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Transportation Research Procedia 91 (2025) 179–186

Transportation Research Procedia

www.elsevier.com/locate/procedia

The Science and Development of Transport - TRANSCODE 2025

Exploring motorcyclist speeding through naturalistic riding data

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Abstract

Motorcyclists represent a vulnerable group of road users, often exhibiting elevated crash severity risk due to speeding and limited physical protection. This study explores speeding behavior among motorcyclists using smartphone-based naturalistic data, a relatively novel approach in motorcycle safety research. The aim of the study was to examine which factors influence rider speeding behavior. A total of 1,853 trips (36,169.3 km) from 19 participants were recorded via a phone application capable of detecting speeding and other riding dynamics in real-world traffic conditions. Linear regression was applied to investigate the effect of several potential predictors, including road type, average speed, speed over the limit, indicators of aggressive maneuvers (acceleration, braking), and contextual variables (daytime, weekend). The model explained 72% of the variance in speeding behavior, with the percentage of trip duration spent speeding as a dependent variable. Key predictors included the average speed over the limit, which was strongly positively associated with the observed outcome, and the proportion of motorway driving, displaying a negative association. Harsh accelerations also had a significant positive effect, while factors such as daylight and weekends did not yield significant effects. Findings highlight the potential of smartphone-based data collection for monitoring speeding in naturalistic settings. While several limitations were acknowledged, this study offers a valuable starting point for broader applications of mobile sensing in road safety, with potential implications for tailored feedback, rider coaching, and intelligent transport systems.

Keywords: Motorcyclists; speeding; naturalistic; smartphone; behavior; safety; regression

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10.1016/j.trpro.2025.10.024

1. Introduction

1.1. Context and motivation

The World Health Organization (2023) reported that, globally, 30% of reported road deaths are related to powered two-wheeler (PTW) riders. According to a report by Slootmans et al. (2024), PTW fatalities accounted for 18.8% of all road deaths in the European Union (EU). While PTW fatalities in the EU declined by 16.5% between 2012 and 2022, all road fatalities dropped significantly (22%). Consequently, the relative share of PTW fatalities has slightly increased over the past decade. When looking at the type of fatal crashes, 37% of motorcyclist fatalities are the outcome of a single-vehicle crash. Additionally, according to Slootmans (2023), motorcyclists are estimated to be between 9 and 30 times more likely to die in traffic crashes compared to car drivers.

Van den Berghe (2021) stated that an estimated 10 to 15% of all road crashes and 30% of fatal injury crashes directly result from excessive or inappropriate speed. According to researchers Temmerman and Roynar (2016), excessive speed is a prevalent issue among motorcyclists, even more so than car drivers. On roads with speed limits ranging from 50 to 90 km/h, the average free-flow speed of motorcyclists was significantly higher than that of car drivers' speed. (Mannering & Grodsky, 1995) found that 70% of motorcyclists tend to exceed the posted speed limits and intend to repeat such behavior in the future. According to Chorlton et al. (2012), motorcyclists' intention to engage in high-speed riding on rural roads can be explained by a combination of factors, including past behavior, attitudes, control beliefs, age, normative beliefs, anticipated regret, self-identity, behavioral beliefs, and training status.

1.2. Literature background on naturalistic data studies

Naturalistic data are collected in real traffic conditions without interfering with driver or rider behavior, as described by van Schagen and Sagberg (2012). These datasets are typically recorded using various tools, such as cameras (onboard, traffic, etc.) or sensors, according to Dingus et al. (2016) and Silva et al. (2022). Data collection can involve a single instrumented vehicle, as shown by Halim, Sartika, et al. (2025), or multiple vehicles equipped individually, as shown by Khairul Alhapiz Ibrahim et al. (2019). Outay et al. (2023) used a post-driving questionnaire filled out by the participants to deepen the observational data. A recent systematic review by Alam et al. (2023) found that naturalistic data are increasingly utilized for examining a wide range of driver behaviors, including distraction, fatigue, risk perception, and responses to safety-critical events. Further, naturalistic methods have become especially valuable for studying risk-related behaviors, such as speeding, distraction, and sudden maneuvers.

Prior studies by Tselentis et al. (2020) and Tselentis et al. (2021) have shown that smartphone-based platforms can effectively capture safety-related behaviors such as harsh braking, speeding, and phone use in naturalistic settings. Based on six linear regression models, Tselentis et al. (2020) concluded that the most influential factors in determining a driver's average speed are the total distance traveled, the frequency of harsh driving events, and the deceleration rate.

