Improving Young Riders' Situational Awareness Through Driving Simulation: A University-Based Study in Indonesia

Attalarik Shulima[1], Lusi Susanti[1] *, Hilma Raimona Zadry[1], Ashila Nurul Huda[1]

[1] Department of Industrial Engineering, Andalas University, Limau Manis, Padang, Indonesia-25163

Corresponding author: lusi@eng.unand.ac.id   Doi: https://doi.org/10.24036/invotek.v25i2.1247

Abstract

Motorcycle-related crash remain a major concern among university students in Indonesia. This study investigates situational awareness (SA) among novice motorcyclists at Universitas Andalas (UNAND) and evaluates the effectiveness of a simulation-based training intervention. Using the QUASA (Quantitative Analysis of Situational Awareness) method, baseline and post-training assessments were conducted to measure SA accuracy. The simulation module, developed using Unreal Engine and AI-assisted audio feedback, presented realistic traffic scenarios designed to enhance cognitive engagement. Findings indicate a substantial improvement in SA, with actual awareness scores increasing by approximately 30 percentage points post-intervention. Perceived accuracy also showed measurable gains. Despite a small simulation sample, results suggest that immersive training improves hazard perception and rider decision-making. These outcomes emphasize the value of technology-enhanced learning in addressing safety risks among young riders. Further research with control groups and larger samples is needed to generalize findings. Ethics clearance, data availability, and conflict of interest disclosures have been included.

Keywords: Driving Simulator, Motorcycle Safety, QUASA, Road Safety Education, Situational Awareness.

1. Introduction

Land transportation plays a vital role in the economy and mobility of the Indonesian people [1], [2]. Over the past five years, the number of motorised vehicles has surged significantly, reaching 160.6 million units by February 2024. Motorcycles dominate this figure, totalling 134.18 million units [3]. This increase in vehicle ownership is directly proportional to the rise in road traffic crashes. In 2023 alone, there were 148,575 recorded crashes, of which 76% involved motorcycles [4]. These data indicate a major shift in mobility patterns and highlight the urgent need for enhanced safety interventions.

Crash records from 2016 to 2023 show fluctuations but reveal a sharp increase in both the number of crashes and fatalities in recent years in Indonesia. According to Central Bureau of Statistics, motorcycle-related crashes have consistently dominated the statistics, underscoring the vulnerability of two-wheeled vehicle users [3]. Among the victims, adolescents and young adults aged 18–21 are disproportionately represented [5] noted 26,906 victims in the 10–19 age group and 29,281 in the 20–29 age group. [6], [7], and [8] further identified that most of motorcycle crash victims fall within the 18–21 age bracket. This demographic trend necessitates targeted safety initiatives focused on this age group.

Traffic crashes are multifactorial events often resulting from a combination of human error, driver-related conditions, road infrastructure, vehicle performance, and environmental factors [9]. Among these causes, human error remains the most dominant, particularly behavioral factors such as traffic violations, inexperience, fatigue, and overconfidence [10]–[13]. Understanding and mitigating these behavioral risks is crucial in improving road safety outcomes.

Situational Awareness (SA) is a critical cognitive factor that shapes driving behavior [14], [15]. It encompasses a rider's capacity to perceive elements in the environment, interpret their significance, and predict potential developments that may affect decision-making on the road [14] Riders with high

SA are more likely to detect hazards early, make appropriate judgments, and respond swiftly in complex traffic conditions [16]–[18]. In contrast, low SA levels have been associated with delayed reactions and a greater risk of errors that can lead to crashes [19]–[21].

1.1 Theoretical Framework: Situational Awareness in Motorcycle Riding

Situational Awareness (SA) is a key cognitive factor influencing safe decision-making in dynamic contexts such as road traffic. Based on [19] model, SA consists of three levels: (1) Perception of environmental elements, (2) Comprehension of their meaning, and (3) Projection of future developments. For motorcyclists, these levels collectively determine the ability to detect hazards, interpret risks, and anticipate potential incidents—critical skills for safe navigation.

This study applies the QUASA (Quantitative Analysis of Situational Awareness) method to assess how accurately novice riders perceive, understand, and predict traffic scenarios. QUASA integrates objective probes and subjective confidence ratings to evaluate both accuracy and self-assessment, offering a robust measure of cognitive calibration. Previous studies in Indonesia [22]–[24] suggest a minimum SA benchmark of 69.81% for safe riding, highlighting the need for systematic evaluation and training.

