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Ludfi Pratiwi Bowo
Research Center for Transportation Technology, Organization Research of Energy and Manufacture, National Research and Innovation Agency

Ahmad Muhtadi
Research Center for Transportation Technology, Organization Research of Energy and Manufacture, National Research and Innovation Agency

Feronika Sekar Puriningsih
Research Center for Transportation Technology, Organization Research of Energy and Manufacture, National Research and Innovation Agency

Sinung Nugroho
Research Center for Transportation Technology, Organization Research of Energy and Manufacture, National Research and Innovation Agency

他

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Understanding the Role of Conspicuity and Behavior in Motorcycle Safety

Ludfi Pratiwi Bowo[1,*], Ahmad Muhtadi[1], Feronika Sekar Puriningsih[1], Sinung Nugroho[1], Hastiya Annisa Fitri[1], Siti Hidayanti Mutiara Kurnia[1], Apid Rustandi[1]

[1]Research Center for Transportation Technology, Organization Research of Energy and Manufacture, National Research and Innovation Agency, Puspiptek Serpong, 15314, KST. BJ Habibie, Gd. Teknologi 2, Lt 3, Serpong, South Tangerang, Banten, Indonesia

*Author to whom correspondence should be addressed:
E-mail: ludf001@brin.go.id

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Abstract: This study systematically reviews motorcycle safety research using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method. PRISMA ensures a transparent and structured approach to identify, screen, and select relevant studies. Data was collected from 553 conspicuity-related and 821 behavior-related papers sourced from Google Scholar, SCOPUS, and Semantic Scholar, with AI-powered tools aiding the search. After screening, 13 conspicuity and 108 behavior studies were included. Findings highlight that improving motorcycle conspicuity enhances safety. Additionally, unsafe driving behaviors—often linked to poor environmental awareness and speed misjudgment—emerge as significant contributors to incidents and accidents. This review underscores the need for targeted interventions to improve motorcycle visibility and promote safer driving behaviors. It also highlights the importance of adopting systematic methods like PRISMA to ensure the reliability and validity of safety research in transportation.

Keywords: motorcycle conspicuity; motorcycle driving behavior; motorcycle safety aspects; unsafe behavior

1. Introduction

The motorcycle is one of the transportation modes widely used in developing countries for the daily commute because its price is cheaper than that of an automobile[1,2]. Furthermore, in developed countries, motorcycles are mostly used for leisure. Unlike the passenger vehicle, the motorcycle's design exposes the motorcyclist to the external environment; it is less stable and less visible[3]. Accident occurrences involving motorcycles are prone to injuries and fatalities if the motorcyclists lack protection and behave unsafely[4].

Most motorcycle collision occurrences occur at intersections when a vehicle maneuvers into the path of an oncoming motorcycle[5]. The risk of motorcycle collisions is not only between motorcyclists but also between other vehicle types, such as cars, trucks, and buses[6]. The probability of fatalities for motorcyclists involved in accidents between other vehicle types is higher because the body of the motorcyclist is exposed and directly hits the other vehicle's body, which is usually harder material[7]. In addition, motorcycle collisions occurred not only in the front-end position but also in the rear-end position with other road users[8].

Based on the data from the traffic police of the Republic of Indonesia, motorcycle accidents have occupied the top position as the incidence of road traffic accidents in Indonesia, accounting for more than 70% of all road traffic accidents every year[9]. Moreover, in-depth research has been conducted in five European countries to examine 921 motorcycle accidents[10]. It was found that in 50% of motorcycle accidents, the motorcyclist was responsible for the cause of the accidents. From that, 50% of motorcyclists are responsible; the factors that led them to accidents were dominated by other vehicles' failure to detect the presence of other motorcycles.

Motorcycle accidents are mostly caused by other road users' inability to detect an oncoming motorcycle; this indicates a lack of visual conspicuity in motorcycles[5,10,11]. Besides the technical problem, unsafe behavior, such as poor speed-spacing judgment and risk perception, are other major causes of motorcycle accidents[12].

The objective of this paper is to comprehensively analyze and synthesize previous research on motorcycle conspicuity and rider behavior, specifically focusing on how these factors contribute to motorcycle safety.

Motorcycle conspicuity, or the ability of a motorcycle and its rider to be seen by other road users, is a crucial aspect of road safety, particularly given the high rates of motorcycle accidents globally. This review seeks to assess the effectiveness of various strategies aimed at enhancing motorcycle conspicuity under different conditions, such as daytime versus nighttime visibility, and varying environmental settings, such as urban, suburban, and rural areas.

One key area of focus is the evaluation of technological and behavioral interventions designed to improve motorcycle visibility. This includes examining the impact of daytime running lights (DRL), high-visibility clothing, and reflective materials on the detection of motorcycles by other road users. The study also explores how different environmental conditions, such as lighting, weather, and road infrastructure, can influence the effectiveness of these conspicuity measures. By analyzing these factors, the paper aims to provide a detailed understanding of how to enhance motorcycle visibility in various driving conditions best, thereby reducing the risk of accidents.

In addition to technical aspects, the paper delves into the driving behaviors of motorcyclists, which are critical in influencing road safety outcomes. Unsafe behaviors, such as speeding, failure to signal, and risky maneuvers like lane splitting or aggressive overtaking, are significant contributors to motorcycle accidents. This review examines the prevalence of these behaviors and their impact on accident rates, as well as explores the psychological and situational factors that may encourage such risky actions. Factors such as rider age, experience level, and socio-cultural influences are considered to understand the root causes of unsafe riding practices.

Furthermore, the paper reviews interventions aimed at modifying rider behavior, such as educational campaigns, training programs, and policy measures. It critically assesses the effectiveness of these interventions in changing risky behaviors and promoting safer riding habits. The paper also considers the role of enforcement measures, such as traffic law enforcement and penalties, in deterring unsafe behaviors among motorcyclists.

Overall, this comprehensive review aims to provide a holistic understanding of the factors influencing motorcycle safety, with a particular emphasis on conspicuity and rider behavior. By synthesizing findings from a wide range of studies, the paper seeks to identify best practices and recommend strategies for improving motorcycle safety on the road. The insights gained from this review are intended to inform policymakers, road safety advocates, and researchers in their efforts to develop effective interventions and policies that can reduce motorcycle-related accidents and enhance the overall safety of motorcyclists.

2. Research Methodology

2.1 Study methodology

All literature search work was carried out on November 7 and 8, 2022. Since there has been much research and development in motorcycle safety over the last 50 years, the search was restricted to research developments from 2000 to 2022. The choice of a 20-year time frame (2000-2022) in motorcycle safety research is driven by the desire to focus on recent and relevant developments.

The authors chose relevant, high-quality papers in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) standards to adequately support further research. The PRISMA Statement was developed to assist authors in accurately reporting systematic reviews and meta-analyses[13]. In 2020, the method part of PRISMA was updated to include advancements in finding, choosing, evaluating, and summarizing studies. Additionally, PRISMA-S 2020 expanded the number of checklists to 27 to facilitate these advancements[14].

Article searching in this study was done using the keywords and search terms in Table 1. Only relevant papers were included in the literature for the systematic review. Several important notes include:

1. Papers have been published in internationally reputable journals. Proceeding papers, books, and technical papers are not used as review material in this paper.
2. Discussing motorcycle safety on the topic of conspicuity and riding behavior.
3. Has novelty output and findings on the development of the topic of conspicuity and riding behavior.
4. Has a positive output from the experiment and method.

Table 1. Keywords and search terms this study employs.

Group	Keyword	Search Terms
Conspicuity	Motorcycle conspicuity and conspicuity in motorcycle.	Conspicuity of motorcycle related to drivers point of view.
Behavior	Human factor in motorcycle, motorcycle riding behavior, and motorcyclists behavior.	Behavioral activity related to safety of motorcycle riding from human factor point of analysis.

2.2 Data Sources and Research Methodology

A systematic search is carried out using search engines, both traditional and those that have applied artificial intelligence. The databases Scopus, Google Scholar, and Semantic Scholar are used. The search was conducted three times using open-source technology.

