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Eyetracking as a Tool to Understand Motorcyclists' Accident Susceptibility

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Abstract
Motorcycle accidents pose a significant challenge to traffic safety, particularly in achieving the Vision Zero goal. This study focuses on evaluating the speed selection and visual attention of motorcyclists while navigating curves with the use of eye-tracking technology and speedometer. Eye-tracking provides valuable insights into the visual distribution and cognitive processes of riders, which are crucial for understanding accident causation and improving safety measures.
Using the Tobii Eye Tracker system, we recorded the eye movements and speed data of 60 motorcyclists across three experience levels: novice riders with less than three years of experience, intermediate riders with more than three years of experience, and professional riders such as police officers and motorcycle driving instructors. The participants rode along a predefined route featuring various curves. Eye fixation data were analyzed to identify the attentional distribution in different segments of the route, while speed data were used to assess their speed selection through curves.
Our findings indicate significant differences in speed selection between the groups. Novice riders tended to enter curves at higher speeds and made more abrupt speed adjustments, suggesting a less efficient speed management strategy. In contrast, professional riders demonstrated smoother speed transitions and more consistent speed control, indicating a more anticipatory and controlled approach to navigating curves. These differences highlight the importance of experience in developing effective speed management strategies for safe riding.
The study underscores the potential of eye-tracking as a tool for enhancing motorcycle safety training programs. By identifying group speed management behaviors associated with higher risk, targeted interventions can be developed to improve riders' speed control and hazard perception skills. Future research should explore the integration of technologies such as eye-tracking with other physiological and behavioral measures to provide a comprehensive understanding of motorcyclist safety.

Keywords: Eye-tracking, motorcyclists, speed, safe riding.

1. Introduction

Motorcycle accidents pose a significant challenge to traffic safety and the vision of zero of no traffic-related fatalities and serious injuries. Recent analyses have highlighted the need for revitalized efforts to enhance motorcycle safety, particularly considering the increasing number of registered mid-weight and heavy motorcycles and the corresponding rise in the number of accidents. A critical aspect of understanding and mitigating these accidents is the study of rider behavior and attention, for example with the use of eye-tracking technology.

Eye-tracking provides a unique and detailed insight into the visual attention and cognitive processes of motorcycle riders. By capturing and analyzing eye glances, researchers can identify where and how riders focus their attention while navigating various road conditions and scenarios. This technology is instrumental in understanding the dynamics of rider behavior, especially in complex and high-risk situations such as navigating curves and intersections.

The Tobii Eye-Tracking glasses, captures raw eye movement data, including fixations and saccades, and then processed them in Tobii Pro Lab [Computer software], to reveal patterns of visual attention. Fixations, where the eyes remain relatively stationary, indicate moments of information processing and cognitive activity, while saccades, rapid movements between fixations, reflect the scanning behavior of the rider.

In this study, eye-tracking data were collected from riders navigating a road segment with various curves. The data was analyzed to determine the distribution and sequence of fixations, the number and duration of saccades, and the overall visual scanning patterns. This analysis helps to identify critical points of attention and potential lapses in focus that could contribute to accidents.The findings are crucial for developing targeted interventions and training programs aimed at improving rider safety. By understanding how riders interact with their environment and where their attention is directed, safety measures can be tailored to address specific risks and enhance overall situational awareness. This approach not only contributes to reducing accidents but also supports the broader goal of achieving zero fatalities on roads.

In conclusion, eye-tracking technology offers a powerful tool for advancing our understanding of motorcycle rider behavior and enhancing traffic safety. Through detailed analysis of visual attention and cognitive processes, researchers can develop more effective strategies to mitigate risks and improve the safety of motorcycle riders. Commissioned by the Norwegian Public Roads Administration, Nord University, in collaboration with SINTEF and the Norwegian council for road safety conducted a research project in 2024 on motorcyclists' decision-making and visual distribution for safe riding.

2. Theoretical framework

2.1. Accidents

Iversen and Njå (2022) in their thematic analysis of serious accidents involving All-Terrain Vehicles, Mopeds, and Motorcycles for the 2015-2020 period, found an increase in the number of registered medium and heavy motorcycles from 2015 to 2020, with a total of 2067 accidents involving such vehicles during the same period. Of these accidents, 32% are considered as Vision Zero accidents (with fatalities and serious injuries to drivers or passengers). Previous accident analyses have shown differences in risk factors between motorcycle accidents and those involving other types of vehicles (Høye, 2017 and Høye et al., 2016).