The research focuses on novice motorcyclists at Universitas Andalas (UNAND), where diverse topography, unpredictable weather, and mixed traffic increase riding complexity. Most students depend on motorcycles, yet campus observations reveal risky behaviors such as speeding, poor helmet use, and inattentiveness. Despite these challenges, UNAND lacks structured safety education for riders.

Globally, simulation-based interventions have shown promise in improving hazard perception [25], [26], though many studies lack realism or context for low- and middle-income countries. Cognitive models such as [27] also demonstrate that SA performance can be predicted using visual and memory-based indicators, yet applications for motorcyclists remain limited.

Addressing this gap, the present study not only measures current SA levels but also introduces a simulation-based training model using a custom-built motorcycle simulator developed with Unreal Engine, a real-time 3D simulation software. This immersive system allows riders to practice hazard recognition safely while their SA is objectively assessed. The outcomes are expected to inform campus safety policies and contribute to scalable, evidence-based traffic safety education for young riders in Indonesia.

2. Methodology

This study employed a mixed-methods approach to assess and improve the situational awareness (SA) of novice motorcycle riders, particularly among students at UNAND. The research was conducted in three sequential phases: (1) baseline assessment using the Quantitative Analysis of Situational Awareness (QUASA) method, (2) development of a simulation-based intervention using the Engineering Design Process (EDP), and (3) evaluation of the intervention's effectiveness through pre-post analysis and user feedback.

2.1 Phase 1 – Situational Awareness Assessment using QUASA

To quantify the situational awareness levels of novice motorcyclists, this study employed the QUASA method, originally developed by [28]. QUASA evaluates SA based on structured scenario responses, comparing a participant's actual observations to expert ben chmarks. This method is particularly suitable for simulation-based assessments, offering measurable insights into cognitive performance during dynamic tasks. The QUASA rubric was designed in alignment with Endsley's three-tier model of SA:

- Level 1 – Perception of Environmental Elements

Indicators at this level include the ability to correctly identify road signs, recognize the presence and behavior of other vehicles, detect road surface anomalies (e.g., potholes, slippery patches), and acknowledge dynamic elements such as pedestrian movement or traffic signals. Example item: "Did the rider notice the speed limit sign on the roadside before entering the curve?"

- Level 2 – Comprehension of the Situation

This level assesses how well the rider integrates perceived cues to interpret current traffic conditions. Indicators include understanding traffic flow, interpreting the intentions of other road users (e.g., braking car, sudden lane change), and identifying potential hazards. Example item: "Did the rider slow down after recognizing that a car ahead was preparing to turn left?"

▪ Level 3 – Projection of Future Status

The third level evaluates predictive reasoning—whether the rider can anticipate the evolution of the scenario based on available cues. This includes preemptive responses to emerging risks, such as preparing for evasive maneuvers or changing speed proactively. Example item: "Did the rider anticipate that the pedestrian might cross the road despite the absence of a zebra crossing?"

Each item in the QUASA rubric was scored using a binary system (correct/incorrect recognition or prediction), and aggregated to generate an overall SA score. The assessment also incorporated perceived accuracy, wherein participants were asked to self-rate their performance post-simulation. This allowed a comparison between actual accuracy (as judged by experts) and perceived awareness, revealing overconfidence or underestimation tendencies both of which are relevant to driving safety.

By mapping QUASA indicators directly to Endsley's SA levels, this study ensures theoretical consistency and provides nuanced insight into which aspects of situational awareness are most underdeveloped among novice riders. This, in turn, informs targeted intervention design, such as focusing simulation training on predictive hazard awareness (Level 3) if that emerges as the weakest domain. The QUASA rubric used in this study is presented in Appendix A.

Sampling was conducted using the Slovin formula at a 10% margin of error. From the 2022 UNAND student population of 31,896, a sample size of 100 respondents was deemed sufficient for statistical analysis.

2.2 Phase 2 – Development of Driving Simulator using Unreal Engine

Informed by the low SA scores identified in Phase 1, the research proceeded with developing a driving simulation intervention. The process followed the Engineering Design Process (EDP), which consisted of:

▪ Problem Identification: Low SA and overconfidence among student motorcyclists.
▪ Literature Review: Identification of best practices in hazard perception training and behavioural interventions.
▪ Brainstorming Solutions: Four strategies were evaluated—training and education, effective communication, technology use, and environmental enhancement.
▪ Strategy Selection: Based on feasibility and impact, training and education were chosen as the core approach.
▪ Design and Development: A realistic driving simulator was created using Unreal Engine, a real-time 3D simulation software, featuring interactive urban traffic scenarios, hazard simulations, and real-time visual-audio feedback. Scenarios included riding through intersections, responding to traffic signals, avoiding distractions (e.g., phone use), and reacting to unexpected hazards.
▪ Prototype Testing: The simulator was tested and refined based on usability trials and expert input.