The first iteration employs "publish or perish," the second employs "ResearchRabbit.ai," and the last employs "litmaps.com." This research utilizes Zotero as a reference manager in regards to compatibility with ResearchRabbit and the online database it provides. Also[15], he states in his paper that "the fewest mistakes were detected in references generated by Zotero for 11 journals and the NLM style, while the second-fewest number of mistakes was found in Mendeley. The largest number of mistakes for nine journals was found in references generated by EndNote. In the other four journals, the largest number of mistakes was detected in RefWorks references."

Publish Or Perish collects scientific papers with the keywords "motorcycle conspicuity," "human factor in motorcycle," "motorcycle riding behavior," and "motorcycle rider behavior" from the Scopus and Google Scholar databases. The listing results are then verified for duplicates, and keywords in the title and abstract are highlighted. The PoP's final listing results are subsequently processed with a ResearchRabbit. Artificial intelligence from ResearchRabbit will recommend publications based on similar, later, and earlier works in the papers the authors upload. Based on the correlations in the keywords and abstracts, the authors added these recommendation papers to the paper list. The output of the second listing is a journal listing in PoP, together with a recommendation from a ResearchRabbit. The last step is to explore citations with the help of a Litmaps application. Based on citations, Litmaps depict the relationships between papers. In the form of citation mapping, the findings from the prior paper list are imported. Then, based on the citations, artificial intelligence will develop

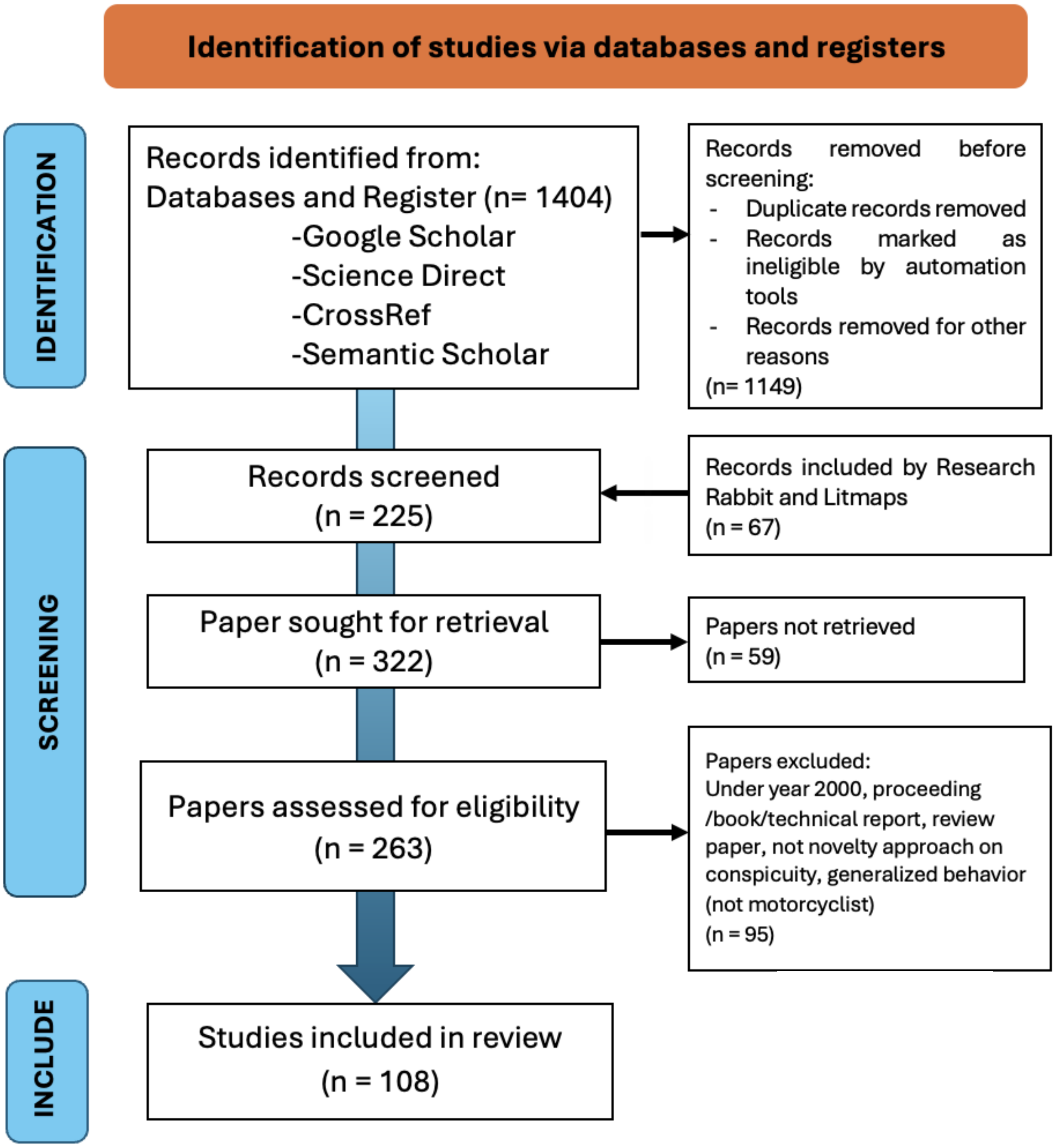

Fig. 1: PRISMA database workflow.

a map of connections and recommend publications that are citation-connected but still need to be added to the list. These suggestions are then included in the list depending on how closely connected the title, keywords, and number of citation linkages are to one another.

The resulting limit for each search iteration is 1000 results on Google Scholar and 200 results on Scopus. On ResearchRabbit and Litmaps, the authors didn't specify the limit on how much the result would be. Still, the authors admit the paper based on how connected the recommended paper is to the current database. The authors only admit papers that are related by at least 4–5 current items and have relevance in their abstract and title. The authors also take notes on the impact of additional papers based on how relevant the application made the papers to each other.

2.3 Literature selection

The PRISMA flowchart, Figure 1 provides a detailed depiction of the systematic selection process for studies included in the review. Initially, 1,404 records were identified from multiple databases and registers, including Google Scholar, Science Direct, CrossRef, and Semantic Scholar. These records were gathered to ensure a comprehensive search of literature related to motorcycle safety, specifically focusing on conspicuity and rider behavior. During the identification phase, 1,149 records were excluded due to duplication, ineligibility marked by automation tools, or other reasons such as irrelevance to the research focus. This step refined the dataset to 255 records for further screening.

The screening phase involved additional efforts to include relevant studies, utilizing Research Rabbit and Litmaps tools to identify 67 supplementary records. At this stage, a total of 322 papers were sought for retrieval. However, 59 papers could not be retrieved due to access limitations or unavailability. The remaining 263 papers were carefully assessed for eligibility based on predefined inclusion and exclusion criteria. Papers were excluded if they were published before the year 2000, categorized as proceedings, books, technical reports, or review papers, or if they lacked novelty in addressing motorcycle conspicuity or behavior specific to motorcycle riders. This rigorous assessment ensured that only relevant and high-quality studies were retained.

Finally, the inclusion phase resulted in 108 studies that met all eligibility criteria and were included in the systematic review. These studies provide valuable insights into improving motorcycle safety by addressing conspicuity and unsafe rider behaviors. The PRISMA approach ensured a transparent and methodical process, minimizing biases and enhancing the credibility of the review findings. By adhering to PRISMA guidelines, this study established a robust foundation for analyzing critical aspects of motorcycle safety, contributing significantly to the body of knowledge in this area.