In motorcycle accidents, rider competence (traffic competence, vehicle experience, and driving experience) is of great importance. This means that the relationship between rider competence and road design or between rider competence and traffic situation are important parameters. For both run-off-road and head-on collisions, accidents involving sharp curves have increased over time, and the relationship between changes in road alignment and crossfall should therefore be examined further (Sagberg et al., 2020).

Table 1: Proportion of riders and passengers killed and injured on medium and heavy motorcycles in the 2015-2020 period (N=2065). (Iversen and Njå, 2022)

Age group	Slightly injured (%)	Seriously injured (%)	Killed (%)
Under 16	0.9	0.4	0.0
16-24	12.3	10.9	14.1
25-34	18.8	17.6	12.1
35-44	16.7	16.9	16.2
45-54	28.3	28.2	37.4
55-64	17.6	19.7	15.2
65-74	4.7	6.0	5.1
75-84	0.8	0.4	0.0
Total	100	100	100

Men are overrepresented in accident involving medium and heavy motorcycles: 1822 men and 245 women were involved in accidents in Norway during the period 2015-2020 (Iversen, T., Njå, O. 2022). Regarding age groups, table 1 shows that the age group of 45-54 years is overrepresented (37.4%) among those killed in motorcycle accidents during the same period (Iversen, T., Njå, O. 2022).

Motorcycle riding is seasonal in Norway, with accidents occurring more frequently from April to September, peaking in June (Iversen, T., Njå, O. 2022). It is currently not determined to what extent traffic competence or riding experience can explain accidents involving drivers in the 45-54 age group. The thematic analysis performed by Iversen et al. (2022) does not describe the riding experience of the deceased or seriously injured or how much these riders used their motorcycles throughout the year.

The thematic analysis of Iversen and Njå (2022) describes a possible attention deficit among motorcyclists. It questions whether momentary lapses and more persistent attention deficits can lead to fatal adverse situations. Run-off-road accidents in curves are a dominant type of motorcycle accident. Other studies also contributed to increased knowledge about motorcycle accidents through in-depth analyses and surveys (Høye, 2017, Høye et al., 2016, Sagberg et al., 2020). These studies discussed the relevance of various contributing factors (types of accidents, timing, lighting conditions, road conditions, purpose, helmet use, etc.), but are less clear in understanding all aspects of the accidents.

2.2. *The Rolling Cycle*

The process when you ride a motorcycle is an action-oriented, cognitive, predictive, perceptual, and affective concept anchored in a biopsychosocial understanding of human performance. Clark (2016) defines the rolling perception-action cycle that solves human problems as follows: *"High-level predictions entrain actions that both test and confirm the predictions, and that help sculpt the sensory flows that recruit new high-level predictions and so on, in a rolling cycle of expectation, sensory stimulation, and action."*

Clark's description of "the rolling cycle" aligns with all the iterative action-oriented, cognitive, and affective elements in the driving process. In Figure 1 below, the driving process as described by Moe (2021) is associated with the cognitive and emotional process based on theories of Cognitive Map and Predictive Error Minimization (PEM)to explain how humans navigate in traffic, for example, as either drivers or motorcyclists. Whereas the Prefrontal cortex plays an important role in the evaluation of the pertinence of sensory information, the amygdala and striatum reward PEM activation processes the incoming information relevant to reward and human emotions such as stress and anxiety, triggered in case of potential dangers.

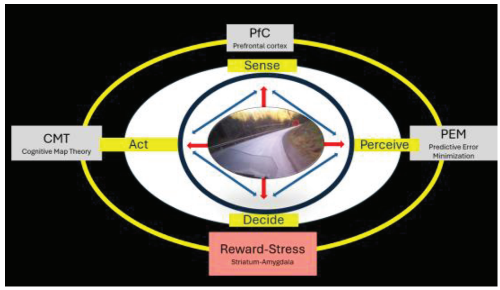

Fig. 1. The driving process associated with theories of Cognitive Map and Predictive Error Minimization. (Moe, 2021)

When road users move in the traffic and other environments, they switch between two types of orientation, egocentric and allocentric. The first one, the egocentric orientation is when they look at each object or vehicle in the environment relative to their own position (for example looking at the edge of the road or the car ahead). The second one, the allocentric orientation is on contrary when they look at an object or a vehicle with respect to the position of other objects and vehicles in this environment (Buzsáki and Moser, 2013; Wang, 2020; Julian, 2021; Vollan, 2024. For example, when they look at the next road curve and the cars coming in the opposite direction.