2.3 Phase 3 – Evaluation of Simulator Effectiveness

To measure the impact of the intervention, participants underwent a structured evaluation comprising:

▪ Knowledge Assessment: Participants completed a pre-test and post-test consisting of safety-related questions. The mean score increase and standard deviation were analysed using paired t-tests to determine statistical significance.
▪ SA Reassessment: The QUASA questionnaire was re-administered after simulation training to identify improvements in SA levels and calibration profiles.
▪ User Feedback: A perception questionnaire was used to gather subjective evaluations of the simulator's realism, usability, and perceived learning effectiveness.

Data Sources: Primary: AQUAS scores (pre and post), knowledge tests, and feedback forms; Secondary: Literature review, expert consultation, and crash statistics. Data Analysis: Quantitative data were analysed with descriptive statistics and inferential tests (t-test); Qualitative feedback was analysed thematically to understand participants' experiences and identify areas for improvement.

3. Result and Discussion

3.1 Result

3.1.1 Situational Awareness Baseline Assessment

Using the QUASA method, the baseline situational awareness of 100 UNAND students was measured. The results showed a disparity between actual accuracy (78.72%) and perceived accuracy (79.61%). The situational awareness score was calculated to be 62.67%, indicating an overconfident behaviour pattern among respondents. Figure 1 illustrates that the average calibration result of participants lies below the well-calibrated line, reflecting an overall tendency toward overconfidence.
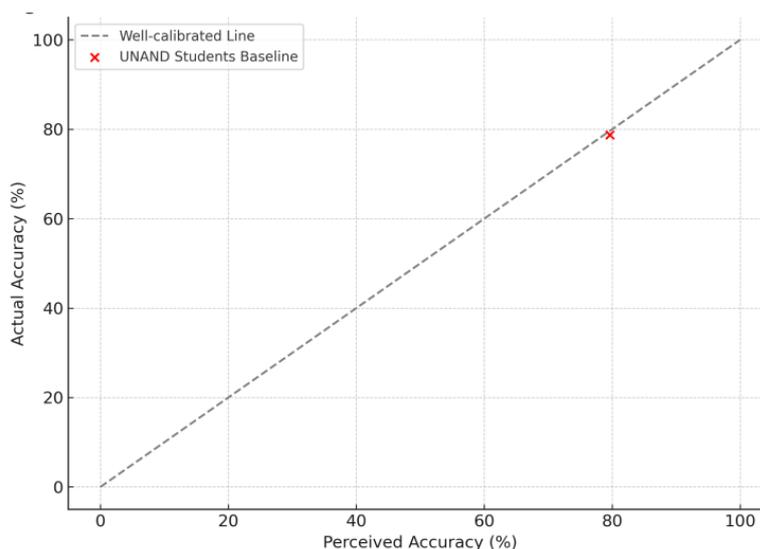

Figure 1. Situational Awareness Calibration Curve of UNAND Student Riders

3.1.2 Development of Driving Simulator

To improve student motorcyclists' situational awareness, this study implemented simulation-based training as the most effective educational intervention [15], [29]. A motorcycle simulator was developed using Unreal Engine, a real-time 3D simulation software, to create realistic and dynamic traffic scenarios under varying road, weather, and traffic conditions. These included situations such as mobile phone use, improper lane selection, and congestion. Real-time AI audio feedback enhanced engagement and comprehension during training. The design process considered user needs, technical performance, and usability to ensure smooth interaction and effective learning. Overall, the simulator provides an immersive and scalable tool for strengthening riders' perception, comprehension, and projection skills, which are key components of situational awareness essential for safe and adaptive decision-making [19].

The simulation scenarios were strategically designed to address each of the three levels of Situational Awareness as conceptualised by Endsley [19]:

▪ Level 1: Perception (Noticing Elements in the Environment)

Scenario: Mobile Phone Distraction.

In this task, the rider is prompted to respond to notifications or calls simulated on a mounted device. The goal is to test their ability to detect and prioritise environmental cues such as road signs and other vehicles while experiencing cognitive distraction.

AI Audio Feedback: If the rider fails to notice a stop sign while interacting with the phone, the AI prompts a real-time alert such as: "Warning: Sign missed due to distraction. Focus ahead!"