3. Results

The safety of motorcycles is influenced by two critical dimensions: technical aspects and behavioral aspects, both of which significantly impact accident prevention and rider safety. Technical aspects encompass the design, functionality, and maintenance of motorcycles, as well as safety features and infrastructure. Various technical aspects of motorcycles might increase the probability of accidents, such as the braking system, the motorcycle's size, and the motorcycle's appearance towards other vehicles. However, in terms of technical aspects, the motorcycle's conspicuity towards other vehicles is a crucial aspect of motorcyclist safety due to the size and characteristics of smaller motorcycles, which have no outer protection like cars. Research regarding motorcycle conspicuity has been conducted since the 1980s until recently. According to those researchers, increasing motorcycle conspicuity might increase road safety because it may increase awareness among other road users of the existence of motorcycles. Many studies have explored various configurations of conspicuity aids, meeting positions, and environmental conditions to represent real-world road scenarios better. These configurations include different placements of reflective materials, lighting enhancements, and biomotion aids to improve visibility. Meeting positions, such as the relative orientation of vehicles and motorcyclists at intersections or during overtaking, have also been examined to understand their impact on detection and response times. These variations aim to provide a comprehensive understanding of how conspicuity aids function in diverse situations, ultimately guiding the development of more effective visibility-enhancing strategies for improving road safety.

Moreover, motorcycle conspicuity is not the only cause that leads to a road accident; the unsafe behavior of the motorcyclist influences it and is a determinant aspect of accident occurrences. Behavioral aspects, on the other hand, focus on the actions and decisions of motorcyclists and other road users. Risky behaviors, such as speeding, abrupt lane changes, and neglecting protective gear, significantly increase the likelihood of accidents. Conversely, defensive riding techniques and adherence to traffic rules reduce risks. The awareness of motorcyclists while driving is essential to detecting the existence of other vehicles as early as possible. The decision to drive the vehicle at a certain speed in a certain situation while driving is also important to make. Many motorcyclists are speeding while driving for various reasons, despite the consequences of getting tickets from traffic police or, even worse, being involved in accidents. The implementation of a safety culture while driving motorcycles, especially in developing countries where motorcycles are used as daily commute transportation, still needs to be higher. The safety culture of wearing helmets should be addressed. In this result section, the review of previous research about motorcycle conspicuity and motorcyclist behavior will be explained. The literature review will use research from 2000 to recent research. Both technical and behavioral aspects are interconnected, as technical measures can mitigate unsafe behaviors, and responsible rider behavior enhances the effectiveness of technical safety features. Addressing these aspects holistically is essential for improving motorcycle safety and reducing accident rates.

3.1 Motorcycle conspicuity

3.1.1 Conspicuity aid configuration

Research on enhancing the appeal of motorcycles has been conducted by examining various configurations of visibility aids, such as increasing the number of lights to support day running light (DRL)[11,16,17]. DRL is a motorcycle light designed to enhance visibility during daylight hours. Unlike headlights, which are primarily used in low-light conditions, DRLs automatically illuminate when the engine starts, providing a constant light source that makes motorcycle more noticeable to other road users. Installing reflective stickers on the front and body of the motorcycle[18]. Additionally, they wore bright-colored clothing and helmets[19,20]. Attwood conducted DRL research for the first time in the 1970s to assess bus accidents. The findings of this study indicate that after DRL is activated, the accident rate per million miles in daytime conditions decreases by up to 40%[21]. Since then, research on the implementation of DRL on other vehicles has increased, including motorcycles. The implementation of DRL transition on motorcycles during both night and daytime has proven to reduce the percentage of accidents[22–25]. Table 2 below illustrates the latest developments in DRL configurations in various environmental conditions.

In addition to implementing DRL, retroreflective tape is another solution to enhance the visibility of motorcycles. Retroreflective tape is a newly developed material that improves the appeal of motorcycles. Previously, retroreflective tape was commonly used on the rear of trucks and has great potential to enhance the appeal of trucks[26]. Retroreflective tape is considered to be simpler and more cost-effective than direct reflection[18]. Retroreflective tape is commonly placed on the front, body, and rear of the motorcycle, typically where the motorcycle manufacturer attaches the motorcycle model sticker. Khalid and others conducted a study on the implementation of retroreflective tape on motorcycle bodies in a scenario of driving in rural traffic at night[20].

Due to motorcycles' relatively small size compared to other vehicles on the road, turning on the DRL during the day and night, as well as wearing bright-colored clothing and helmets, can enhance their visibility and detection in urban traffic environments[19,20].

The use of software that can alert users to obstacles through sound or vibration aids users in navigating safely and efficiently. Advanced Driver-Assistance (ADAS) Systems), Utilizing cameras and computer vision as the primary sensors to comprehend the surrounding environment of the car[27) . The implementation of ADAS in rural and intercity roads is still in its early stages, but this technology has the potential to improve safety and efficiency on these roads significantly[28,29]. ADAS technology plays a crucial role in the development of autonomous vehicles[30]. The Probability Hypothesis Density (PHD) Filter technique shows great potential for ADAS, particularly in accurately tracking multiple vehicles. However, it is important to take into account limitations such as its performance in low visibility scenarios[31]. The proposed algorithm for enhancing the quality of stereo images shows significant potential in improving the performance of ADAS under various lighting and visual conditions[32]

3.1.2 Lane conditions

Unlike cars, motorcycles can maneuver in various lane conditions. In developed countries, motorcycles of a certain size and type may enter the highway along with high-speed cars and other big vehicles. Motorcycles can also access narrow streets in residential areas, which are mostly found in developing countries. Due to their flexibility in maneuvering, most motorcyclists feel freer to maneuver than cars, and sometimes, motorcyclists' unsafe maneuvering behavior may lead to accidents[33].

Intersections are among the most dangerous conditions for motorcycles due to the increased risk of accidents caused by poor visibility and unsafe rider behavior[19,34–37]. Experimental studies have indicated that improving lighting in motorcycles and adding signs at intersections can reduce accidents. Furthermore, statistical studies have shown that accidents at intersections account for approximately 35% of all motorcycle accidents[33].

Motorcycle visibility studies also use the straight road, both in parallel with other vehicles and when the motorcycle is behind a vehicle[20,38,39]. DRLs, reflective materials, and brightly colored attire have been demonstrated to enhance motorcycle visibility in this situation. Cutting-edge technologies like camera-based driver assistance systems and sensors can also help improve safety across different road conditions[40,41].

Motorcyclists face various challenges on the road and in urban areas, such as traffic congestion that can reduce their visibility. Research indicates that bright colors on clothing and helmets can enhance the detection of motorcycles in urban environments, because these areas often have a visually complex background filled with various objects, lights, and colors. Bright clothing and helmets stand out against such cluttered surroundings, increasing the sensory conspicuity of motorcycles and making them easier for drivers to detect. Whereas, in rural areas, dark clothing is more effective because rural environments typically feature less visual complexity, with natural landscapes like trees, grass, and open roads. Bright colors may blend with the natural lighting and surroundings, whereas dark clothing provides higher contrast, improving sensory conspicuity[19].

3.1.3 Environmental conditions

Motorcycles are small and agile modes of transportation that can navigate through various parts of the road. Most visibility research on motorcycles is conducted experimentally by setting up environments that closely resemble real conditions[19,42,43]. The study on the conspicuity of motorcycles was conducted in urban and rural areas, both during the day and at night[44–46]. Traffic accidents can occur in various situations and conditions[47,48]. Research indicates that accidents are more likely to happen in sunny weather and familiar circumstances[49]. This pertains to the situational awareness of motorcycle riders, where, in bad weather, people tend to be more cautious[50].

The driving environment characteristics differ between daytime and nighttime[51]. In the daytime, motorcycles are typically more visible than at night, but traffic congestion is greater[52]. In addition to turning on the DRL, wearing bright clothing while riding a motorcycle during the day can increase visibility[53]. Driving at night increases the risk of accidents[54]. The level of conspicuity at night is limited, and not all roads have good street lighting. Therefore, assistance configurations to enhance the conspicuity of motorcycles and riders need to be further developed[55,56]

Urban traffic has a greater density of vehicles compared to rural traffic, yet this does not make rural traffic safer. With the higher vehicle density in urban areas, the traffic background becomes more complex and colorful; hence, wearing bright clothing can enhance visibility[57]. Conversely, in rural areas where the backdrop is predominantly a bright sky, wearing dark clothing can improve visibility and decrease the chances of traffic accidents by 37%[19,23]. The use of DRL during both day and night can enhance the visibility of motorcycles[58]. Utilizing bright-colored attire and helmets can also improve motorcyclists' visibility[19,20]. The development of new technology that can enhance visibility, such as specialized ADAS systems for motorcycles, is also a crucial step[41,59]. This technology must be integrated and utilized by everyday drivers[40,60,61].