3. Methodology

3.1. *Participants*

The project was conducted with 60 riders divided into three groups: Group 1: Riders with less than three years of riding experience who use the motorcycle for leisure and utility riding. This group consists of individuals who have had a license for three years but may not have ridden much during this period. Although they have had their license for three years, they may lack practical experience and routine on the road. This could be due to not riding regularly or only riding under limited conditions, such as in good weather or on familiar roads. The group also includes riders who have gained large experience over these three years. Group 2: Riders with more than three years of riding experience who regularly use the motorcycle for leisure and utility riding. Riders in this group have had a license for more than three years but can be both experienced and inexperienced. Some have ridden regularly under varied conditions, while others have ridden less frequently. Even though they have had their license for a long time, a lack of frequent riding or exposure to different riding situations may mean that they have not developed the same skills and confidence as more active riders. Group 3: Riders with extensive professional experience on motorcycles, such as police officers, riding test examiners at the Norwegian Public Roads Administration, riding instructors, and instructors at driver development courses for track/road. The police have internal training that ensures motorcycle competence at all levels. Examiners at the Norwegian Public Roads Administration participate in internal courses and gatherings to maintain their competence. Instructors at driver development courses train frequently on tracks to maintain their skills. Experienced driving instructors have broad competence under various weather and road conditions as well as traffic situations. All these groups are expected to have higher competence compared to both Group 1 and Group 2.

3.2. Ethics

All study participants were comprehensively informed about the project's objectives and potential risks. Each informant was provided with a written consent form prior to their participation. The project received approval from Sikt: Norwegian Agency for Shared Services in Education and Research (SIKT, 2023), previously known as the Norwegian Centre for Research Data (NSD), in compliance with GDPR principles.

3.3 *Eye tracking and speedometer*

The Tobii Eye tracker is composed of glasses that the motorcyclists wear when riding. The glasses have cameras to register the raw eye movements of the riders and the environment. The data metrics provided by the system include both the fixation points and the saccades over time. The sampling rate was 50 Hz. Only participants with high quality gaze data sampling (over 90%) have been analysed. Blinking is often responsible for data loss of 5-10 %. Riders with low data sampling due to various conditions were not considered. In addition, the motorcycle was equipped with a Global Positioning System tracker, that registered the vehicle position and speed during the ride.

4. Results

Eye-tracking is a valuable tool for research on motorcyclists' behaviour, providing insights into how riders distribute their attention and make decisions while riding. We have analysed the speed choice and attention distribution among 62 different motorcyclists.

Table 2 shows the illustrative explanation carried out by examining the speed choice and areas of interest (i.e., attentional allocation of motorcyclists over road and traffic locations) when riding through road curves.

Table 2. Results of the illustrative explanation from Eye-tracking and speed data

Motorcyclists' riding in curves	Illustrative explanation
1. Speed in curves	The motorcyclist's speed entering and navigating through curve combinations.
2. Attention distribution	The motorcyclist's areas of interest (i.e., attentional allocation over road and traffic locations).

4.1. Speed in curves

During the study, the speed of the different motorcyclists entering and navigating through the curve was examined according to their position in the curve. The curve was divided in seven sections (Figure 3), based on current knowledge regarding run-off-road accidents in curves.. Results could indicate whether there were differences in speeds between the three groups and whether this could have an impact on accident susceptibility. More experienced motorcyclists (Group 3) have higher speeds and smoother riding compared to less experienced riders. This conclusion is supported by a methodological approach that combines extensive data collection, advanced data processing, and detailed data visualization and analysis. The study has effectively identified and analyzed key aspects of riding behavior, such as gaze use and action choices for safe riding, contributing to a better understanding of how experience affects riding style among motorcyclists.

It is also important to note that there is considerable variation within each group, as seen from the dashed lines. Nevertheless, it is remarkable that the average curves so clearly demonstrate the original hypothesis that Group 3 rides faster than the other groups.

