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Analysis of Risk Factors in Motorcycle Riding and Distribution of Attention Using Eye Tracking, Interview, and Video—Preliminary Study

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Nord University and SINTEF Community, in collaboration with Trygg Trafikk, have carried out a preliminary research study examining the motorcycle accident risk factors and the possible causal relationships of single-motorcycle accidents and multiple-vehicle collisions. The objective was to investigate the distribution of motorcyclists' attention using eye-tracking, interview, and video analysis. The main research question of the study was: What are the most critical factors for riding a motorcycle safely? Nine motorcyclists with different knowledge and experience levels in riding a motorcycle participated in the study. The Tobii eye-tracking system was used to record and reveal the ability of motorcyclists to orient themselves when riding the same route with roundabouts, intersections, and roads with different speed limits. Their riding tours were recorded, and the eye fixation points, fixation point durations, and eye movements were analyzed. All the motorcyclists were interviewed after riding the specific route to understand individual differences in their subjective experiences: self-reported behavior related to planning, attention seeking, speed selection, and road positioning. The study provides findings that strengthen the knowledge base for those who plan and carry out the education of motorcycle instructors and motorcycle riders. The findings will be of high interest for road safety decision makers and for launching new awareness and information campaigns.

Keywords: Motorcycle, Eye tracking, Accidents, Cognitive maps, Vision Zero strategy

1. Introduction

In 2022, fatal motorcycle accidents accounted for over 20% of all traffic fatalities in Norway (SVV 2022). A total of 21 motorcyclists lost their lives, the highest number since 2016 (Statistics Norway, 2023). Approximately 52% of these accidents are single-motorcycle accidents. Among those who died in motorcycle accidents in the 2015–2022 period, the 45–54 age group and men are overrepresented (SSB). There is a need to understand why the number of motorcycle accidents are increasing in Norway. Safety for motorcyclists is discussed both in the National Transport Plan (NTP, 2021) and in the Norwegian Public Road Administration's (NPRA) Action Plan for Traffic Safety for light and heavy motorcycles and mopeds (NPRA, 2022).

The Norwegian Vision Zero strategy (NPRA, 2021) lays down an ambition to reduce fatalities and serious injuries in road traffic to a maximum of 350 by 2030, of which a maximum of 50 is fatalities. No one should die in road traffic accidents in 2050. To achieve this goal, important measures must be taken to reduce the number of motorcycle accidents.

Previous research showed that individual driving characteristics and driving behavior are the two main risk factors contributing to motorcycle accidents (Lin & Kraus, 2009; Sexton, 2004). In a review of 220 publications on motorcycle crashes, Lin and Kraus (2009) reported that inexperience, risk taking, and speeding increase motorcycle crash risk and injury severity.

The Norwegian motorcycle training model is a step-by-step training, based on the goals defined in the Driver Education matrix (Peräaho et al., 2003). The compulsory education training contains both theoretical and practical learning (Lovdata reference), and in the curricula for light and heavy motorcycle and moped license classes (A, A1, and A2), the learning steps and achievements are either compulsory or noncompulsory (NPRA, 2016). Motorcyclists are evaluated through a theoretical and a practical test. The practical test is based on requirements and regulations set down by the EU in Directive126 2006 (EUR-Lex, 2006). This directive governs the content and form of the test, ensuring quality riding skills and knowledge and understanding of road traffic. The tests are carried out under the control of the NPRA.

To propose new adapted traffic safety measures, it is important to understand the underlying cognitive–perceptual mechanisms, the individual cognitive maps (i.e., mental representation of locations and environment), and action-oriented processes of behavior that serve to plan, predict, and inhibit when moving in both known and new environments. Everyday humans use prior knowledge stored in their semantic and episodic memory to make predictions of the world around them when driving a car, walking in the streets, or riding a motorcycle. The ability to find out where they are, what is going to happen, and when it will happen are essential and critical cognitive and perceptual skills for survival (Bridge et al., 2017; Sugar & Moser, 2019). Humans also use cognitive maps in planning, predictions, and visual searches (Henderson, 2017). These cognitive maps, located in the hippocampus, are central in making episodic memories connected to what is happening in specific locations and transferred to the long-term memory for consolidation in the semantic memory (O`Keefe, 1978; Sugar & Moser, 2019). The hippocampus and the oculomotor system (responsible for eye movements) guide the visual search and collect relevant information from the surroundings to integrate this information into memory (Ryan, 2019; Nau, 2018). In addition, there is a critical interaction for attentional processing between the hippocampal system and the frontoparietal network. Thus, the retrieval of relevant memories contributes to memory-guided visual exploration strategies (Hannula & Ranganath, 2013; Bridge, 2017). Our visual explorations continuously create our cognitive maps, "movies" of what is happening during navigation in traffic (Sugar & Moser, 2019).

