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Transport Research Arena (TRA) Conference

Real use of vehicle dynamic capacities: Motorcyclists versus motorists

Claire Naude^{a,*}, Christophe Perrin^a, Thierry Serre^a

^aTS2 – LMA, Univ. Gustave Eiffel, 304 chemin de la Croix Blanche, Salon de Provence, 13300, France

Abstract

The risk of serious crashes is much higher for motorcyclists than for motorists, yet there is a lack of knowledge about their behavior and performance on the road. This paper aims to compare the actual use of PTWs' dynamic capacities to that of passenger cars, based on objective data collected during three naturalistic driving/riding studies conducted in France between 2012 and 2018. Motorcyclists accelerate and brake more often and with greater intensity. PTWs endure medium to high yaw rates slightly more often than cars, and sometimes reached very high levels never endured by cars. The comparison of speeds is more contrasted and does not confirm the common belief that motorcyclists often ride faster than motorists drive.

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Keywords: car, motorcycle; vehicle dynamics; road safety; driver behavior; naturalistic driving

1. Introduction

In France, users of Powered Two Wheelers (PTW) are less than 2% of the traffic but, in accidents, they represent 23% of fatalities, 34% of serious injuries and 23% of slightly injured, according to ONISR (2020). Furthermore, the decrease in fatalities in crashes involving cars continues or stagnates, while there is an increase in motorcycle mortality. It could be explained by the increase in PTW traffic, by their higher vulnerability in case of crash but also by a variety of factors related to the rider's behavior, skills and interactions with other road users. Overall, the high risk of severe accident occurrence raises the need for further research. Yet current research on PTW safety is not as extensive as for other road users like passenger cars or other vulnerable users (pedestrians, bikers...), as showed Theofilatos and Yannis (2014).

* Corresponding author. Tel.: +33-490568624 ; fax: +33-490568618 .

E-mail address: claire.naude@univ-eiffel.fr

Studies based on accident reports are of major interest in motorcycle safety but are not sufficient both in terms of qualitative and quantitative data. The behavioral considerations, the risk and severity issues require PTW safety data that are more complete than accident reports. As pointed by OECD/ITF (2015), there is a need to extend the knowledge on PTW mobility and crash mechanisms and to analyze the rider's behavior by accessing exposure data. It could allow a better understanding of fatal and injury crash patterns and causes. Especially for critical pre-crash phase, data such as braking and handling are crucial but extremely difficult to be massively collected on motorcycles. A few studies use naturalistic riding data, such as the work on the detection of PTW incidents by Vlahogianni et al. (2014) and the study on the cognitive compatibility of motorcyclists and car drivers by Walker et al. (2011). On the contrary, approaches using Naturalistic Driving Studies are commonly used to get a better understanding of car crash mechanisms and to improve road safety, as did Dingus et al. (2006), Wu et al. (2014) and Naude et al., (2017a). There are no comparable studies for PTW observing their real behavior objectively measured and compared to passenger cars.

This paper aims to compare the actual use of PTW's dynamic capacities to the one of passenger cars. The analysis is based on three Naturalistic Driving Studies (NDS) or Naturalistic Riding Studies (NRS) conducted in France with cars and/or motorcycles. The vehicles were equipped with specific Event Data Recorders, which integrate an algorithm enabling the real time collection of "synthesis data". These syntheses are used to get the distribution of accelerations, rotation rates and speeds, which are characteristic of the use of dynamic performances for driver-car and rider-motorcycle pairs. First, the dynamic parameters are compared in terms of time spent with medium or high demands, in longitudinal direction (accelerations / braking) and in lateral direction (cornering). Then the comparison focuses on the highest values reached at least once by the vehicles. Finally, the levels of speed are compared, which was never done at this scale at least in France. It is commonly admitted that the PTW speeds are higher than passenger car speeds. Perco (2008) has shown that the difference is considerable in a free-flow urban area in Italy. A study of Temmerman and Roynard (2016) conducted in Belgium revealed that the average free speed of motorcyclists on 50 to 90 km/h roads was significantly higher than that of car drivers. This paper will compare motorcyclist and car driver levels of speed in the three experiments to confirm or challenge these results.