Winkelbauer et al. (2019) utilized naturalistic GPS and sensor data from the UDRIVE project to analyze time headway and following distances under real-world conditions. Their findings showed that motorcycles are typically followed more closely than other vehicles and that headway decreases as speed increases. Balsa-Barreiro et al. (2023) point out that applying GPS mapping is one of the advantages of conducting naturalistic studies.

Aupetit et al. (2015) conducted a naturalistic study of motorcyclists commuting in the Paris region. Using video-equipped motorcycles and follow-up self-confrontation interviews, the authors revealed that perceptual activities play a key role in rider behavior, particularly anticipating risk and efforts to enhance visual conspicuity in dense urban traffic. Naude et al. (2022) showed that motorcycles were more often exposed to medium and high positive acceleration and braking levels, though car drivers tended to brake more intensely overall. Furthermore, Halim, Sartika, et al. (2025) equipped an electric motorcycle with sensors and cameras to collect data about speed, throttle position, brake and horn activation, turn signal usage, and motorcycle tilt.

McCall et al. (2014) examined the influence of environmental conditions on motorcyclist behavior using data from a large-scale naturalistic riding study. Findings revealed that cold temperatures and precipitation significantly impacted rider behavior, notably reducing riding frequency and influencing speed profiles. Furthermore, naturalistic studies can support assessing driving ability affected by aging, according to Knoefel et al. (2018).

Based on the above, naturalistic studies offer valuable insights into real-world driving and riding. While commonly applied to car drivers, their use in motorcycle research remains limited, especially with smartphone-based data. Smartphones provide a low-cost, scalable, and unobtrusive way to record riding metrics such as speed, acceleration, and phone use.

1.3. Paper objectives and contribution

The main objective of this study is to explore how unobtrusively collected smartphone-based data can be used to quantify motorcyclist speeding behavior under real-world traffic conditions. Using continuous metrics (speed, speeding, harsh events, travel time, and distance) and other variables (road type, rider age, weekend/daylight ride) from naturally occurring motorcycle trips, this work provides a data-driven approach to analyzing speed-related riding patterns without experimental influence. The central aim of the study is to explore what influences rider speeding, observed through the percentage of travel time spent above the speed limit. Furthermore, the study relies on driving characteristics and environmental data in relation to speeding, without including personal traits or subjective opinion. The conceptual framework assumes that features such as road type, temporal context, and riding dynamics influence speeding behavior.

This paper makes several contributions to the literature. First, it demonstrates the value of using smartphone applications to gather large-scale behavioral data in a motorcycling context, a relatively underexplored area compared to car driving. Second, the analysis focuses on a log-transformed dependent variable representing the percentage of time spent speeding, allowing for more precise modeling of skewed data distribution. It sets the groundwork for future research incorporating broader contextual and behavioral variables. This research presents a scalable and cost-effective methodological foundation for understanding and eventually influencing risky motorcyclist behavior.

2. Methods

2.1. Participants and data collection

This study uses data from participants' motorcycle trips collected through a smartphone application, TOECAN, developed under the Horizon 2020 i-DREAMS project. Each recorded trip includes GPS traces, average and over speed, acceleration and deceleration events, time-stamped start and end points, and behavioral indicators such as time spent speeding. The data were collected passively, with no instructions or constraints imposed on the participants.

The Ethical Committee of the Faculty of Transport and Traffic Sciences, University of Zagreb, approved the data collection. The research was introduced through public presentations at relevant events and gatherings, as well as mutual invitations between motorcyclists. Participants joined voluntarily, and the inclusion criteria required participants to be of legal age, to hold a valid motorcycle driving license, and to own a mobile phone device compatible with the data collection app. In the *Participant Information Sheet and Consent to Participate in the Research*, participants were informed about the app used, the handling of their data, and data storage. After receiving detailed information about the study, all participants provided informed consent prior to participation. They were invited to install the monitoring application on their smartphones upon consent. The recruitment process did not target specific riding profiles, and participation was open to all eligible individuals, ensuring a degree of randomness and diversity in the sample.