▪ Level 2: Comprehension (Understanding the Situation)

Scenario: Lane Choice at an Intersection.

The rider must interpret road markings, signage, and vehicle flow to choose the correct lane. This scenario challenges their understanding of traffic rules and dynamic context interpretation.

AI Audio Feedback: If the rider selects an incorrect lane, the system responds: "Incorrect lane for turn. Observe road signs carefully."

▪ Level 3: Projection (Anticipating Future Events)

Scenario: Vehicle Cutting Across Suddenly.

A vehicle enters the rider's path unexpectedly, requiring a quick judgment to avoid collision. This tests their ability to anticipate the actions of others and adapt behaviour accordingly.

AI Audio Feedback: If the rider reacts late or swerves dangerously, a voice alert says: "Late response—anticipate vehicle behaviour at junctions."

The integration of AI-powered audio feedback plays a critical role in facilitating real-time learning [30]. As riders make errors or delays in judgment, the system offers immediate verbal guidance, reinforcing correct behaviour and prompting reflection. This dynamic loop of action-feedback-correction is designed to help users: (1) Advance from noticing (Level 1) to interpreting (Level 2); (2) Then move towards predicting and responding proactively (Level 3). By aligning each scenario with a specific SA level and reinforcing it through targeted audio prompts, the simulation ensures structured cognitive progression during training. A session in the simulator engine is presented in Figure 2.
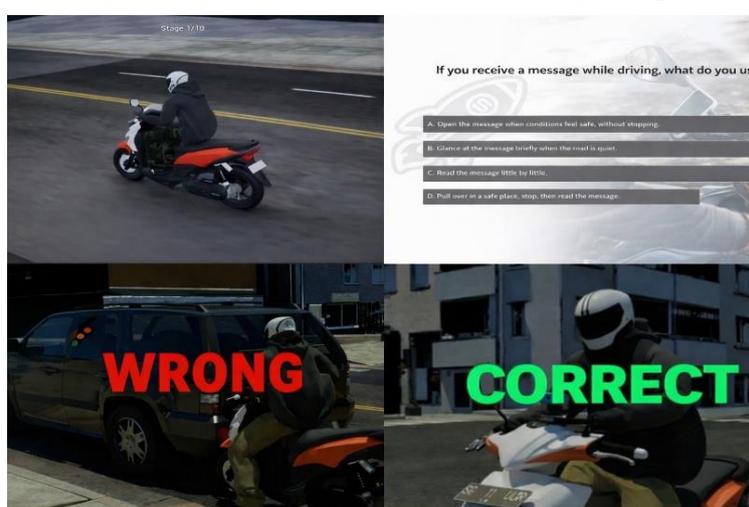

Figure 2. The Session on How Users Make Decisions While Driving

To ensure relevant and accurate simulation content, scenarios were reviewed by two road safety experts and a transportation psychologist. Their input enhanced the simulator's realism and instructional quality. This expert-validated, user-centered approach provides a realistic and scalable tool for improving situational awareness and promoting safer riding behavior among young motorcyclists.

3.1.3 Evaluation of Simulator Effectiveness: Knowledge Assessment

A pre-test and post-test with ten students were conducted to assess learning improvements after using the motorcycle simulator. The average score rose from 78.3 to 92.6, and the standard deviation decreased from 8.9 to 4.7, showing more consistent performance. A paired t-test confirmed the improvement was statistically significant ($p = 0.00036$) (Table 1 and Table 2). These findings indicate that the simulator effectively enhances situational awareness, hazard response, and decision-making through its immersive, feedback-based design. Participants also reported higher confidence in handling hazards, reflecting better risk awareness. Although the sample size was small, the results demonstrate measurable benefits, suggesting the simulator's strong potential for wider application in motorcycle safety training.