2. Material and methods

2.1. Experiments

In all three experiments, all the legal conditions to implement EDR in French public fleets of vehicles were respected, in accordance to the prescriptions of the CNIL (French administrative authority protecting privacy and personal data), integrating European regulations and respect of Human Rights, as specified in Guilbot et al. (2016).

2.1.1. SVRAI NDS with cars

The first data used in this study come from the SVRAI project (Saving Lives through Road Incident Analysis Feedback). Specific Event Data Recorders (EDRs) implemented in 46 light vehicles of five public fleets located in three different regions of France acquired data during 12 months (2012-2013, see Fig. 1). All were company vehicles dedicated or not to one person. 221 drivers volunteered to take part in the experiment and could potentially drive the cars. The device described by Lechner and Naude (2011) was designed for the purpose of detecting some critical driving situations, called incidents, in which a vehicle faces high dynamics demands in the longitudinal, lateral or combined directions, as well as potential accidents. It is fixed under the driver seat and continuously acquires analog data from sensors directly integrated into the EDR (3 axis accelerometers and gyro meters for naturalistic driving, and 2 axis accelerometers for crashes), data provided by a GPS (trajectory and speed), and data available on the vehicle on-board diagnosis system (CAN bus, information depending on the car model). To get more information about this project see Naude et al. (2017b). The data exploited in this paper concern about 106 000 km travelled by 46 cars with a great variety of roads from highways to rural roads and urban areas.

2.1.2. DYMOA NRS with motorcycles and cars

In 2014-2017, a new project called DYMOA (Infrastructure Diagnosis and Vehicle Dynamics for Motorcycles and Cars) was carried out to acquire Naturalistic Riding Data, in order to obtain knowledge about the vehicle dynamics of PTW and the use of road infrastructures by riders. 26 private motorcycles and 5 passenger cars were implemented with smartphones used as Event Data Recorders (EDR), fixed under the driver seat. In three regions of France (see Fig. 1), during 18 months, the devices continuously collected data on riding, on driving behavior and on maneuvers performed by the riders and drivers. The measurements come from the smartphone's accelerometers, gyro meters, and GPS. Trajectories and syntheses of dynamic parameters were collected in real time for all their professional and personal travels. To get more information about this project see Naude et al. (2018, 2019). From the experiment, 15000 km in cars and 83700 km in PTW were exploited.

2.1.3. MOSCOVICE NRS with motorcycles

In the framework of a PhD thesis by Tamisier (2017) that measured the effectiveness of different communication methods on actual speed reduction by riders, about 40 motorcycles were equipped with the same device as in DYMOA. The data collection was carried out in two regions of France and lasted 3 months; only work commutes were recorded. The dynamic behavior of the couple rider-PTW was collected thanks to the same algorithm as DYMOA, described in the next section. More information about this experiment is available in Cornen et al. (2019). The study presented here exploits the data of 29 riders having travelled about 25500 km.

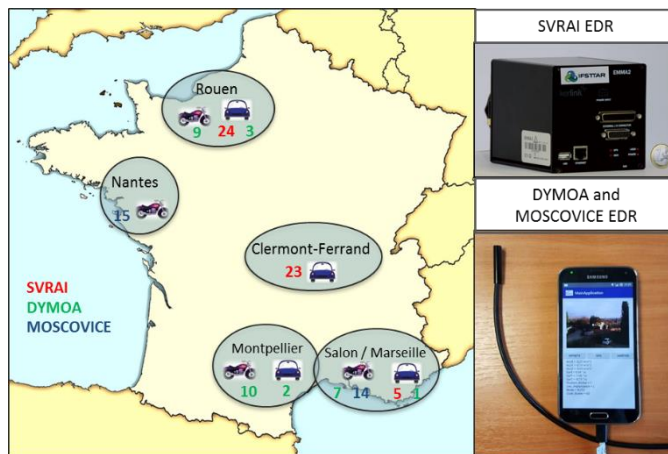


Fig. 1. Geographical breakdown of equipped vehicles in France (Left) – Event Data Recorders (Right).