Table 2. Motorcycle conspicuity research.

Researchers	**Method/study design**	**Sample size**	**Conspicuity aid configuration**	**Lane conditions**	**Environmental conditions**	**Main findings**
Ranchet, M., et al.[62].	Experimental study using video graphic design.	57 people (12 women and 45 men).	Using white and yellow color light with this configuration: 1. DRL only. 2. DRL, light on helmet, light on the left and right side beside front wheel.	Intersections.	Urban traffic in day time conditions.	Yellow color DRL improved motorcycle detection by clearly distinguishing motorcycles from other light sources.
Pinto, M., et al.[11].	Experimental study using color photographs.	60 people (27 women and 33 men).	1. DRL only (white color). 2. DRL and lights on the backside left and right rearview mirror. 3. DRL and light on the helmet. 4. DRL only (yellow color).	Intersections.	Urban traffic in day time conditions.	Better motorcycle-detection performance for both the yellow headlight and the helmet configuration than for the standard configuration (single central white headlight).
Rößger, L., et al.[63].	Experimental study using color photographs.	56 people (43 women and 13 men).	1. DRL only. 2. DRL, light on the left and right side of rearview mirror and front wheel. 3. Above configuration plus light on helmet.	Intersections.	No description.	Motorcycles with a T-shaped light configuration are more quickly identified, particularly when the motorcycles are in visual competition with other motorized road users.
Weaver, B.W., and Delucia, P.R.[64].	Experimental study using video graphic design.	35 people (21 women and 14 men).	There are two experiments. First experiment using this kind of configurations: 1. Four front light in horizontal configuration. 2. Four front lamps in vertical configuration. 3. Four front lamps in diamond configuration.	Two-Way left turn lane.	Rural traffic in night time conditions.	A headlight configuration that features the full height and width of a motorcycle might help other road users' perceptual judgment of closing.
		35 people (25 women and 10 men).	The second experiment's configurations: 1. DRL only. 2. DRL and light on the left and right side beside front wheel.	Two-Way left turn lane.	Rural traffic in night time conditions.	Other road users are more sensitive to smaller headlights configurations.

Researchers	**Method/study design**	**Sample size**	**Conspicuity aid configuration**	**Lane conditions**	**Environmental conditions**	**Main findings**
			3. DRL, light on helmet, light on the left and right side beside front wheel. 4. Above configuration plus light on left and right rearview mirror.			
Khalid,M. S. A., et al.[20].	Experimental study with video recording.	Nor available.	1. Bright attire. 2. Bright helmet. 3. DRL only. 4. Retroreflective tape. 5. Combination of 1,2, and 3. 6. Combination of 1,2,3, and 4.	Straight road and intersection.	Rural traffic in night time conditions.	All combination of conspicuity aid, bright attire, bright helmet, DRL, and retroreflective tape enhance the motorcycle conspicuity in the low light situation.
Syukri, M., et al.[65].	Experimental study with video recording.	30 people (13 women and 17 men).	1. DRL only. 2. Retroreflective tape. 3. Combination of DRL and retroreflective tape.	Straight road and intersection.	Rural traffic in night time conditions.	Retroreflective tape enhance the motorcycle conspicuity in every road configuration and could be detected from further distance.
Smither, J.A., and Torrez, L.I.[66].	Experimental study with video recording.	75 people.	1. DRL only. 2. No DRL.	Intersection.	Urban traffic in day time condition.	The differences of age affect the ability to detect the existence of motorcycle on the road.
Hua, T., et al.[67].	Experimental study using color photographs.	100 people (all men).	1. No DRL. 2. White helmet. 3. White outfit. 4. Retroreflective tape. 5. DRL only. 6. Black helmet.	Intersection.	Urban traffic in day time condition.	White helmet and white outfit make the motorcyclist easier to identify by the truck driver in the shorter and longer distance.
Cavallo, V., et al.[68].	Experimental study using video graphic design.	23 people (8 women and 15 men).	1. DRL only. 2. DRL and lights on the backside left and right rearview mirror. 3. DRL, light on helmet, light on the left and right side beside front wheel.	Intersection.	Rural traffic in night time, dusk time and day time.	Configuration number 3 and 4 significantly increase conspicuity at nighttime. However, it less pronounced at dusk time and no significant during day time.

Researchers	Method/study design	Sample size	Conspicuity aid configuration	Lane conditions	Environmental conditions	Main findings
			4. DRL, light on helmet, light on the left and right side beside front wheel and backside of rearview mirror.			
Khalid, M.S.A., et al.[69].	Experimental study with video recording.	38 people (17 women and 21 men).	1. Bright attire. 2. Bright helmet. 3. DRL only. 4. Retroreflective tape. 5. Combination of 1,2, and 3. 6. Combination of 1,2,3, and 4.	Straight road and intersection.	Rural traffic in night time conditions.	Brighter motorcyclists' and motorcycle's appearances have improved motorcycle detectability at night time.
Rogé, J., et al.[70].	Experimental study with car-driving simulator.	42 people.	1. Bright color of the body of motorcycle, attires, and helmets. 2. Darker color of the body of motorcycle, attires, and helmets.	Straight road, intersection, and roundabout road.	Urban traffic.	Motorcycle which has contrast color with the environmental background (bright color) enhance the conspicuity of it when appeared from the front side of the car.
Lee, Y.M. and Sheppard, E.[71].	Experimental study using color photographs.	19 people (10 women and 9 men).	1. DRL on. 2. DRL off.	Intersection.	Rural traffic in day time and night time conditions.	Switching on the DRL enhanced driver's perception and safety judgment of approaching motorcycles regardless of the time of day.
Gershon, P., et al.[72].	Experimental study using color photographs.	66 people (36 women and 30 men).	Motorcyclist attires' color 1. Black. 2. White. 3. Reflective.	Straight road and roundabout road.	Urban and rural traffic conditions.	In urban traffic, white and reflective attire increase motorcyclists conspicuity, otherwise, in rural traffic, black outfit is increasing the conspicuity. These are because of the contrast of the attire and the environment situation.

3.2 Motorcyclist’s behavior

3.2.1 Speeding

Traffic conditions that have a high density of vehicles and public transportation systems that do not support people’s mobility encourage people, especially in developing countries, to ride a motorcycle as a daily commuting vehicle[2]. Motorcycles are also dominantly used as transportation for students, even though they do not have driver's licenses[2]. The idea that a motorcycle is a cost-effective and adaptable vehicle supports this claim. The presence of various motorcycle types has increased people's interest in owning a motorcycle[73]. By riding a motorcycle, people are more agile in penetrating the traffic flow between narrow vehicle gaps. Driving behavior like this creates danger for motorcyclists. Based on the data from the Indonesian Ministry of Transportation, every hour, three people die due to road traffic accidents. The main causal factor for Indonesian road traffic accidents is 61% due to human factors related to driver skills and behavior[74].

Speeding behavior is one of the factors that can cause road traffic accidents[75]. Sukor et al.[76] explained that there is a complex relationship between the use of separate lanes, the psychological factors of motorcyclists, and their risky behavior. There is a statistically significant correlation between speeding behavior and exclusive motorcycle lane use. Motorcyclists can enjoy speeding while riding in lanes that completely separate them from other road users. Motorcyclists on main roads with double barriers often speed their vehicles beyond the speed limit. Various factors, including road characteristics, rider characteristics, and type of motorcycle influence this behavior[77].

Male and younger motorcyclists tend to have more aggressive behavior and a desire to engage in risky behavior. In line with the research43,44) that highlighted the risky driving behavior of motorcyclists at unsignalized intersections in Malaysia, Demographic profiles such as age, gender, and travel patterns on risky driving behavior show that age and trip frequency are strongly related to risky driving behavior. Crossing a stop-controlled T intersection without stopping completely is the behavior with the highest number of significant factors. The desire to ride fast is one of the reasons motorcyclists refrain from using turn signals when changing lanes, turning, or overtaking other vehicles.