The action-oriented process is connected to the human ability to adapt and rooted in the notion of Prediction Error Minimization (PEM). PEM explains how the human brain is always seeking to minimize the discrepancies between its predictions and what is happening (Hohwy, 2013). The motorcyclists are riding in traffic environments where the conditions are constantly changing, and they must keep riding in a safe and efficient way. To succeed, they continuously examine the changes around them that may affect their riding. Their ability to predict supports them in reducing the uncertainties and surprises. At the same time, their predictions contain some errors that must be detected as soon as possible so they can correct their plan and the execution of their actions (Clark, 2016).

Nord University and SINTEF Community, in collaboration with Trygg Trafikk—the national public organization working on traffic safety—present in this paper a preliminary study on the risk factors of single-motorcycle accidents and multiple-vehicle collisions.

2. Methodology

The objective was to identify the risk factors and patterns of motorcycle accidents by analyzing nine motorcyclists' behavior and visual attention. The motorcyclists were asked to ride a predefined route with specific traffic and road environments. They were interviewed after their riding tour, and we analyzed and compared the videos and eye-tracking data. The analysis was based on the understanding of current motorcycle education and training and recent knowledge about the cognitive mapping function and navigation system of brain.

2.1. Participants

Two groups of motorcyclists participated in the study. Group 1 consisted of 5 motorcyclists (3 men and 2 women) with "normal riding experience" (non-professional riding under 30.000km/year) who have had a motorcycle license for more than 2 years and who mainly ride their motorcycle for leisure.

This recreational riding consists of holiday riding tours in Norway and/or abroad, alone and with organized motorcycle club groups. They also use their motorcycle for commuting and have not worked with traffic education or been active in the motorsport environment. Group 2 consisted of 4 motorcyclists (4 men) with "broad riding experience." (professional riding over 30.000 km/year). The motorcyclists in group 2 have experience in motorcycle training, emergency instructor training, and censoring practical tests on motorcycles, driver training, and/or the motorsport environments. They are all between 45 and 64 years of age. The purpose of group 2 was to establish a reference group with very high traffic competence and/or very high technical riding skills to be able to compare their riding against normal behavior.

2.2. Riding tours

The motorcyclists were asked to ride on a route composed of several road sections with different speed limits. Roundabouts, curves, and sections with cracks in the pavement were selected for further analysis in this study. The roundabouts are in an urban area and have moderate traffic flow and visibility. The curves are on county roads with a maximal speed limit of 80 km/h.

2.3. Analyses

2.3.1. *Questionnaires*

Data from the transcribed interviews were first coded, categorized according to the inductive principles inspired by the Grounded Theory (Strauss & Corbin, 1990), and finally analyzed in conjunction with the Driving Process Model (Moe, 2021) used as a traffic methodical analysis approach. The in-depth interviews were conducted by traffic education teachers of driving instructors of two-wheeled vehicles (e.g., mopeds and light and heavy motorcycles). They designed the interview guide to analyze the ability of riders to predict and inhibit different traffic situations, and their strategic and tactical choices when crossing intersections and roundabouts or when riding on curvy roads. The interviews started with open questions, followed by questions requiring clear answers. The purpose was to investigate how the riders understood and perceived their riding and the strong and weak aspects of their understanding.

2.3.2. *Eye tracking and cognitive maps*

The portable Tobii eye-tracking system with the Tobii Pro Lab computer software (Version 1.162, Danderyd, Sweden: Tobii Pro AB) was used in this study to register and analyze the eye gaze behavior of the motorcyclists. The eye-tracking system is composed of glasses with a microphone, a scene camera providing the field of view, and eye cameras and infrared illuminations integrated in the lenses to create reflections on the corneas and pupils. These images are processed to find the eyes' movements in space and the points of gaze. The recording device can be placed in a jacket pocket. The Pro Lab software supports the analysis and visualization of eye movement and gaze data. The system collects saccadic eye movements (moving the gaze from one point to another) and fixation points with a 50 Hz sampling frequency. The duration of fixation points is between 100–700 ms and the saccades between 20–40 ms.