Table 1 summarizes the main characteristics of the three experiments and the four fleets of vehicles, which were compared in this work.

Table 1. Main characteristics of experiments.

Project	SVRAI	DYMOA	DYMOA	MOSCOVICE
Type	Cars	Cars	PTWs	PTWs
Number of vehicles	46	5	26	29
Drivers/riders	max 221	5	26	29
Duration	12 months	12 months	18 months	3 months
Distance (km)	106 000	15 000	83 700	25 500
Color in Figures	red	orange	dark blue	light blue

2.2. Travel synthesis data

The syntheses are based on the principle of the “friction circle”, developed by Lechner and Perrin (1993), whose experiment with cars aimed at acquiring knowledge on the behavior of the couple driver-vehicle in usual driving situations. For cars, the syntheses aggregate the time spent in every longitudinal and lateral combination of dynamic demands, also considering the speed, data being stored in matrices as explained in Naude et al (2017b). This concept was transposed for motorcycles using the roll or yaw rate instead of the lateral acceleration to consider the specific behavior of PTWs. This kind of data provides different levels of knowledge about the use of dynamic capacities of the vehicle and allows a comparison between motorcycles and cars. Accelerations and rotation rates are counted by intervals of 1 m/s^2 and $10^\circ/\text{s}$, the speed by 5 km/h . The main parameters of the vehicle dynamics are compared in terms of time spent beyond the usual values and considering the exploration of extreme values:

- Levels of longitudinal acceleration (accelerations and braking for PTWs and cars)
- Levels of lateral acceleration (cornering for cars)
- Levels of roll rate (speed of leaning mainly for PTWs)
- Levels of yaw rate (speed of rotating around the vertical axis for PTWs and cars),
- Levels of speed for PTWs and cars.

The measured signals were filtered before the synthesis algorithm was applied, especially accelerations, which noise depends on the type of vehicle. The demand distributions were established by excluding the periods spent below 5 km/h , for the sake of homogeneity between the experiments and to avoid considering dynamic demands at standstill.

3. Results

3.1. 3.1. Levels of accelerations and rotation rates

Travel syntheses provide information at different levels. The spectre of each vehicle dynamics' parameter tells us the distribution of time spent in low and high demands, in longitudinal direction (accelerations / braking) as well as in lateral direction (cornering). These distributions can be compared between cars and motorcycles. The four fleets of equipped vehicles, two with cars and two with motorcycles, are compared in Fig. 2. Times spent in acceleration levels beyond 2, 3 and 4 m/s^2 were calculated as a percentage of the total time of all journeys considered. The same analysis is made for rotation rate levels beyond 10, 20 and $30^\circ/\text{s}$.

The longitudinal behavior can be directly compared between cars and motorcycles. Concerning positive accelerations, both PTW fleets are beyond 2 m/s^2 about three times more often than both car fleets. The cars are very rarely beyond 3 m/s^2 , less than 0.2% of the time, whereas PTWs accelerate around 1.3% of the time with such values. When it comes to values beyond 4 m/s^2 , there is almost never any acceleration by car drivers, whereas motorcyclists accelerate from 0.3 to 0.5% of the time. The difference between cars and motorcycles in levels of braking goes in the same direction but is less marked: the motorcyclists perform braking maneuvers 3.5% of the time beyond 2 m/s^2 against 1.7 to 2.6% for car drivers. It can be noticed that when it comes to cars there is more time spent in braking above 3 m/s^2 than there is in acceleration. On the contrary, PTWs brake less than they accelerate. It can be explained by cars limited capacities of acceleration compared to those of motorcycles.