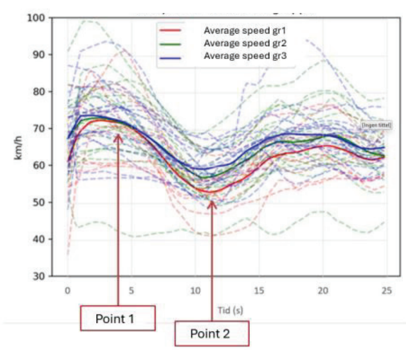

Fig. 2. Speed profiles of motorcyclists through the curve and average speed profiles for the three groups.

The motorcyclists generally have the same speed, slightly over 70 km/h (Point 1), on the straight section leading up to the right curve. Group 3 has a higher speed than the other two groups at the entrance to and through the right curve (Point 2). Group 1 reduces speed more than the other two groups and starts accelerating approximately in the middle of the curve, most likely when they realize that the speed could have been higher.

4.2. Motorcyclist's attention and distribution in a series of curves

We selected a road with a combination of curves. The right curve shown in figures 2 and 3 was divided into seven sections to understand the attentional distribution of the motorcyclists. The objective was to evaluate to what extent the riders adopt either an egocentric or an allocentric perspective with their gaze. This means being able to use an allocentric orientation when it is required to gather information further ahead, in this case, the next curve.

Fig. 3. Division of the curve in sections for analyses of motorcyclists' speed choice and attentional allocation.

Results showed that group 1 focuses more on the edge of the road and remains in the egocentric phase longer before transitioning to the allocentric phase in sections 6 and 7 of the curve, where they look towards the left curve. Skilled motorcyclists continuously switch between egocentric and allocentric perspectives while riding through varying landscapes and environments. This ability to shift perspectives is crucial for making accurate predictions and decisions that contribute to controlled, safe, and efficient riding. Group 3 follows the edge of the road (egocentric) for a shorter period and begins the allocentric phase early in sections 4-5 of the curve.

In Figure 4 below, the motorcyclist approaches the right curve, fixating on the beginning of the curve and then immediately looking forward to the next critical point, which is a left curve.

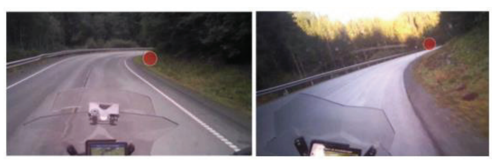

Fig. 4. Example of a Group 3 motorcyclist riding through the right curve and using an allocentric perspective.

5. Discussion

5.1. Speed in curves

Run-off-road accidents in curves are the clearly dominant type of accident among motorcyclists in Norway (Høye et al., 2016; Iversen & and Njå, 2022). This prevalence underscores the critical need for targeted interventions and preventive measures. Additionally, two out of three fatal riders have exhibited extreme or blameworthy behavior, with the most common type being excessive speed for the road and traffic conditions (Høye et al., 2016).

In this context, the following should be noted: A potential source of error in classifying speed as "too high for the conditions" is a circular reasoning of the type: "The rider failed to keep the motorcycle on the road, therefore the speed must have been too high for the conditions." However, this says little about whether the speed was objectively [our emphasis] too high (if a more skilled rider would also not have been able to keep the motorcycle on the road) or whether other factors were present that contributed to the accident (Høye et al., 2016, p. 28). This highlights the necessity for a more nuanced approach in accident analysis, considering multiple variables beyond mere speed.

This problematization of objectivity highlights the importance of individual rider skills as an area of investigation, and the rider's subjective experience, subjective assessment, and choice of speed become particularly interesting for achieving a better understanding of aspects of the causes of the dominant types of accidents. "Speed for the conditions" can thus include "speed for the rider's capabilities." Therefore, future research should focus on developing comprehensive rider profiles that integrate both objective and subjective measures of riding performance.

We observe from the speed data that Group 3 has a higher speed through the curves than Groups 1 and 2. Group 2 has a slightly higher speed than Group 1. It must be assumed that experience, both through several years of holding a license and more kilometers ridden, provides a basis for better mastery. With such experience, it is assumed that the individual rider is both better in technical execution and has ridden more curves in their career, thus daring to maintain higher speeds. On the other hand, it can be assumed that broader experience also includes encounters of a more negative nature. This dichotomy suggests that while experience can enhance technical skills, it may also expose riders to a wider range of hazardous situations, potentially influencing their risk perception and behavior.

Given this background, the results are somewhat surprising, as one might assume that such experiences would lead to more caution. Motorcycling is considered a technically demanding task. Against this background, the results may be natural. This paradox warrants further investigation to understand the interplay between experience, risk-taking, and accident propensity among motorcyclists.