The behavior of street racers among illegal motorcycle racers in Malaysia[79] highlights speeding behavior. Illegal motorcycle racers perform dangerous stunts while riding to earn respect and honor from their peers and the streets. The behavior of street racers is mostly that of students, and there are several riders under the legal age to ride a motorcycle in Malaysia who are 16 years old. Wang et al.[80] put forward the importance of safety knowledge to avoid speeding behavior. Safety knowledge and safety behavior interact with personality traits and have a potential relationship with risky riding behavior. Younger riders tend to commit more speeding violations than others[81]. Motorcyclists who are used to committing violations tend to ride at excessive speeds.

Meanwhile, older motorcyclists who are concerned with safety tend not to commit speeding violations. Speeding behavior is also inseparable from overtaking behavior. Halim et al.[82] analyzed the relationship between motorcycle overtaking behavior characteristics and traffic accidents. Based on the longitudinal direction, it is known that the greater the vehicle distance, the smaller the risk of accidents that arise at a safe distance of 4.62 meters. While in the sideways direction, it is known that the farther the distance between the vehicles, the greater the risk of an accident. The safe distance between vehicles in a sideways direction is 1.88 meters. Duration of street racing, risky behavior such as attractions and drinking alcohol while racing, and high masculinity scores have a positive relationship with racing frequency[83].

Motorcyclists who drink alcohol before riding are more likely to engage in dangerous behavior on the road, such as speeding, not wearing a helmet, or not having a motorbike driving license[84]. Young, single, male drivers and those using large-engined vehicles are at high risk of accidents because they often speed[85].

Violation of speed limits is the cause of approximately 60% of fatal accidents, while speeds above the safe speed limit are involved in approximately 71% of accidents that result in injuries[86]. The evaluation results show that the recommended maximum speed limit for urban roads is 60 km/h for motorbikes and passenger cars, 55 km/h for pickups and light trucks, and 50 km/h for buses and trucks[87].

The combination of speed feedback signs and consistent law enforcement is the most effective in reducing average speeds and decreasing speed limit violations[88]. Effective traffic law enforcement and programs that influence drivers' moral views on speeding can be a successful strategy to reduce the payment of traffic fines.

3.2.2 Risky behavior

A common deviant behavior that can be dangerous for motorcyclists or other public road users is riding while calling and texting. Cell phone use is one factor that can cause traffic accidents[75]. Driving while distracted (such as playing with a cell phone) is the main cause of accidents among young drivers[89].

Experts concur that using a mobile phone while driving is a significant factor contributing to traffic accidents. Phones disrupt the driver's concentration, making them the main cause of accidents among young drivers in the Netherlands[75,90]. This practice endangers safety[91]. Observations in Taiwan have revealed risky behaviors such as using a mobile phone while driving and chatting on the road, especially among young drivers and delivery drivers[92]. In Indonesia, the prevalence of mobile phone usage by motorcyclists reaches 75%, with a small portion of riders experiencing accidents due to phone usage.

The human factor is the main cause of traffic accidents. Motorcyclists tend to take more risks compared to car drivers due to the performance characteristics of motorcycles, such as greater acceleration[93–96]. Disrupted drivers, such as making improper turns or stopping in the wrong place, increase the likelihood of accidents. Disrupted driving behavior increases the likelihood of accidents by 54%[96].

De Waard et al.[91] observed patterns of telephone use while driving, which is a common practice that endangers driving safety in the Netherlands. In terms of safety, the use of mobile phones while driving can distract the driver's concentration56,57). Through observations[92] of motorcyclists at three signalized intersections in Tainan, Taiwan, unsafe behavior was observed in the form of using a telephone while riding and the habit of chatting on the road while riding, which ranks second after ignoring turn signals and running red lights. Younger male motorcyclists, delivery drivers, and when traveling with adult passengers all engage in this unsafe behavior. In a previous study by[98] through roadside observations, of all motorcyclists, 125 (0.2%) were seen using cell phones. Although the percentage is smaller, cell phone use can cause accidents. It is believed that motorcyclists' risky behavior is to blame for the high number of traffic accidents in Indonesia. According to Ari's research[99], the prevalence of cellphone use among motorcyclists in Indonesia is 75%. It is emphasized[100] that calling while riding is the most common risky behavior among motorcyclists. About 5% of motorcyclists reported having had an accident or fall when they were using their cell phone to make a call, with 3.8% of motorists experiencing an injury.

A number of studies on the behavior of motorcyclists have been conducted to explain the relationship between behavior and accidents involving motorcyclists. Farooq et al. stated that human factors are the main cause of road traffic accidents[93,95]. Horswill and Helman conducted an experiment comparing the driving behavior of car drivers and motorcyclists to that of one hundred and six British motorcyclists, which was divided into three variable groups: age, sex, time, distance traveled, and experience of the driver. In general, motorcyclists take more risks than car drivers[96]. Motorcycle performance characteristics, such as greater acceleration, lead to faster and more agile movements. Horswill and Helman used the proportional odds (PO) model and a binary logistic regression model to examine the effect of motorcycle riding experience on deviant driving behavior and traffic accidents. No direct relationship was found between the experience of riding a motorcycle and road traffic accidents. However, it is proven that distracted driving, such as improper road turns, wrong overtaking, stopping at random places on the road, etc., can cause road traffic accidents[101]. An increase in one unit of the disturbed offense increases the probability of being involved in a traffic accident by 54%[96].

Widyastuti and Santoso[2] used the parameters of road traffic errors, speed violations, control errors, traffic violations, safety violations, and stunts to explore the relationship between behaviors towards risky driving behavior, driving behavior, and road traffic accidents using the Structural Equation Modeling approach. Driving behavior is significantly influenced by the driver's behavior toward risky driving behavior[102]. In addition, several driving behavior parameters have been shown to affect traffic accidents differently. Cheng and Lee[103] identified a relationship between behavior and motorcycle accidents. Highly impulsive motorcyclists engage in more risk-taking behaviors and are less able to inhibit responses than low-impulsive motorcyclists. Motorcyclists with moderate impulsivity and drivers with high impulsivity are five times more likely to be actively involved in a motorcycle accident than those with low impulsivity. A relationship was identified between riding violation behavior and perceived risk by Andy S.K. Cheng[104], both of which are significant predictors of involvement in motorcycle accidents. Hojjat Hosseinpourfeizi[75], offering the Persian version of the short motorcycle riding behavior questionnaire (SMRBQ) with 23 items, was found to be a valid, reliable, and feasible tool for assessing motorcycle riding behavior in the population studied. The 23 items include speeding (when reaching a bend), speeding (on residential roads), riding between fast lanes of traffic, not wearing a helmet while driving, not wearing a helmet by the pillion passenger, passing a red light, riding against legal traffic directions, and mobile conversations or messages while riding.

Motorcyclists with personality traits that tend to seek novelty and have high self-confidence are more likely to engage in risky behavior, which contributes to motorcycle accidents[105]. Encouraging and empowering approaches offer a more effective way to reduce motorcyclists' risky behavior compared to enforcement and punishment approaches[106]. Positive affect and age have a significant influence on motorcyclist risk behavior. Increasing positive influences and encouraging a safe driving culture can help reduce risky behavior and improve road safety[107]. Knowledge about the risk of accidents, positive attitudes towards helmet use, and social norms that support helmet use can increase the level of helmet use[108]. A better understanding of the factors that contribute to accidents can help in developing effective interventions to improve road safety[109].

Interventions designed to increase positive attitudes and PBC towards safe driving behavior may help increase compliance with traffic rules and reduce accidents[110]. Lee and Jang were[111] developing new ways to analyze driving data and find drivers who are at high risk of causing accidents. This method can help to make roads safer. Sumit et al.[112] proposed a modified version of the motorcycle risk behavior questionnaire (MRBQ) that has proven effective in assessing risk behavior among young riders. Joint angle-based driving behavior recognition with multisensor data fusion is an effective way to improve traffic safety and driving training[113].