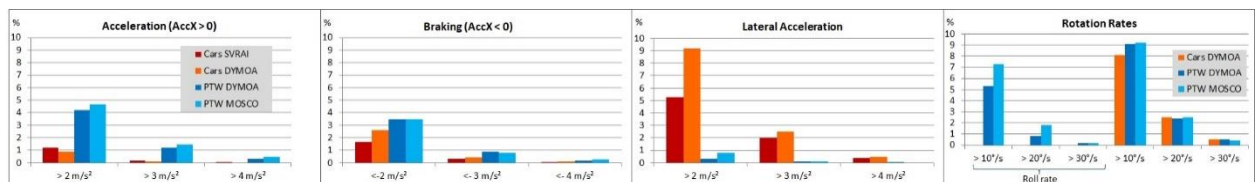


Fig. 2. Comparison of accelerations and rotation rates between cars and PTW in 3 experiments (Percentages of time spent).

The lateral dynamic performances are more delicate to compare since the PTW behavior in cornering differs considerably from the car behavior. The motorcyclist leans with his motorcycle, which implies at first glance that he endures little to no lateral acceleration in the motorcycle coordinate system. The lateral acceleration is more

representative of the lateral behavior of the cars and the roll rate is more accurate to measure the lateral behavior of motorcycles. The yaw rate represents for both types of vehicle a clear measure of cornering and its comparison is more relevant.

As expected, there is nearly no lateral acceleration for the PTWs, whereas the cars lateral accelerations exceed 2 m/s² from 5.3% to 6.7% of the time and 3 m/s² about 2% of the time. The cars reach lateral accelerations of 4 m/s² and more around 0.4% of the time, which is rare but way higher than what is observed for PTWs. The roll and yaw rates were compared only for DYMOA and MOSCOVICE, since this data was not available for SVRAI. In fact, the roll rate is always below 10°/s for cars, whereas it exceeds this value from 5.3% to 7.3% of the time for motorcycles. The high levels of roll rate are rare since the PTWs spend less than 2% of the time beyond 20°/s and only 0.2% beyond 30°/s. The high levels of yaw rate are present for cars and motorcycles, which seems logical because when cornering, both vehicles turn (more or less) around their vertical axis. There is more time spent beyond 10°/s for PTWs than there is for cars (9.1% vs 8%), but the times spent beyond 3°/s and 4°/s are more or less similar for both types of vehicle.

3.2. Extreme values of accelerations and rotation rates

The crossings of dynamic parameters in two dimensions highlight the maximal extended area of the dynamic demands endured at least once by a vehicle during its travel, especially the extreme values reached. Fig. 3 presents the following crossings for DYMOA (cars and PTWs) and MOSCOVICE (PTWs) for the whole data sets:

- The crossing between longitudinal and lateral accelerations, which is more representative of the car dynamic performances
- The crossing between longitudinal acceleration and roll rate, which is more appropriate for PTWs
- The crossing between longitudinal acceleration and yaw rate, which is more relevant to show differences between both types of vehicle.

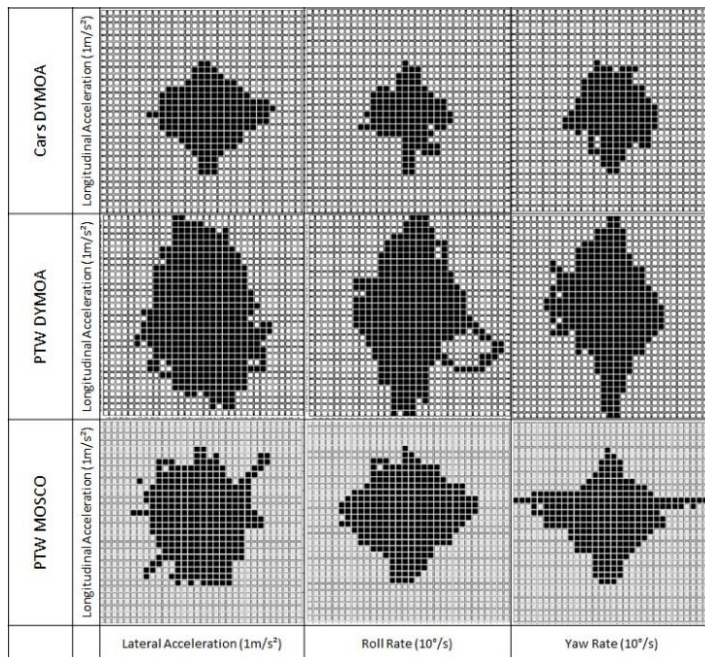


Fig. 3. Comparison of extreme accelerations and rotation rates between cars and PTW in 2 experiments.

