Cueing	Total Score
1	Cruden (6-DoF)	2.0	0.5	2.0	2.0	2.0	8.5
2	DESMORI (6-DoF)	2.0	1.5	1.5	2.0	1.0	8.0
3	UNIPD (4-DoF)	1.5	0.5	1.0	2.0	2.0	7.0
4	INRETS-UEVE (3-DoF)	1.0	1.0	1.0	2.0	2.0	7.0
5	MUARC (3-DoF)	1.0	1.0	1.0	2.0	1.0	6.0
6	IMACOM (3-DoF)	1.0	1.0	1.0	2.0	1.0	6.0
7	NIHON (2-DoF)	0.5	1.5	1.0	2.0	1.0	6.0
8	MTW (3-DoF)	1.0	0.5	1.0	2.0	1.0	5.5
9	Enhanced Postura Motergo™ (2-DoF)	0.5	0.5	1.0	2.0	1.0	5.0
10	IFSTTAR (3-DoF)	1.0	0.5	0.0	2.0	1.0	4.5
11	MotorcycleSim (1-DoF)	0.5	0.5	0.0	2.0	1.0	4.0
12	DESMORI Prototype (0-DoF)	0	1.5	0.0	2.0	0.0	3.5
13	MOVING (1-DoF)	0.5	0.5	0.0	1.0	0.0	2.0

The simulators exhibit a range of realism scores, reflecting differences in design features such as motion fidelity, sensory feedback, visual immersion, control fidelity, and motion cueing. At the top of the scale, Cruden and DESMORI achieved the highest realism ratings, scoring between 8 and 8.5 out of 10. Both are equipped with six degrees of freedom (6-DoF), which allows for highly dynamic and immersive simulation experiences. The second tier includes UNIPD, INRETS-UEVE, MUARC, IMACOM, and NIHON, with realism scores ranging from 6 to 7. The third group—comprising MTW, Enhanced Postura Motergo, IFSTTAR, and MotorcycleSim—received realism scores between 4 and 5.5. Finally, DESMORI Prototype and MOVING scored the lowest, with realism ratings at or below 3.5, indicating minimal immersive or technical capabilities.

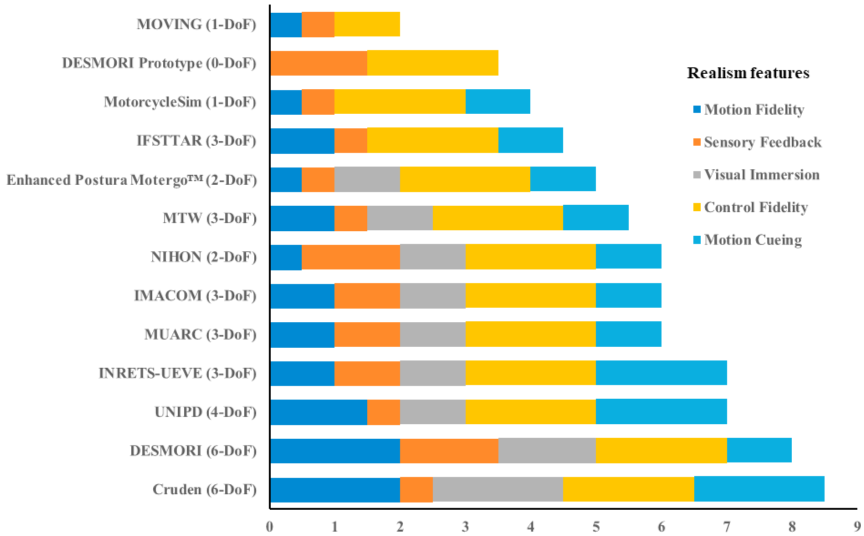


Fig. 1. Physical realism scores for motorcycle simulators

4. Discussion

This paper aims to provide an overview of the key physical aspects of motorcycle simulators, including motion fidelity, control accuracy, sensory feedback, motion cuing and visual immersion. Additionally, it evaluates these aspects in terms of realism in the simulator.