5.2. Motorcyclist`s attention and distribution in a series of curves

Group 1 riders attempt to look far ahead but frequently check the road surface directly in front of the motorcycle. This behavior is likely due to a need to be aware of the surface they are riding on, such as gravel, potholes, cracks in the asphalt, and wet road surfaces can be perceived as threats to traction (Nagayama et al., 1979; Silva, 2024). Such vigilance is crucial for maintaining stability and control. Most in Group 1 try to avoid cracks and potholes in the asphalt, spending more time in the egocentric phase approaching and through the curve compared to Group 3.

Group 2 riders show a balance between egocentric and allocentric gaze use. They often look towards the end of the curve or the vanishing point on the road, and fewer riders in this group check the road surface close to the motorcycle. This balanced approach may enhance their ability to anticipate and react to upcoming road conditions. This group transitions to the allocentric phase earlier than Group 1 but not as early as Group 3.

Group 3 riders direct their gaze further ahead than Groups 1 and 2. They shift their gaze much faster up and forward, spending less time in the egocentric phase approaching and through the curve, prioritizing the allocentric phase more. This advanced gaze strategy suggests a higher level of confidence and proficiency in handling the motorcycle. This group does not focus on checking the road surface, likely due to better maneuvering skills and a reduced need to monitor the surface they are riding on.

Based on qualitative and quantitative findings, it is reasonable to believe that riding experience is a central factor for Groups 1 and 2 in how they use their gaze. Group 2 has the ability to lift their gaze earlier approaching and through the curve compared to Group 1. This indicates a progression in skill development with increased experience. The findings also show that riding alone is not enough, especially when comparing Groups 1 and 2 to Group 3. Several participants in Group 2 have much more experience than others in Group 3 but are not as skilled at demonstrating their ability to look further ahead much earlier than Group 2. This discrepancy highlights the complexity of skill acquisition and the potential influence of other factors such as training quality and individual learning styles. If the goal in training is for all motorcyclists to increase their competence, it is necessary to examine why there is a gap between Group 3 and the other groups.

6. Implications

The findings on egocentric and allocentric gaze use among different groups of motorcyclists have significant implications for rider training. Customized training programs can be developed to address the specific needs of each group. For instance, Group 1 riders, who tend to focus on the road surface directly in front of them, may benefit from exercises that encourage looking further ahead and anticipating road conditions. Emphasizing hazard awareness and managing potential threats like gravel, potholes, and wet surfaces can build confidence and reduce the need for constant road surface checks.

For Group 2 riders, training can focus on refining their ability to balance egocentric and allocentric perspectives, including advanced maneuvering skills and techniques for better curve navigation. Enhancing predictive abilities and decision-making skills can further benefit Group 3 riders, who already demonstrate advanced gaze use. Experience-based learning, such as simulated rides or real-world practice sessions, can help riders gain the necessary skills and confidence.

Using objective assessment tools like eye-tracking cameras can provide personalized feedback and track progress over time, ensuring that training is effective and targeted. By addressing these areas, training programs can help motorcyclists develop the skills needed for safer and more efficient riding, ultimately reducing the risk of accidents and improving overall road safety.

Knowledge provides the theoretical foundation necessary to understand the principles of gaze behavior. It encompasses an awareness of how visual information is processed and utilized during navigation. For instance, understanding the distinction between egocentric and allocentric perspectives is crucial

The interplay between knowledge and skill in gaze usage during curving is critical. Theoretical understanding provides the necessary framework, while practical skills enable the effective application of this knowledge. Together, they enhance an individual's ability to navigate complex environments by leveraging both egocentric and allocentric information processing.

The education of motorcycle instructors and the content of curricula should place greater emphasis on the importance of proper visual techniques and speed adjustment before and through curves. The study highlights the need to ensure the quality of both knowledge and skills in these areas

7. Conclusion

The research question was: How does experience level affect the speed selection and information processing of motorcyclists in curves, and what are the implications for the development of safety measures and training programs?”

Experience level significantly affects motorcyclists' speed selection and information processing in curves. Experienced riders (Group 3) maintain higher speeds and effectively switch between egocentric and allocentric perspectives, enhancing their ability to anticipate and navigate curves. Intermediate riders (Group 2) show developing skills in this area, while inexperienced riders (Group 1) focus more on the immediate road surface, limiting their anticipatory abilities.

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