The intervals considered are 1 m/s² for accelerations and 10°/s for the roll rate and the yaw rates; the ranges are +/- 15 m/s² for accelerations and +/- 150°/s for rotation rates with a last category for values beyond these limits. The SVRAI data does not allow drawing such graphs, because the limits for accelerations were only +/- 11 m/s² versus +/- 15 m/s²

and the roll and yaw rates were not counted in the syntheses. For all three types of crossing, there is a lower extent of synthesis in the vertical direction, corresponding to longitudinal acceleration, for cars compared to PTWs. It expresses lower longitudinal accelerations, i.e. lower braking maneuvers and accelerations. The most extreme levels of acceleration and braking were achieved by the DYMOA motorcyclists. As expected the extent of roll rate is higher in PTW whereas for cars the extent of lateral acceleration is higher. For the crossing with the yaw rate, extreme values are also reached by PTWs, representative of a more intense use of the vehicle dynamic capacities.

This use of the dynamic capacities by the vehicles can be quantified by an indicator calculated as the ratio between the number of black squares and the total number of possible squares. Table 2 shows the values of this indicator as percentages, for the three crossings and the three fleets of vehicles. In the DYMOA experiment, the PTWs values are 2 to 3 times the cars values. For MOSCOVICE PTWs the difference is lower but also significant: their indicators are 1.6 to 2.2 times higher. It can be noticed that this difference also exists in the crossing between longitudinal and lateral accelerations, which is relevant for cars dynamics. It should be pointed out that the highest values of longitudinal acceleration for PTWs influence the three indicators. Nevertheless, the third rate is also influenced by the higher yaw rates of PTWs compared to cars.

Table 2. Quantification of the real use of extreme dynamic parameters by PTWs and Cars. (Values in parenthesis are given for information but have to be compared with care due to the difference in dynamic behavior between cars and PTW).

Fleet	DYMOA Cars	DYMOA PTWs	MOSCOVICE PTWs
Longitudinal Acceleration X Lateral Acceleration	17.1 %	(40.5 %)	(28.1 %)
Longitudinal Acceleration X Roll Rate	(12.0 %)	35.8 %	26.1 %
Longitudinal Acceleration X Yaw Rate	15.0 %	29.3 %	23.9 %

In addition, the distance travelled by cars in the DYMOA experiment is clearly lower than those of PTWs in both experiments, and the vehicles had fewer occasions to explore the extremes even once. Unfortunately, these indicators could not be calculated for the SVRAI experiment with more cars, because only the first crossing was computed at the time, and with a lower range of measurement: from -11 m/s^2 to $+11 \text{ m/s}^2$ whereas in DYMOA and MOSCOVICE it was from -15 to $+15 \text{ m/s}^2$. The difference between the uses of dynamic capacities between the two PTW experiments could be explained by the fact that in MOSCOVICE the commutes were the only journeys taken into consideration, thus less varied than journeys in DYMOA.

Considering the higher levels of use of longitudinal and lateral dynamic capacities for PTWs, it became necessary and relevant to explore the differences in speed between cars and PTWs.

3.3. Levels of speed

The comparison was done first for the DYMOA and MOSCOVICE data with similar format. Concerning the speed distributions, the interval is 5 km/h and the range 0-150 km/h, with a category “superior to 150 km/h”, whereas for the SVRAI speed data the interval is 10 km/h and the range 0-130 km/h with a last category “superior to 130 km/h”. Fig 4 (Left) shows the time spent in different levels of speed for all cars and all PTWs in these experiments, as percentage of the total time. To make the comparison easier, the first interval 0-5 km/h was not represented. It would be the highest category in terms of time spent, due to the fact that the vehicles are often at rest during their journeys.