The assessment of thirteen motorcycle simulators reveals significant variation in system complexity, yet notable convergence across key design realism features, namely motion fidelity, sensory feedback, visual immersion, control system fidelity, and motion cueing systems. Simulators like Cruden, DESMORI, and UNIPD stand out with high motion fidelity, offering 4 to 6 DoFs, while simpler systems such as MOVING, MotorcycleSim, and the DESMORI Prototype, operate with minimal motion capabilities (0–1 DoF), often relying on passive or static configurations. Most simulators offer moderate motion (3 DoFs), which may suffice for specific applications but fall short of replicating the full dynamic experience of motorcycling. Sensory feedback is a key area of convergence, particularly with audio feedback, which is nearly universal across platforms. Simulators such as Cruden, MOVING, and UNIPD employ audio extensively, including surround sound setups, while others enrich the sensory environment with wind simulation, haptic cues, and vibration. Notably, NIHON and INRETS-UEVE incorporate advanced haptic systems and even simulate tire forces, enhancing realism. Wind effects, either physical or audio-based, were integrated into systems like DESMORI, NIHON, and Postura Motergo, underscoring the growing attention to multisensory fidelity.

Visual immersion varies widely, primarily through differences in display configuration. Multi-screen and wrap-around setups dominate in high-fidelity systems (e.g., UNIPD, MUARC, IMACOM, DESMORI), offering wide fields of view and peripheral engagement. Conversely, systems like IFSTTAR, MOVING, and MotorcycleSim rely on single or flat screens, limiting immersion. Cruden's use of a VR headset represents a distinct approach, enhancing spatial presence despite physical motion limitations. Control fidelity is another domain where higher-end simulators converge. Most incorporate full motorcycle controls (steering, throttle, brakes), with several, such as IMACOM, INRETS-UEVE, and NIHON, integrating force feedback mechanisms for added realism. MUARC adds elastic feedback, and MotorcycleSim stands out for embedding controls within an actual motorcycle framework. However, systems like MOVING only partially implement control inputs, reducing operational authenticity. The motion cueing system is the most technically divergent element. Advanced systems such as Cruden, INRETS-UEVE, and UNIPD employ sophisticated cueing techniques like washout filters and tilt coordination, significantly enhancing visual and physical motion correspondence. In contrast, simpler simulators either apply unfiltered actuator outputs (e.g., IFSTTAR and MotorcycleSim) or exclude motion cueing entirely, relying solely on visual and audio cues (e.g., MOVING and WIVW Static). These technical dimensions directly shape simulator physical realism, as evaluated in Table 3. Simulators with high technical sophistication, particularly Cruden and DESMORI, earned top realism scores (8–8.5/10), confirming the importance of integrated, high-fidelity features. Systems like UNIPD, INRETS-UEVE, and MUARC formed a second tier, balancing technical robustness with cost-effective trade-offs. Mid-level simulators such as MTW and MotorcycleSim offered partial immersion, while basic setups like DESMORI Prototype and MOVING ranked lowest due to minimal motion, visual, or sensory capabilities. and validation.

As illustrated in Table 3, the overall scores for physical realism are predominantly associated with the integration of motion fidelity, control fidelity, and motion cueing, as demonstrated by the highest-ranked simulators. Sensory feedback and visual immersion also play a contributory role but are most effective when integrated with comprehensive motion and control systems. In contrast, simulators with limited DoF or reduced motion fidelity tend to receive lower overall scores, even if they possess moderate sensory or visual features. This observation suggests that these features interact synergistically rather than independently to enhance physical realism. Overall, realism is strongly tethered to the extent of physical motion, sensory integration, and visual depth, making these features critical benchmarks in simulator development. Research indicates that the degree of physical realism in motorcycle simulators significantly affects training efficacy and reliability, although the relationship is intricate. Enhanced tactile feedback and fidelity can improve immersion, engagement, and skill transfer [27, 28]. However, studies also suggest that lower levels of realism may still be effective, particularly for specific skills or novice training, and can alleviate task load [27]. In general, while higher realism can facilitate learning, it does not inherently ensure superior outcomes; therefore, careful simulator design and training types are crucial [29, 30]. This review has important implications for both researchers and simulator developers. For researchers, it is crucial to understand how motion realism, control accuracy, sensory feedback, motion cues, and visual immersion interact. These factors can help assess how effectively a simulator represents the real world and ensures consistent outcomes. For developers, these same factors highlight the necessity of physical fidelity, along with addressing issues of technical realism and user adaptability. This understanding will be helpful in creating simulators that are both scientifically rigorous and practically useful.