3.2.3 Safety culture

Motorcyclists use helmets to measure riding behavior[75]. Every motorcyclist must wear a helmet as a mandatory safety device. Regulations for using helmets in Indonesia have been implemented since the early 1970s, when these rules were contained in the announcement of the Head of the National Police on November 1, 1971. This regulation requires users of two-wheeled motorized vehicles to wear helmets. Apart from being personal protective equipment, the use of a helmet is also a form of compliance with traffic regulations in accordance with Law No. 22 of 2009 concerning Road Traffic and Transportation article 57 paragraphs 1 and 2, which requires that every motorized vehicle user on the road must be equipped with motor vehicle equipment in the form of an Indonesian national standard helmet. However, awareness of the importance of using a helmet for personal safety is still lacking,[114] revealing that awareness of the importance of the benefits of personal protective equipment and helmets can make a real contribution to greater road traffic safety[115,116]. Observations of motorcyclists in Tainan, Taiwan[92], found that risk-taking behavior was more common among riders who did not use helmets. Almost all riders wear helmets, but the majority of riders use non-standard helmets rather than full-face motorcycle helmets. In the research[92] through roadside observations, out of all motorcyclists, as many as 6.0% were seen not wearing helmets.

Setoodehzahde et al.[117] explored motorcyclist deviant behavior in Pakistan using a modified Manchester Driver Behavior Questionnaire (DBQ). Motorcyclist behavior in Pakistan tends to lack discipline. Pakistani drivers and motorcyclists honk more often, make risky overtakes, tend to force their way out of the lane, and frequently ignore stop lines,[118] suggests that the role of the family in educating and fostering certain values is important for improving the behavior of drivers and motorcyclists on the road. This implies that respondents who uphold the values of ethics and decency tend to behave in an orderly manner and consequently tend to comply with speed regulations (speed limits at various places and times, avoiding unofficial road racing, etc.) to minimize control errors in assessing the traffic situation and to avoid stunts. In contrast to previous research, which stated that peers are one of the factors that influence risky driving behavior, Smorti et al.[119] revealed that maternal bonds only indirectly affect adolescents' risky driving through resistance to peer influence. Parental bonding was not associated with adolescents' parenting practices or risky driving behavior. However, teenage mother relationships shape adolescents' abilities to resist peer influence, which, in turn, influences adolescents' risky driving behavior.

In understanding behavior, the theory that is often used to research driver behavior is the theory of reasoned action (TRA). This theory states that behavior is formed by will. This will is formed due to the motorcyclists’ behavior and the norms that exist in society. This TRA theory was further developed into the Theory of Planned Behavior. This theory adds a controlling factor for motorcyclists to comply with applicable regulations[120]. The three-minds theory is used to change the behavior that has been formed. This theory explains that conative aspects (human behavior) are influenced by affective aspects (willingness to do something) and cognitive aspects (knowledge or understanding of something). Change behavior requires intervention in these three aspects. Increasing the perception that pro-social behavior is normal can also be an effective strategy for improving cyclist safety. This can be done by spreading positive messages, modeling pro-social behavior, and providing rewards and recognition[121]. Parents' approach to educating children can influence the tendency to make safe driving decisions[122]. Forming a safety culture attitude from an early age is an important foundation for forming safe driving behavior on the road[123].

Di Stasi et al.[24] conducted tests on risky driving behavior among novice and expert riders to determine the impact of training. By doing the training, the riding ability of novice riders improves, and their gaze patterns imitate those of expert riders. Table 3 shows the list of motorcyclist behaviour research from 3 aspects, speeding, risky behavior, and safety culture. Providing skills and training is believed to reduce mental workload by generating strategies and abilities to deal with problems. Innovation continues to produce safer motorcycle designs by designing better vehicles, studying accidents, and increasing awareness about safety[125].

Table 3. Motorcyclist Behavior Research.

Aspect	Contributing		Implication		Recommendation, Regulation	
Speeding	Soehodho, 2017[74]; Hosseinpourfeizi et al., 2018[75]; Wong, 2011[79]; Soames Job & Brodie, 2022[126]; Lemarie et al., 2019[127].	• Agile riding and penetrating traffic flow • Danger for motorcyclists • Human factors • Speeding as a contributing factor • Risk of road traffic accidents • Causative role in accidents • Highlight on speeding behavior • Dangerous stunts for respect and honor • Street racers, mostly students • Riders under the age of 15 • Speeding violations • Speed above safe limits	Leong et al., 2021[128]; Wang et al., 2018[80].	• Risky driving behavior at unsignalized intersections • Desire to ride fast and non-use of turn signals • Age and speeding violations • Habitual violators and excessive speeds • Inseparable from overtaking behavior	Halim et al., 2020[82]; Sugiyanto & Malkhamah, 2018[129]; Sukor et al., 2017[76]; Lemarié et al. 2019[78]; dos Santos et al., 2019[130]; Javid et al., 2022[131]; Abdul Manan et al., 2017[132]; Wong, 2011[79]; Subaryata et al., 2022[73]; Widyastuti & Santoso, 2022[2]; Wang et al., 2018[80].	• Analysis of overtaking behavior characteristics • Consideration of vehicle distance • Speed limits • Adaptation to urban context • Complex relationship • Motorcycle-specific lanes • Safety enhancement • Separation design • Alcohol consumption • Absence of helmet usage • Lack of motorcycle driving license (sim) • Young drivers • Male gender • Users of large vehicles • Characteristics of the road • Type of motorcycle • Street racing duration • Risk-taking behavior • High masculinity scores
Risky Behavior	Hosseinpourfeizi et al., 2018[75]; De Waard et al., 2015[91]; Huemer et al., 2018[97]; Yang & Huemer, 2022[92]; Rusli et al., 2020[98]; Truong et al., 2019[100]; Farooq et al., 2020[93]; Zhang et al., 2019[95]; Horswill	• Distraction • Reaction decline • Decision-making errors • Traffic rule violations • Safety of other road users • Low risk assessment • Cross-modal distraction • Cultural and behavioral aspects • Cognitive distraction • Increased crash risk • Dangers of manual and visual distraction • Technological countermeasures	Cheng & Lee, 2012[103]; Cheng et al., 2015[104].	• Inhibition of responses • Relevance to motorcycle accidents • Implications for intervention and education • Significant predictors of involvement in motorcycle accidents • Perceived risk as a cognitive factor	Hosseinpourfeizi et al., 2018[75]; Truong et al., 2019[100]; Al Reesi et al., 2018[90]; Sumit et al., 2021[133]; Romero et al., 2019[134]; Mohd Shafie et al., 2023[135]; Truong et al., 2019[100]; Goh & Leong, 2020[136]; Steg & Brussel, 2009[137]; Hussain et al., 2022[138]; Jomnonkwao et al., 2020[125]; Lee & Jang,	• The importance of safety education campaigns • Modified motorcycle rider behavior questionnaire (mrbq) • Effectiveness in assessing risk behavior • Empowerment approach • Empowerment effectiveness • Behavior change strategy • Risk perception • Positive influence and age • Increased understanding of contributing factors

	& Helman, 2003[96]; Widyastuti & Santoso, 2022[2].	• Unsafe phone usage • Risky behaviors • Demographic patterns • Human factors • Motorcycle performance characteristics		• Behavioral manifestation in riding violation • Implications for road safety interventions	2019[139]; Javid & Al-Roushdi, 2019[140]; Liu et al., 2020[141]; Zhao et al., 2019[142]; Cristea & Gheorghiu, 2016[143].	• Development of effective interventions • Knowledge of accident risk • Positive attitude towards helmet use • New approaches to data analysis • Identify high risk drivers • Increased traffic safety • Safety training and improvement • Driving attitude and basic characteristics • Reducing illegal driving behavior
Safety Culture	Hosseinpourfeizi et al., 2018[75]; Topolšek & Dragan, 2018[114]; Adebayo et al., 2023[116]; Champahom et al., 2022[115]; Yang & Huemer, 2022[92]; Setoodehzadeh et al., 2021[117]; Batool & Carsten, 2017[118]; Smorti et al., 2014[119]; Bosnjak et al., 2020[120]; Di Stasi et al., 2011[124]; Ward et al., 2020[144].	• Safety norms • Individual safety awareness • Monitoring, enforcement and safety dissemination • Awareness of personal protective equipment • Contribution to road traffic safety • Understanding security standards • Roles, values, and orderly family behavior • Avoiding unofficial road racing, minimizing mistakes, and endurance • Peer influence, family dynamics, and resilience • Theory of reasoned action (tra), theory of planned behavior, and • The importance of compliance • Three-minds theory, impact of training, and improvement in riding • Reduction of mental workload	Nævestad et al., 2020[145]; Jomnonkwao et al., 2020[125]; Ju et al., 2020[146].	• The influence of road safety culture • Key role in shaping behavior • Impact on road user behavior • Vehicle design improvements • Increased safety awareness • Parental influence on risk taking tendencies • Impact on risky behavior in adulthood • The role of education in safety culture	All points are recommendations.	