A total of 19 motorcyclists (16 male, 3 female) participated in the data collection. Table 1 shows the basic demographic characteristics of the study participants. The average age of participants was 45.2 years (SD = 12.9), ranging from 18 to 64 years, indicating a fairly broad age distribution. The average number of years holding a motorcycle license was 16.7 years (SD = 13.7). However, at the same time, the wide variance (186.8) and range (1–43 years) indicate that the sample included both novice and highly experienced motorcyclists. These aspects suggest a heterogeneous group regarding riding experience, which supports the generalizability of the findings across different rider profiles. However, we aimed to achieve a distribution of participants that was as similar as possible to the actual population of motorcycle riders in Croatia.

The total amount of recorded rides was 1853 (36,169.3 km) in the 15th March-21st May 2025 period. Based on the proportion of distance traveled in different road contexts, trips were performed as follows: 0% ridden on motorway (n = 1468; 79.2%), 1–50% ridden on motorway (n = 224; 12.1%), and more than 50% of the trip ridden on motorway (n = 161; 8.7%).

Table 1. Participants' description

	N	Min.	Max.	Mean	Std. Dev.	Variance
Participant age	19	18	64	45.19	12.903	166.477
Driving license age (motorcycle)	19	1	43	16.72	13.667	186.785

2.2. Data analysis

The primary outcome variable analyzed in this study was the percentage of riding time spent speeding, computed for each trip as the share of time a rider exceeded the posted speed limit. This measure captures both the prevalence and duration of speeding behavior in a continuous, scalable way. However, the variable displayed a highly right-skewed distribution with a large proportion of zero values, indicating that many trips involved no speeding. A logarithmic transformation (base-10 logarithm) was applied to address this skewness and ensure the assumptions of linear regression were satisfied. This transformation compressed extreme values and normalized the residual distribution, making the outcome suitable for further parametric modeling.

A multiple linear regression model was applied using the log-transformed percentage of riding time spent speeding as the dependent variable (DV) to investigate the factors associated with motorcyclists' speeding behavior. The potential independent variables (IVs) included trip duration and distance, percentage of trip distance driven on motorways, average trip speed, average speed over the limit, number of harsh braking and acceleration events, daylight condition (day/night), and weekend indicator (weekend/no weekend). These variables describe riding characteristics, road context, and temporal perspective.

Before running the regression, multicollinearity was assessed using Variance Inflation Factors (VIF), with 5 as an acceptance threshold. All analyses were conducted in SPSS (version 29.0), using the enter method for regression.

3. Results

3.1. Descriptive statistics of trip characteristics

For this study, 1853 trips (36,169.3 km) were recorded. Table 2 presents cumulative descriptive statistics for continuous variables across all motorcycle trips included in the dataset. The average trip distance was 19.52 km (SD = 34.15), with a skewed distribution, indicated by the wide range (0.5–422.8 km) and a median of only 7.5 km. Trip durations were generally short, averaging 0.35 hours (approximately 21 minutes), with a maximum of 4.35 hours.

On average, 9.96% of trip distances were traveled on motorways, but the median value was 0%, reflecting that most trips did not include motorway segments. The average speed across all trips was 47.78 km/h, while the average speed exceeding the speed limit was 11.79 km/h. Riders spent on average 6.79% of their riding time speeding, with considerable variability (SD = 10.39) and a maximum of 79%, again pointing to a skewed distribution of speeding behavior.

Regarding maneuver intensity, the average number of harsh brakes per trip was 1.68, and harsh accelerations were 1.43. However, both variables exhibited large standard deviations and medians close to 0 or 1, suggesting that a small number of trips accounted for the most extreme behaviors.

Table 2. Cumulative statistics (continuous variables)

Variable	Min.	Max.	Mean	Median	Std. Dev.	Variance
Distance (km)	0.50	422.80	19.52	7.50	34.153	1166.394
Duration (h)	0.02	4.35	0.35	0.24	0.407	0.166

Percentage of trip driven on motorway (%)	0.00	100.00	9.96	0.00	23.165	536.596
Average. speed of the trip (km/h)	15.00	138.00	47.78	43.00	19.190	368.239
Speeding (% of riding time)*	0	79.00	6.79	3.00	10.387	107.896
Average. speed over speed limit (km/h)	0	51.00	11.79	14.00	9.768	95.421
No. of harsh brakes	0	27.00	1.68	1.00	2.552	6.513
No. of harsh accelerations	0	36.00	1.43	0.00	3.762	14.150

* Dependent variable.

Table 3 presents the distribution of the categorical variables included in the analysis. Most trips (95%) were completed during daylight, indicating a strong daytime riding pattern among participants. Additionally, 37.7% of trips occurred during the weekend, suggesting that a considerable proportion of riding was leisure-related or outside weekday commuting hours. These distributions provide important context for understanding the temporal characteristics of the sample and may influence riding behavior.