This review has limitations. Although the development of the physical realism checklist was informed by prior research, the checklist itself has yet to undergo standardization. The absence of a widely accepted framework for evaluating this realism may affect the accuracy and consistency of classifying motorcycle simulators based on their features. Consequently, this may affect comparisons across various studies or categories. Future research could focus on establishing and validating a standardized tool for assessing realism to improve the reliability of simulator classifications and facilitate cross-simulator comparisons. This review did not consider subjective realism, where participants' perception of realism in connection to the simulator can be understood. Future research could consider subjective realism for a comprehensive understanding of overall realism in motorcycle simulators. This review focuses on research-based motorcycle simulators due to their transparency, reproducibility, and availability of technical details. However, commercial simulators, typically designed for entertainment purposes, prioritize user experience and accessibility over research fidelity and analytical rigor [11, 31] lacking the detailed research validation found in academic [15]. In contrast, research-oriented systems employ more rigorous designs focused on ergonomics, human factors, and safety evaluation [15, 32]. This gap highlights the need for a future paper that rigorously evaluates research-based motorcycle simulators against their commercial counterparts.

In sum, the evaluation of thirteen motorcycle simulators shows that, although the complexity of the systems varies significantly, realism is consistently influenced by the convergence of key features. These features include motion fidelity, sensory feedback, visual immersion, and control fidelity. High-end simulators such as Cruden and DESMORI demonstrate that integrated, multisensory, and dynamic capabilities greatly enhance realism. As a result, these features can be considered as essential benchmarks for developing and validating simulators.

Acknowledgements

Research reported in this publication was supported by the Qatar Research Development and Innovation Council [ARG01-0517-230203]. The content is solely the responsibility of the authors and does not necessarily represent the official views of Qatar Research Development and Innovation Council