4. Discussion and suggestions for future research

Motorcycles are increasingly popular in developing countries. They are agile, break through traffic jams, and are the main choice of transportation. The high number of accidents involving motorcyclists has attracted the interest of researchers in conducting research related to motorcycle safety, especially technical and behavioral issues such as motorcycle conspicuity and the relationship between risky driving behavior and accidents.

4.1 Technical Safety Aspects: Enhancing Motorcycle Conspicuity

Motorcycle accidents frequently occur due to the failure of other road users to detect the presence of motorcycles[147]. This issue of motorcycle conspicuity is paramount to road safety and has prompted extensive research to enhance the visibility of motorcycles and motorcyclists.

Daytime Running Lights (DRL) have emerged as a crucial technological advancement in this area. The implementation of DRL on motorcycles has shown a significant reduction in road traffic accidents, particularly during daytime hours. This has led to policies in many countries mandating the use of DRL whenever motorcycles are on the road. The constant illumination provided by DRL improves the chances of motorcycles being noticed by other drivers, thereby reducing the likelihood of collisions.

However, the effectiveness of DRL is only relative. Research indicates that while DRL significantly enhances visibility, there are still instances where motorcycles are not detected. This suggests a need for further improvements in lighting technology, integrating adaptive lighting systems that adjust intensity based on ambient light conditions and traffic density.

The color and design of motorcyclist attire also play critical roles in enhancing conspicuity. High-visibility clothing, particularly those incorporating fluorescent colors and retroreflective materials, can significantly improve the detection of motorcyclists in urban and rural settings. The difference in background contrast between these environments necessitates different strategies; for example, urban areas with complex and colorful backgrounds might benefit more from retroreflective materials, while rural settings might see more benefit from bright, fluorescent colors.

Studies have shown that motorcyclists wearing high-visibility gear are more readily seen by other road users, reducing the risk of accidents. However, high-visibility attire needs to be standardized and promoted among motorcyclists. Public awareness campaigns and regulatory measures could play a pivotal role in this regard.

Many cyclists and pedestrians are unaware of the importance of biomotion reflective strips in enhancing their safety during nighttime activities[148]. The regulation requiring cyclists to wear high-visibility clothing has not significantly reduced the number of cyclist accidents[149]. Integrating communication tools into high-visibility vests is a promising approach to improving road safety for vulnerable users[150]. Biomotion clothing must adhere to relevant safety standards and regulations, ensuring that reflective elements and design meet specific visibility requirements[151]. For motorcyclists, biomotion could also play a critical role in improving their visibility to other road users. By incorporating reflective strips or biomotion-inspired designs on motorcycle clothing, gloves, and helmets, motorcyclists can emphasize their body movements, such as hand or leg motions, which drivers, especially in low-light conditions more easily recognize. This could help reduce collisions by making motorcyclists more conspicuous at night.

Pedestrians may not be easily seen at night and might not wear reflective clothing due to unawareness of its effectiveness during nighttime. For motorcyclists, implementing curved reflector designs or innovative materials that maximize visibility from various angles could further improve safety. Additionally, incorporating these advancements into motorcycle gear and ensuring adherence to relevant safety standards can create practical, scalable solutions to improve the conspicuity of motorcyclists in diverse road conditions.

Previous research on motorcycle conspicuity has often involved controlled experiments that simulate dangerous conditions. These studies have provided valuable insights but have limitations in their applicability to real-life situations. Typically, these experiments focus on specific lane conditions or controlled environments, which only partially capture the complexity and variability of real-world traffic.

Future research should aim to model real-world scenarios more accurately. This includes studying conspicuity in diverse traffic conditions, different weather scenarios, and varying times of day. Advanced simulation tools and on-road testing in live traffic environments can provide more comprehensive data, leading to better-informed strategies for enhancing motorcycle visibility.

Beyond DRL and high-visibility attire, other technical measures can further improve motorcycle conspicuity. These include the use of auxiliary lights, reflective tape on the motorcycle itself, and innovative technologies such as smart helmets equipped with LED lights and augmented reality displays. Each of these measures can contribute to making motorcycles more visible to other road users.

Despite these advancements, there remains potential for further improvements. Research suggests that studies should more accurately represent real-world scenarios to develop more effective safety measures. For instance, experimental conditions often fail to replicate the complexities of real-life traffic environments, which can limit the applicability of the findings.

4.2 Behavioral Safety Aspects: Addressing Risky Riding Behaviors

In terms of motorcyclist behavior, the results showed that there was a significant relationship between risky driving behavior and traffic accidents. Motorcyclists tend to take greater risks than other vehicle drivers. Risky riding behaviors that are often carried out by motorcyclists in traffic include turning without turning on the turn signal, driving in narrow gaps between other vehicles, stopping anywhere on the road, not stopping when the red light is on, speeding, not wearing a helmet or wearing a helmet but not standard, going against the direction, using the phone while driving, and chatting with other motorists. Risky driving behavior occurs in almost all countries, both in developed and developing countries.

Male motorcyclists and younger motorcyclists are more likely to engage in unsafe behavior. In cases that result in fatal accidents, they generally involve male motorcyclists[152)]. Status and recognition to be appreciated among teenagers encourage them to make more risky decisions by doing illegal races, speeding, and challenging things[153)]. In a study of high school students, male students had more unsafe driving practices than female students[154)]. Such unsafe behavior is a potential hazard that must be addressed immediately before it develops into an accident[155)]. These potential hazards must be understood by both motorcyclists and decision-makers in order to improve driving safety[156)]. At-risk driver behavior is influenced by internal factors, such as the driver himself, and external factors, such as discipline enforcement, the role of parents, the role of peers, and environmental conditions.

Emotions and moods influence a motorcyclist's cognition of unsafe riding[157)]. A bad mood will have an impact on the motorcyclist's attitude toward taking risks while riding. The need for skilled motorcyclists affects bad driving behavior. A person who is just learning to ride a motorcycle tends to take dangerous actions, drive recklessly, start the vehicle suddenly without turning on the signal lights, stop suddenly without turning on the signal lights, and turn quickly without turning on the turn signal[158)]. Such conditions will be more dangerous if the driver is not skilled at riding in public places that are crowded with other types of vehicles or in places where the road conditions are dangerous, such as downhill or uphill.

Unsafe acts or distractions while riding can result in the loss of life for motorcyclists[159,160)]. Fatal accidents often occur on the highway involving large vehicles, and motorcyclists are overturned due to being bumped or swayed and getting under the truck. The decision to overtake the vehicle at the wrong time can result in a fatal accident. The lack of understanding of traffic safety causes motorcyclists not to realize that the invisibility of motorcycles by other vehicle drivers is a factor in fatal accidents[161)].