Table 3. Cumulative statistics (categorical variables)

Variable		Frequency	Percent	Variable		Frequency	Percent
Daylight	No	92	5.0	Weekend	No	1154	62.3
	Yes	1761	95.0		Yes	699	37.7

3.2. Explaining speeding behavior using linear regression

In order to quantify the factors contributing to speeding behavior, a linear regression model was developed. All variables from Table 2 and Table 3 were considered potential predictors in observing speeding behavior. However, a high degree of multicollinearity was identified between distance and duration (Pearson's $r = 0.940$), and the VIF for distance exceeded 10 in preliminary models. To reduce redundancy and maintain model stability, trip distance was excluded, and duration was retained as an exposure variable. Furthermore, the VIF value for average speed (km/h) exceeded 5; therefore, it was excluded from further analysis.

The final model included trip duration (h), percentage of trip distance on motorways (%), average speed over the limit (km/h), number of harsh braking and acceleration events, daylight indicator, and weekend indicator. All VIFs were well below the conventional threshold of 5, indicating no multicollinearity concerns.

The multiple linear regression model aimed to explain the natural logarithm of the percentage of riding time spent speeding (DV) based on several trip-level independent variables. The model was statistically significant ($F(7, 1845) = 684.35$, $p < 0.001$), indicating that the included predictors collectively explained a substantial proportion of the variance in the dependent variable. The model yielded an R^2 of 0.722, with an adjusted R^2 of 0.721, suggesting that the included variables accounted for approximately 72.1% of the variance.

The standard error of the estimate was 0.281, indicating a relatively good model fit given the log-transformation of the dependent variable. These findings reflect a robust model and confirm that the selected variables are jointly informative for understanding variation in speeding behavior.

Table 4 presents the multiple linear regression model's independent variables' coefficients. To support the interpretation of the results, the unstandardized regression coefficients from the log-transformed model were converted into approximate percentage changes in the original dependent variable. Given that the dependent variable was transformed using a base-10 logarithm, the transformation $(10^B - 1) \times 100$ was applied. This estimates the relative change in the percentage of riding time spent speeding for a one-unit increase in each predictor, shown in the last column in Table 4.

The results show that the average speed over the speed limit had the most substantial effect. Each additional kilometer per hour over the limit was associated with a 10.9% increase in the percentage of riding time spent speeding.

Additionally, each harsh acceleration was associated with an estimated 2.3% increase in speeding time, indicating that aggressive throttle behavior is closely linked to prolonged speeding. The percentage of trip distance driven on motorways showed a small but significant negative effect, with every 1-percentage-point increase associated with a 0.2% decrease in speeding duration.

Table 4. Regression coefficients

Independent variable	B	Std. Error	Beta	Sig.	VIF	Approx. % change in DV (original scale)
(Constant)	0.027	0.031		0.382		
Duration (h)	-0.015	0.021	-0.011	0.478	1.712	-3.4
Percentage of trip driven on motorway (%)	-0.001	0	-0.047	**0.003**	1.627	**-0.2**
Average. speed over speed limit (km/h)	0.045	0.001	0.832	**<0.001**	1.454	**10.9**
No. of harsh brakes	0.001	0.004	0.003	0.869	2.143	0.2
No. of harsh accelerations	0.010	0.002	0.068	**<0.001**	2.034	**2.3**
Daylight	0.002	0.03	0.001	0.952	1.002	0.5
Weekend	0.020	0.014	0.018	0.140	1.022	4.7

4. Discussion

4.1. Interpretation of key findings

Among the predictors, average speed over the speed limit emerged as the most influential variable ($B = 0.045$, $p < 0.001$), with a standardized coefficient ($\beta = 0.832$), indicating that higher overspeeding levels are strongly associated with greater speeding duration. This is consistent with an earlier study by Ferko et al. (2024), stating that higher speed limits are associated with a reduced likelihood of speeding.

The percentage of trip distance traveled on motorways was negatively associated with speeding ($B = -0.001$, $p = 0.003$), suggesting that motorway riding tends to reduce the time spent speeding, potentially reflecting stricter enforcement, safer infrastructure, or more consistent traffic flow on motorways. This can further be related to the research by Abdul Manan et al. (2017), indicating that motorcyclists are significantly more likely to ride at excessive speeds on roads without shoulders than on those with shoulders. Additionally, primary roads had nearly five times greater odds of motorcyclists exceeding the 85th percentile speed than expressways. According to Seefong et al. (2024), when the road design appears safe, riders may become more confident in their ability to manage higher speeds, which can encourage risk-taking behaviors like excessive speeding.