2.2.3. Video analysis

The video analysis was carried out by professionals at Nord University who are responsible for training all Norwegian motorcycle instructors’. They have also contributed to the curriculum for the motorcycle class on behalf of the Norwegian Road Administration. The main goal was to evaluate the strategies and tactics of the riders in traffic contexts by analyzing the riding videos and use of gazes registered by the eye tracker glasses. The selected roundabouts and curves were analyzed several times and checked according to the motorcycle rider education and learning programs. «Individual and group behavior at several roundabouts or curves were compared to examine if they had the same riding behavior and eye attentional processing.

In addition to this, the analysis was reinforced by comparing tactical choices with statements in interviews.

3. Results

Table 1 below presents the analysis of motorcycle accident risk factors based on the motorcyclists’ behavior and knowledge from the motorcycle education and learning.

Table 1. Risk factors associated with motorcycle accidents

Road sections	Risk factors
Riding through intersections and roundabouts	Lack of theoretical understanding and knowledge of multiple-vehicle collisions. Lack of preparedness and inadequate prevention.
Curvy roads and poor road surfaces	Lack of adapted gaze usage and distribution of attention. Unclear strategies for speed adaptation on curvy roads. Lack of preparedness and inadequate prevention for left road curves.

3.1. Riding through intersections

3.1.1 Theoretical understanding and knowledge

Our findings show large variations between the two groups in theoretical understanding and knowledge of risk factors associated with multiple-vehicle collisions.

• Group 1 showed a weak theoretical understanding of multiple-vehicle accidents. This weak understanding was expressed by the fact that most of the motorcyclists did not focus on the risk of collision when riding through roundabouts where other vehicles have a duty to give way to the motorcyclist. However, two participants stated during the interviews that they did not trust the other road users without explaining the impact this had on their own behavior. When asked directly about their way of thinking, most drivers shifted the focus on their own driving style. For example, they were most concerned with finding openings so that they could continue driving. Some of them were concerned with their own riding technical skills and challenges related to the riding of a motorbike through intersections and roundabouts. None of them commented on the measures they took to be better perceived by other road users while driving.

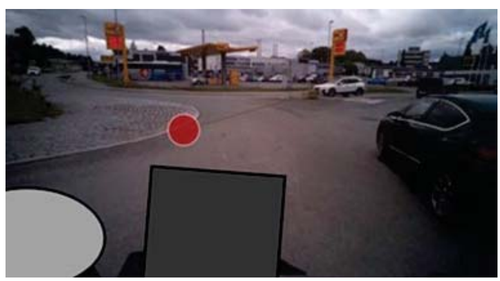
• Group 2 showed a better theoretical understanding of behavioral determinants as risk factors for accident prevention at road intersections and roundabouts and how they, as motorcycle riders, should behave when they are in the danger zone of other road users.

3.1.2. Preparedness in intersections

Our findings reveal differences in the degree of preparedness when riding through roundabouts and intersections for the two groups in the survey.

• Group 1 participants have varying or little readiness of traffic contexts. For group 1, we found varying degrees of preparedness at intersections, when they are in the danger zone (i.e., at risk of getting into a traffic accident by other road users due to a possible violation of the give way right, even though they have a duty to give way to the rider). For example, participants rode as if there was no other vehicle at the intersection, without paying any particular attention to the potential risk of collision. However, two of them paid attention to potential risk collisions until they had passed the danger zone, but they were not consistent.

• Group 2 were on standby in intersection situations until they were out of the danger zone. Riders were on alert, being ready to adapt to cars moving forward until they were out of the danger zone. They exhibited preparedness attitudes and behaviors when predicting what might happen and are prepared in the case of someone violating the duty to give way. During their interviews, all the riders described concrete strategies explaining how they ride through intersections and what they do when they are in danger zones.



Picture 1. Preparedness situation at the intersection. A rider in group 1 enters the roundabout at 48 km/h without being adequately prepared for the traffic in the nearest lane and for the traffic entering the roundabout.

3.1.3. Prevention at intersections

Our findings show that the two groups had different preventive riding at intersections.

• Group 1 showed to a small and varying extent preventive riding for avoiding conflict points and potential risk at intersections.

Picture 2. Prevention when arriving at intersections. A rider from group 1 approaches the roundabout at 56 km/h without prevention in riding for avoiding conflicts.

They drove where there was space and opportunity, without adapting their driving to make themselves visible or to give other road users time to perceive them. Nevertheless, there were exceptions among the riders, concerned either by riding correctly or by the importance of having extra lights on their motorcycle for increased visibility. In interviews with group 1, preventive riding was not a topic raised by the riders themselves, and when asked about it, they did not expand much on the topic.