Table 1. Summary of Pre-test and Post-test Scores

Variable	Mean	SD	Max	Min
Pre-Test	78.3	8.9	90	65
Post-Test	92.6	4.7	100	82

Table 2. Paired t-test of Pre-test and Post-test

Statistic	Value
t_{Stat}	-5.55
Df	9
p_{-value} (two-tail)	0.00036

3.1.4 Evaluation of Situational Awareness Improvement using the QUASA Method on Drive Simulator Users

A subset of participants completed QUASA assessments before and after simulator use. The average situational awareness score increased from 53.25% to 83.20%, a 29.95-point improvement in hazard recognition and response. Analysis by level showed consistent gains: Perception improved from 46.18% to 79.93%, Comprehension from 65.78% to 85.29%, and Projection from 47% to 89%, indicating stronger anticipation of traffic risks (Figure 3). These findings demonstrate that simulation-based training with real-time feedback effectively enhances all levels of situational awareness. The simulator successfully replicates real-world hazards, improving participants' decision-making and risk anticipation. Supporting data also showed higher self-reported awareness, with perceived accuracy increasing from 80.20% to 88.13%, confirming both objective and subjective improvements in situational awareness.
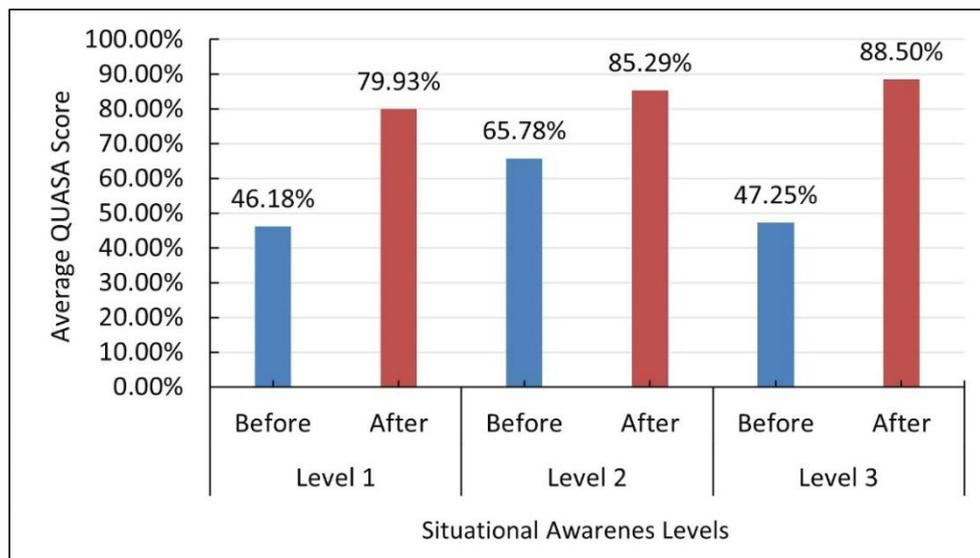

Figure 3. Comparison of QUASA Scores by Situational Awareness (SA) Level Before and After Simulator-Based Training

3.2 Discussion

This study examined the situational awareness (SA) of university student motorcyclists and evaluated the effectiveness of an Unreal Engine-based simulator as a cognitive training tool. The findings revealed a significant gap between perceived and actual SA, showing that young riders often overestimate their abilities. This miscalibration, measured using the QUASA rubric, was notably reduced after simulator training, indicating improvements in both objective awareness and self-assessment.

Consistent with earlier studies [31] and [32], the results confirm that poor calibration between perceived and actual SA contributes to risky behavior among novice riders. The pre-training SA average of 53.25% fell below the 69.81% benchmark for safe decision-making [22] and [23] underscoring the need to enhance both knowledge and self-awareness in early rider education. The simulator, developed using the Engineering Design Process, presented scenarios aligned with SA levels: distraction tasks for Perception, route selection for Comprehension, and hazard anticipation for Projection. Real-time AI feedback supported active learning and progression through these levels, consistent with [19] SA framework.

Statistical analysis showed strong improvements across all levels—Perception from 46% to 80%, Comprehension from 66% to 85%, and Projection from 47% to 89%. These gains demonstrate the simulator's ability to strengthen hazard detection, contextual understanding, and predictive judgment. The results affirm the pedagogical value of immersive simulation in improving cognitive and behavioral safety skills, particularly for young riders in low- and middle-income countries. By integrating SA-based digital tools into driver education, institutions can foster scalable, engaging, and effective approaches to promote safer riding behavior.

3.2.1 Study Trengths

A key strength of this study lies in its integration of quantitative and qualitative evaluation methods, combining objective tests, subjective feedback, and QUASA-based calibration curves for a comprehensive assessment of the simulator's impact. The user-centered development process, guided by the Engineering Design Process and supported by the open-source Unreal Engine, a real-time 3D simulation software, enhances both replicability and scalability. Targeting young motorcyclists, a high-risk group in Indonesia, further strengthens the study's relevance, while the use of calibration-based situational awareness assessment addresses an important methodological gap in national road safety research.