The number of harsh acceleration events was a significant positive predictor ($B = 0.010$, $p < 0.001$), indicating that trips with more aggressive acceleration are also characterized by greater speeding. In a similar study conducted by Kontaxi et al. (2021), statistically significant variables on the percentage of time spent speeding were trip duration, distance driven during risky hours, morning peak hours, and the number of harsh accelerations.

From the above, it can be concluded that speed control and management are of greater importance on rural roads (outside urban areas) that provide opportunities for "go-for-it" riding, with relatively low speed limits, but also with low traffic. Broughton et al. (2009) confirmed that motorcycle riders are more likely to speed on rural roads, and speeding is also more likely in the daytime. Other potential predictors in this study (trip duration, number of harsh brakes, daylight conditions, and weekend trips) did not significantly contribute to explaining the variance in speeding ($p > 0.05$).

These effects highlight that both the amount of overspeeding and aggressive acceleration patterns are key contributors to extended periods of speeding, while motorway riding (potentially due to more stable speed environments and stricter enforcement, as well as high effect of other traffic and higher speed limits) has a modest mitigating influence.

4.2. Study's limitations and future research implications

This study provides novel insights into motorcyclist safety research, but several limitations should be acknowledged. The sample comprised 19 riders, which limits generalizability and statistical power, particularly for subgroup analysis. Nevertheless, despite a relatively small sample of riders, the study includes over 1800 trips (36,169.3 km), offering robust insight into naturalistic motorcycle riding behavior. Moreover, as participation was voluntary, it is possible that the participants were generally more safety-conscious and aware of road safety, for themselves and other road users, which may have also motivated them to participate in the study. This self-selection bias could mean the findings underestimate riskier behaviors in the broader riding population.

Additionally, rides were analyzed collectively rather than stratified by individual or rider subgroups, which limits the ability to identify within-participant patterns or differences across distinct behavioral profiles. The assumption of potential differences between groups of motorcyclists is in line with the conclusions by Eyssartier et al. (2017). Vehicle characteristics were also not available in the dataset; including factors such as engine power, motorcycle type, or safety features could have yielded further behavioral insights. Furthermore, contextual variables such as weather, traffic density, road geometry, or enforcement presence were not captured, all of which may influence speeding behavior.

Despite these limitations, this study represents a promising starting point for this behavioral traffic safety research type. Future analyses will benefit from resolving these limitations and incorporating additional variables such as ride-scoring metrics, mobile phone use during riding, and geographic context. Broadening the research will allow a more nuanced and comprehensive understanding of motorcyclist behavior in real-world traffic environments.

5. Conclusions

This study explored speeding among motorcyclists using smartphone-based naturalistic data, offering an innovative, minimally intrusive approach to understanding real-world riding dynamics. Using log-transformed speeding duration as the dependent variable allowed for better modeling of right-skewed data distribution and yielded a robust linear regression model with high explanatory power (adjusted $R^2 = 0.721$).

The results confirmed that average speed over the posted limit is the most influential predictor of speeding duration, followed by acceleration intensity. Furthermore, riders who rode more of their trips on motorways tended to spend less time speeding, suggesting that infrastructure type and traffic flow speed may moderate speeding behavior. Other predictors, such as trip duration, daylight, and weekend travel, showed non-significant effects.

From a practical standpoint, these findings provide an empirical basis for developing targeted behavioral feedback in smartphone-based safety applications. For example, by monitoring acceleration and over-speed metrics in real time, digital tools could offer riders actionable feedback to reduce risky behaviors. Additionally, the study supports the potential of leveraging mobile technologies for large-scale, low-cost road safety monitoring.

Despite its limitations, this study marks an important step toward integrating digital behavioral data into road safety research. As smartphone technologies and data processing capabilities continue to advance, the approach used here could be scaled and refined to support evidence-based interventions to improve motorcyclist safety.

Acknowledgements

This work has been funded by the European Union's Horizon Europe Coordination and Support Actions TWIN-SAFE project under grant agreement No 101159114. Also, the study was supported by the Special Research Fund (BOF) of Hasselt University with the BOF number "BOF21BL03".

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