• Group 2 showed active preventive riding by avoiding conflict points and potential risks at intersections. The findings show that riders in group 2 had a riding style integrating prevention in riding in a consistent way. The preventive strategies were, for example, waiting out the situation until it became safe enough, calculating safe meeting situations or not meeting traffic, not driving side by side, make themselves visible by positioning and adjusting their speed, and giving other road users enough time to spot the motorcycle.

3.2. Challenges related to curvy roads and poor road surfaces

3.2.1. Attention to road surface

Our findings show that the two groups had different eye gaze attention focus when riding over road asphalt cracks and uneven surfaces.

• Group 1 to some extent focused too much on adjusting their trajectory when approaching and riding over road cracks and potholes, even though they stated that they did not do so. Analysis of eye-tracker data shows that participants started fixating their gaze approximately 20–40 m ahead of the obstacle, during which they had an unstable handling of their motorcycle.

• Group 2 kept their attention forward, focused on curves while watching cracks and potholes. They then followed stable and adapted trajectories at curves (i.e., riding over the cracks without changing their trajectory).

Picture 3 shows the avoidant position and eye gaze attention of a rider of group 1 when riding over cracks on road.

Picture 3. Eye tracking on a poor road surface. A rider from group 1 tries to avoid cracks on the road.

3.2.2. Unclear strategies

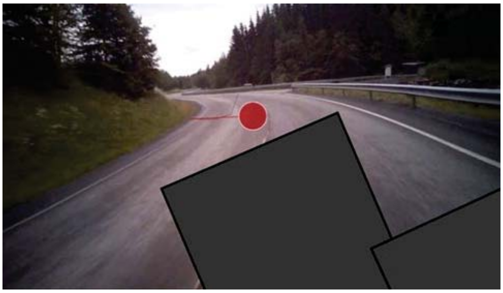
The two groups employed different strategies for speed adaptation on curves.

• Group 1 exhibited unclear strategies for safe speed adjustment on road curves. Riders were imprecise regarding the choice of a reasonable speed before, during, and after the road curve. Neither throttle control nor braking were mentioned during the interviews as possible actions. However, they could explain their choices in position and speed when riding on road curves. One participant mentioned how important visibility and speed adaptation are in avoiding being surprised by the presence of pedestrians and cyclists at the curve.

• Group 2 showed clear, consistent, and well-thought-out strategies for speed adjustment at curves. Riders in group 2 expressed that they have speed adaptation strategies before and during the curve (eventually increasing speed if possible). There was no consensus among riders regarding when, where, and how speed and braking adjustments should occur at curves.

3.2.3. Turning point

The groups used different techniques to turn their motorcycles into left curves.



Picture 4. A rider from group 1 turns too early into a left curve

• Group 1 showed tendencies to cut left turns too early with a high probability of conflicts with oncoming traffic which would lead to making them change their trajectory. During the post-ride interviews, none of the riders mentioned their cutting of road, regardless of which basic strategy for positioning (normal positioning and/or waiting until the turn ends) they had.
• Group 2 showed clear and well-executed guidance and strategies for positioning themselves in curves.

The interview and video analysis for group 2 riders show clear and implemented guidance and strategies for positioning in curves. The time to cut the turn varied somewhat between the drivers, but none of them drove in such a way that they can come into conflict with oncoming traffic.

4. Discussion

4.1. Riding through intersections

4.1.1 Theoretical understanding and knowledge

Group 1 showed a general lack of theoretical understanding of multiple-vehicle collisions, and most of them were not aware of the potential accident risk factors at intersections. This lack of knowledge explains the poor quality of their memory-guided visual exploration of the surroundings (Henderson, 2017). According to accident statistics, men over 45 are more likely to be involved in a motorcycle fatality, and these riders are to some extent representative of the group of men over 45 who ride occasionally during the motorcycle season in Norway. These results may partly explain the increase in the number of motorcycle accidents of this middle-aged group.

This preliminary study identifies a clear need to provide regular updating of skills and knowledge for motorcyclists. At the same time, current education and training also require a new and updated knowledge base considering the latest research findings on cognitive mapping processes.

4.1.2. Preparedness of riders at intersections

The groups differed concerning their degree of preparedness when riding through intersections. Group 1 exhibited excessive trust in other road users and a lack of focus on the potential risk of collision.