3.2.2 Study Limitations

Despite promising results, this study has several limitations. The small sample size may limit the generalizability of findings, and simulator scenarios, though expert-reviewed, lacked broader validation from traffic authorities or instructors. The research also measured only short-term improvements without assessing long-term retention or real-world behavioral change. Additionally, the QUASA method depends on self-reported confidence, which may be influenced by bias or cognitive load. Future studies should include behavioral and physiological measures, larger and more diverse samples, and longitudinal evaluations to better understand sustained situational awareness development.

3.2.3 Practical and Policy Implications Based on Situational Awareness (SA)

The findings of this study have key implications for driving education and safety policy. Integrating situational awareness (SA) assessment into motorcycle licensing could provide a more complete measure of rider competence beyond procedural knowledge. The developed simulator, featuring real-time AI feedback and immersive scenarios, can serve as a model for national training programs to strengthen perception, comprehension, and projection skills safely. Moreover, the concept could be scaled into a mobile-based educational app with gamified SA challenges to reach wider audiences, particularly in rural areas. Overall, embedding SA as both a training and assessment standard could enhance road safety education and rider preparedness.

4. Conclusion

This study shows that young motorcycle riders, especially university students, often overestimate their situational awareness (SA), increasing crash risk. Using the QUASA method, a clear gap between perceived and actual competence was identified, emphasizing overconfidence as a key safety issue. The Unreal Engine-based simulator effectively improved SA across perception, comprehension, and projection levels, enhancing hazard recognition and decision-making. These results confirm the value of simulation-based training in strengthening cognitive readiness and reducing risky behavior among novice riders. Future work should explore long-term behavioral impacts, integrate objective measures like eye tracking, and develop scalable, low-cost simulation tools for broader use in education and licensing systems.

Acknowledgment

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Appendix A: QUASA Rubric

Level SA (Endsley, 1995)	No.	Aspect	Indicator	Criteria
Level 1 (Perception of Environmental Elements)	1	Using both rear-view mirrors	I always use both rear-view mirrors when riding	Yes/No
	2	Checking that both brakes function	I always check that both brakes are working properly before riding	Yes/No
	3	Ensuring turn signals are functioning	I always make sure the turn signals are functioning properly before riding	Yes/No
	4	Ensuring front and rear headlights are working	I always ensure the front and rear headlights are working properly when I ride	Yes/No
	5	Wearing a certified helmet	I always wear a certified helmet every time I ride	Yes/No
	6	Riding in good physical condition	I always make sure I am in good health when riding	Yes/No
	7	Not riding under the influence of alcohol	I have ridden a motorcycle while under the influence of alcohol	Yes/No
	8	Riding only in good weather	I only ride when the weather is good	Yes/No
	9	Not using a mobile phone while riding	I often use my mobile phone while riding (e.g., calling, listening to music)	Yes/No
	10	Having a valid driving licence	I only ride when I have a valid motorcycle licence	Yes/No
	11	Riding while drowsy	I still ride even when I feel drowsy or sleepy	Yes/No
	12	Checking the speedometer	I always make sure the speedometer is working before I ride	Yes/No
Level 2 (Comprehension of the Situation)	13	Giving priority to pedestrians crossing the road	I always give way to pedestrians who are about to cross the road	Yes/No
	14	Yielding to emergency vehicles when hearing sirens	I give way when I hear the siren of an ambulance or fire truck	Yes/No
	15	Riding in a rush due to time pressure	I ride in a hurry when I'm pressed for time	Yes/No
	16	Impatience in traffic congestion	I feel impatient when riding in traffic jams	Yes/No
	17	Using turn signals before turning	I always use my turn signals before making a turn	Yes/No
	18	Using the correct turn signal direction	I always use the correct direction when signalling a turn	Yes/No
	19	Riding against the flow of traffic	I often ride against the direction of traffic	Yes/No
	20	Ignoring traffic signs	I often ignore traffic signs	Yes/No
	21	Monitoring the speedometer to regulate speed	I always monitor the speedometer to control my riding speed	Yes/No
Level 3 (Projection of Future Status)	22	Increasing speed when the traffic light turns yellow or nearly red	I tend to speed up when the traffic light turns yellow or is about to turn red	Yes/No

23	Crossing or cutting across the road without looking left and right	I sometimes cross or cut across the road without checking both sides	Yes/No
24	Adjusting speed and lane when passing through potholes	I always adjust my speed and choose the appropriate lane when riding through potholes	Yes/No
25	Controlling speed correctly when overtaking vehicles	I am able to control my speed properly when overtaking vehicles in front	Yes/No