Helmets are a mandatory safety device that must be used by every motorcyclist, with no exception in Indonesia. Regulations for using helmets in Indonesia have been implemented since the early 1970s, when these rules were contained in the announcement of the Head of the National Police on November 1, 1971. This regulation requires users of two-wheeled motorized vehicles to wear helmets. Apart from being personal protective equipment, the use of a helmet is also a form of compliance with traffic regulations in accordance with Law No. 22 of 2009 concerning Road Traffic and Transportation article 57 paragraphs 1 and 2, which requires that every motorized vehicle user on the road must be equipped with motor vehicle equipment in the form of an Indonesian national standard helmet or SNI. However, many motorcyclists still do not use or use non-standard helmets. Awareness of the importance of protecting the head from impact still needs to be improved. Motorcyclists do not wear helmets because they feel uncomfortable and hot, ruin their hair, drive short distances, and are not driving on the highway. The safety of the head is the main thing, more than anything else, and it must be protected from all kinds of collisions[162)].

4.3 Policy and Education Interventions

Policy and education interventions play a critical role in shaping safe and secure driving behaviors among motorcyclists and other road users[163)]. This section explores various strategies and their impact on motorcycle safety, emphasizing the need for comprehensive and continuous efforts in this domain.

Safety education and skills training are foundational to developing safe driving habits, particularly among novice motorcyclists. Studies have shown that targeted education and training programs can significantly improve the skills and safety awareness of beginner drivers. During pre-license training, novice motorcyclists are taught essential skills and safety protocols, which they continue to develop during their first year of riding experience. Effective training programs often include practical riding sessions, theoretical knowledge of traffic laws, and defensive driving techniques.

The enforcement of traffic regulations by law enforcement agencies is crucial in reducing risky driving behaviors. Strict enforcement of speed limits, helmet use, and adherence to traffic signals can deter motorcyclists from engaging in dangerous behaviors. However, the effectiveness of enforcement could be improved by the limited number of traffic police available for monitoring and controlling traffic violations. Inconsistent enforcement can lead to a lack of compliance among motorcyclists, highlighting the need for increased resources and better coordination within traffic law enforcement agencies[164)].

Parents and the broader community play a significant role in influencing the driving behaviors of young motorcyclists[165)]. As primary role models, parents can instill good driving habits and emphasize the importance of road safety. By setting positive examples and reinforcing safe driving practices, parents can help reduce the likelihood of their children engaging in risky behaviors. Community outreach programs and local safety campaigns can also raise awareness about motorcycle safety and encourage collective responsibility for safer roads.

Government intervention is essential in creating a safe transportation system. Policymakers must develop and implement comprehensive road safety policies that address both the technical and behavioral aspects of motorcycle safety. This includes setting and enforcing safety standards for motorcycles and protective gear, such as helmets, and improving road infrastructure to make it safer for motorcyclists. Dedicated motorcycle lanes, better road signage, and regular maintenance of road surfaces can significantly reduce accident risks.

Moreover, governments can invest in technology-driven solutions, such as traffic monitoring systems and automated enforcement tools, to enhance the efficiency and effectiveness of traffic law enforcement. Government agencies can also lead public awareness campaigns to educate motorcyclists and other road users about safe driving practices and the importance of complying with traffic regulations.

Continuous education and refresher courses for motorcyclists can help maintain and improve safety standards over time. Periodic training sessions can update riders on new traffic laws, advanced riding techniques, and the latest safety equipment. These courses can be particularly beneficial for older motorcyclists or those who have developed unsafe riding habits over time. By reinforcing safe riding practices and keeping motorcyclists informed about current safety trends, continuous education can contribute to long-term improvements in road safety.

The integration of technology into education and enforcement strategies offers new opportunities to enhance motorcycle safety. Simulation-based training programs can provide realistic and immersive experiences for novice riders, helping them develop critical riding skills in a safe environment. Mobile applications and online platforms can deliver interactive safety courses, making education more accessible and engaging.

4.4 Study Limitations and Future Research Directions

This study reviews only the limitations of motorcycles and motorcyclists. Therefore, bicycles and electric bicycles are outside the scope of the study. Furthermore, most of the riding environment employed in this study is on the road, not in a residential area.

The current literature review provides comprehensive studies regarding the previous studies on motorcycle safety aspects. This review can help in explaining the direction in which research on motorcycles in the future must be done. Some recommended research directions are summarized as follows:

a. Analysis of the motorcycle's reaction time for braking distance (time/distance). When the vehicle ahead acts (e.g., braking, turning). The goal of this study is to measure how fast and distance it takes motorcyclists to react when a vehicle in front of them deviates off course.
b. An analysis of the motorcycle drivers' tendencies to choose road lanes on busy (VCR > 70%) and quiet road conditions. This research is to determine the characteristics of road lane selection by motorcyclists (based on gender, age group, type of motorcycle, and engine volume).
c. An analysis of motorcyclist behavior at intersections (including turning right from the far left lane) is needed to find out the characteristics of drivers at signalized and non-signalized intersections. For signalized intersections, how many percent of drivers stop before the stop line, and how many percent run through the traffic light? For the case of unsignalized intersections, how many percent choose to stop for a moment before turning, and how many percent turn by cutting lanes (changing lanes when at an intersection)?
d. Relationship between a rider's fitness and its load with their capability of riding a motorcycle. To find out how much the influence of those factors affects the skills of riding a motorcycle is a question for another study.
e. A novelty helmet design that maintains a wide view area and minimizes the reduction of hearing capability.
f. Rearview mirror design that minimizes the blind spot when detecting incoming motorcycles.
g. Research regarding reflective materials according to Indonesian environmental conditions
h. Reflective material design on motorcycles (place, area, and color)
i. Rider behavior (riding technique) on roads with poor road geometry (horizontal or vertical alignment). The purpose of this study is to discover how motorcyclists perceive road conditions with substandard horizontal alignments, the hazards they pose, the risks of existing hazards, and their anticipation of them.

5. **Conclusions**

This study provides a comprehensive analysis and synthesis of previous research on motorcycle conspicuity and rider behavior, emphasizing their contribution to improving motorcycle safety. The findings highlight that enhancing motorcycle conspicuity through technical solutions, such as reflective clothing, biomotion aids, advanced lighting systems, and curved reflectors, can significantly reduce the risk of accidents by increasing the visibility of motorcycles, especially in low-light and complex environments. Similarly, addressing unsafe rider behaviors, such as speeding, poor situational awareness, and failure to wear protective gear, plays a crucial role in reducing accident rates. The interplay between these technical and behavioral factors is critical for developing effective safety strategies.

Technical and behavioral aspects are closely interlinked in improving motorcycle safety. While technical advancements provide the tools to enhance conspicuity and protect riders, their effectiveness depends heavily on how motorcyclists and other road users interact with these solutions. For example, reflective clothing and advanced lighting systems are only beneficial when consistently used by riders and when drivers are attentive to their presence. On the other hand, promoting safe riding practices, such as defensive driving and adherence to traffic rules, maximizes the utility of these technical aids. This correlation underscores the need for a holistic approach that addresses both dimensions simultaneously.

The research findings also indicate that motorcycle conspicuity and rider behavior must be tailored to specific environmental conditions. For instance, bright clothing is more effective in urban environments with cluttered backgrounds, while dark clothing contrasts better in rural areas with simpler, natural surroundings. These insights suggest that targeted interventions, considering both the technical and behavioral aspects of conspicuity, can significantly enhance safety outcomes. Moreover, integrating education and training programs with conspicuity technologies can further promote their adoption and effectiveness among motorcyclists.

By examining these factors comprehensively, the study achieves its aim of synthesizing research on motorcycle conspicuity and rider behavior to provide actionable insights for improving motorcycle safety. Future efforts should focus on leveraging the correlation between technical and behavioral aspects to design multifaceted safety strategies. These could include the development of adaptive conspicuity aids that adjust to environmental conditions, awareness campaigns highlighting the importance of conspicuity, and rider training programs emphasizing the use of safety gear and adherence to traffic rules.

In conclusion, motorcycle safety requires a combined effort to address both technical and behavioral factors. While advancements in conspicuity aids and safety technologies lay a strong foundation, their full potential can only be realized through responsible rider behavior and targeted interventions that consider the interaction between these aspects. This integrated approach is essential for reducing motorcycle-related accidents and ensuring the safety of motorcyclists on the road.

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