The findings may indicate a need to update the skills of middle-aged riders in this group regarding preparedness when riding through intersections. In addition, motorcycle-riding preparedness education and learning programs should also integrate new knowledge about the theory of PEM that explains how drivers or riders usually collect information from traffic situations in order to predict what will happen, where, and when (Hohwy, 2013; Sugar & Moser, 2019). The ability to predict requires training that goes beyond the knowledge of traffic rules, and this should be consolidated through education.

4.1.3. Prevention at intersections

The groups differed concerning their preventive riding for avoiding conflict points and accidents. The findings may indicate that riders in group 1 were not focusing enough on being visible to other road users nor actively improving their visibility by adapting their speed, distance, and road positioning. On the contrary, group 2 used better mental navigation strategies to identify conflict points and to adapt their behavior and positioning to the context (Nau, 2018). Navigation and behavior adaptation strategies should be integrated in new education and learning programs.

4.2. Challenges related to curvy roads and poor road surfaces

4.2.1. Attention on road surface

Even though riders in group 2 moved their attention back and forth on uneven surfaces and cracks in the asphalt, they mainly focused their attention forward on the curve, and consequently they were prepared for upcoming cars. They also had stable and adapted trajectories at curves (i.e., riding over the cracks without changing their trajectory), which was not the case for group 1.

These results are in accordance with theories about uncertainty and how to be prepared to avoid surprises (Hohwy, 2013; Clark, 2016). Riders in group 1 showed the need to improve their attention-distribution skills when meeting road cracks or any other unexpected events.

4.2.2. Unclear strategies

The lack of unclear strategies in group 1 and the diversity of strategies in group 2 related to when, where, and how speed and braking adjustments should be done at curves indicate a need for more research in line with theories on the use of cognitive maps and semantic memories to safely navigate risky environments (Sugar & Moser, 2019; Ryan, 2020).

4.2.3. Turning point

Several drivers in group 1 cut the curve too early, so they had to correct their course when they encountered traffic. Group 2 showed clear strategies for positioning themselves in curves, even if choosing different trajectories. According to the PEM theory, actions such as cutting the curve too early connect to efficient planning and prediction of the riding course (Hohwy, 2013; Sugar & Moser, 2019), so this knowledge should be integrated in education and learning programs.

5. Limitations and further research

5.1. *Limitations of the present study*

This preliminary study has the following limitations: 1) the limited number of participants, and 2) participants with varying experience. In addition, we used this preliminary study to understand the limitations of using an eye-tracking system with motorcyclists. The eye tracker is difficult to use with adverse weather conditions (e.g., rain, fog) or with direct low and/or strong sunlight conditions. This makes the plan and validation of tests challenging since a large percentage of gaze points (80–90%) for each participant is necessary to validate the results. The participants cannot also use glasses or multifocal contact lenses. The eye tracker glasses were not completely adapted to the motorcycle helmets and to tight helmets, making them somewhat uncomfortable for some motorcyclists. The system did not collect data with rough riding and high motorcycle vibrations (e.g., damaged road surfaces).

5.2. *Further research*

Through this project, we have provided a solid knowledge base for carrying out new studies on risk factors of motorcycle accidents. The next studies should investigate with representative samples of motorcyclists whether some groups use their memory, attention, and visual search for potential risks (i.e., selecting relevant stimuli) in a better way than other groups. Based on the results of this preliminary study, our hypotheses are that motorcycle riders with professional riding knowledge have a more complete memory-guided cognitive map compared to the group of middle-aged motorcyclists. They also have better planning; make better predictions of what, where, and when something is going to happen during navigation in traffic; and make better choices regarding adapted speed, position, and safety margins (i.e., distance between the motorcycle and the vehicle in front). It is therefore crucial to understand what should be changed in education and learning to educate motorcyclists and motorcycle instructors and to understand how to update the knowledge and skills of long-licensed motorcycle riders. Further research should validate these hypotheses with larger samples with different backgrounds (e.g., gender and age groups, socio-cultural contexts, riding experience, safety culture and behaviour). Studies can be also performed to improve road infrastructure and maintenance to prevent failures or mistakes of road users

6. Conclusion

The project deals with middle-aged motorcycle drivers with different experience backgrounds. This preliminary research focused on analyzing strategic and tactical choices against single-motorcycle accidents and multiple-vehicle collisions. This research has yielded findings that strengthen the knowledge base for those who plan and carry out the education of motorcycle instructors and motorcycle riders. Furthermore, the findings will provide new and updated knowledge for authorities in making new awareness and information campaigns. The results also showed that underlying cognitive–perceptual mechanisms, individual cognitive maps, and action-oriented processes of behavior are important factors to be considered when examining motorcycle accident risk factors.

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