References

[1] Susilo, Y.O., T.B. Joewono, and U. Vandebona, *Reasons underlying behaviour of motorcyclists disregarding traffic regulations in urban areas of Indonesia.* Accident Analysis & Prevention, 2015. 75: p. 272-284.
[2] Chang, W.J. and L.B. Chen, *Design and Implementation of an Intelligent Motorcycle Helmet for Large Vehicle Approach Intimation.* IEEE Sensors Journal, 2019. 19(10): p. 3882-3892.
[3] Gupta, M. and N.R. Velaga, *Validation of motorized two-wheeler virtual environment: Influence of perceived realism and simulator fidelity.* Transportation Research Part F: Traffic Psychology and Behaviour, 2025. 109: p. 672-688.
[4] Rifaat, S.M., R. Tay, and A. de Barros, *Severity of motorcycle crashes in Calgary.* Accident Analysis & Prevention, 2012. 49: p. 44-49.
[5] WHO, *Global status report on road safety 2023.* 2023.
[6] Di Miceli, D., et al., *Sensibilization of a motorcycle simulator to the effects of the roll motion: Modelling and experimental validation.* Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 2023. 237(14): p. 3519-3535.
[7] Lobjois, R. and F. Mars, *Effects of motorcycle simulator configurations on steering control and gaze behavior in bends.* Journal of experimental psychology: applied, 2020. 26(1): p. 108.
[8] Westerhof, B., et al. *Evaluation of a motorcycle simulator*. 2020. Symposium on the Dynamics and Control of Single Track Vehicles.
[9] Stedmon, A.W., et al., *'MotorcycleSim': An Evaluation of Rider Interaction with an Innovative Motorcycle Simulator.* The Computer Journal, 2011. 54(7): p. 1010-1025.
[10] Benedetto, S., et al., *A comparison of immersive and interactive motorcycle simulator configurations.* Transportation Research Part F: Traffic Psychology and Behaviour, 2014. 23: p. 88-100.
[11] Ferrazzin, D., et al., *THE MORIS MOTORCYCLE SIMULATOR: AN OVERVIEW.* SAE Transactions, 2002. 111: p. 199-210.
[12] Arioui, H., et al., *Mechatronics, Design, and Modeling of a Motorcycle Riding Simulator.* IEEE/ASME Transactions on Mechatronics, 2010. 15(5): p. 805-818.
[13] Owen, L., *From fairies to SimMan: Tolkien and realism in simulation.* Journal of Surgical Simulation, 2016. 3: p. 8-12.
[14] Nehaoua, L., et al. *Design and Modeling of a New Motorcycle Riding Simulator*. in *2007 American Control Conference*. 2007.
[15] Wildner, D. and F. Diermeyer. *Systematic Literature Review: Motorcycle Simulators*. in *The Evolving Scholar-BMD 2023, 5th Edition*. 2024.
[16] Wynne, R.A., V. Beanland, and P.M. Salmon, *Systematic review of driving simulator validation studies.* Safety Science, 2019. 117: p. 138-151.
[17] Perroud, B., et al. *Realism Score for Immersive Virtual Reality Systems and Driving Simulators*. 2016.
[18] Grottoli, M., *Development and evaluation of a motorcycle riding simulator for low speed maneuvering*. 2021, Delft University of Technology Delft, The Netherlands.
[19] Will, S., Hammer, Thomas, Merkel, Nora, Pleß, Raphael,, *Motorcycle Rider Reaction Times as Response to Visual Warnings.*, in *4th International Motorcycle Conference (ifz)*. 2022: Cologne, Germany.
[20] Cossalter, V., et al., *Development and validation of an advanced motorcycle riding simulator.* Proceedings of the Institution of Mechanical Engineers, Part D, 2011. 225(6): p. 705-720.
[21] Nugent, M., et al., *Evaluating rider steering responses to an unexpected collision hazard using a motorcycle riding simulator.* Transportation Research Part F: Traffic Psychology and Behaviour, 2019. 66: p. 292-309.
[22] Michel, P., et al., *Rider in the Loop Dynamic Motorcycle Simulator: An Instrumentation Strategy Focused on Human Acceptability.* Electronics, 2022. 11(17): p. 2690.
[23] Kageyama, I. and N. Tagami, *Development of a riding simulator for two-wheeled vehicles.* JSAE Review, 2002. 23(3): p. 347-352.
[24] Will, S. and E.A. Schmidt, *Powered two wheelers' workload assessment with various methods using a motorcycle simulator.* IET intelligent transport systems, 2015. 9(7): p. 702-709.
[25] Wan Fauzi, W.M.S., A.R. Omar, and H. Rashid, *Enhancement of postura motergoTM: from an ergonomic motorcycle test rig to a full-scale simulator.* Journal of Mechanical Engineering (JMechE), 2017(4): p. 43-59.
[26] Nehaoua, L., et al. *Open-loop test and validation of a new two-wheeled vehicle riding simulator*. in *2007 European Control Conference (ECC)*. 2007.
[27] Yang, E., S. Park, and J. Ryu, *The effects of physical fidelity and task repetition on perceived task load and performance in the virtual reality-based training simulation.* Br. J. Educ. Technol., 2023. 55: p. 1507-1527.
[28] Irani, R., *Tactile Feedback Within Virtual Reality Training: An Immersive Study for Motorcycle Training.* 2022.
[29] Grottoli, M., M. Mulder, and R. Happee, *Motorcycle simulator subjective and objective validation for low speed maneuvering.* Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 2022. 237: p. 2175-2189.
[30] Bunker, W., *Training Effectiveness Versus Simulation Realism.* 1978. 0162.
[31] Stedmon, A.W., et al. *'STISIM-Drive' Meets 'MotorcycleSim': Using Driving Simulation Software to Develop a Unique Motorcycle Simulator for Rider Behavior Research*. in *HCI International 2011 – Posters' Extended Abstracts*. 2011. Berlin, Heidelberg: Springer Berlin Heidelberg.
[32] Stedmon, A., et al., *MotorcycleSim: a user-centred approach in developing a simulator for motorcycle ergonomics and rider human factors research.* Advances in Transportation Studies, 2012(27).