The first observation is about PTWs: there is a big difference between the two experiments. The motorcyclists in MOSCOVICE ride faster than in DYMOA. They spend less time under 70 km/h than they do beyond. It could be explained by the fact that the MOSCOVICE experiment took place from May to July, when the weather is favorable for high speeds, whereas the DYMOA experiment lasted one year, including wintertime. Furthermore, in DYMOA they drove in different geographic areas including the region of Rouen, which is colder than the South of France and Nantes.

Despite this difference, both motorcycles specters of speed are similarly different from the cars speed distribution. Car drivers drive clearly more often under 30 km/h and under 90 km/h than riders, which corresponds to the French speed limits in some urban areas and on national and regional roads. The most common 50 km/h speed limit in towns does not appear in the same way: motorcyclists spend more time between 30 and 70 km/h than car drivers, who are

forced to stay in the traffic. The motorcyclists drive more often between 90 km/h and 115 km/h than drivers, but it is the opposite between 115 and 130 km/h. There again the car drivers are more often under the speed limit of 130 km/h on highways than riders. However, it is noticeable that time spent between 135 and 145 km/h is higher for cars than for motorcycles. Beyond 150 km/h, there are only riders, with a percentage going from 0.4 to 1% of their time. Overall, the motorcyclists’ speed is higher than the car drivers’ speed but the distribution is not as definite as we could expect.

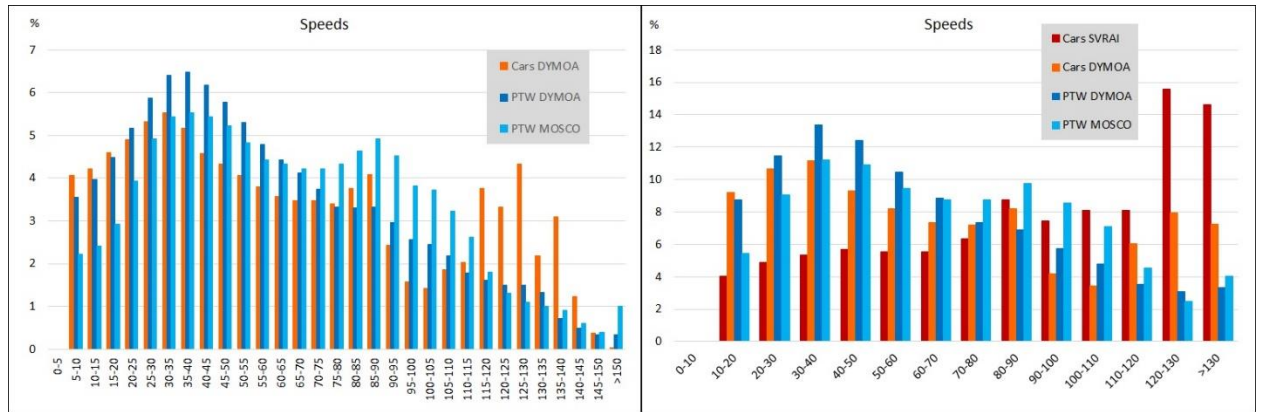


Fig. 4. Comparison of speeds between cars and PTW in 2 (Left) or 3 experiments (Right).

As in DYMOA, the distance travelled and the number of cars is low, the comparison was also done with SVRAI data (Fig. 4, Right) but with 10 km/h-intervals and up to the category “above 130 km/h”. The analysis is less discriminating but is more representative of the car speeds. SVRAI drivers speed data contradicts DYMOA under 30 km/h and between 90 and 120 km/h. SVRAI motorists drive faster: there are less often below 90 km/h than DYMOA motorists, and even less often than motorcyclists under 80 km/h, and again between 100 and 120 km/h. Over 120 km/h, they spent even more time than DYMOA drivers who were already above motorcyclists. The SVRAI experiment lasted one year in three different regions of France, so it is comparable with DYMOA. However, the roads on which the vehicles travelled were probably different, with cars travelling more on motorway.

4. Conclusion

The real use of vehicle dynamic capacities by riders and drivers were compared using data from three NDS or NRS experiments conducted in France. The distributions of accelerations, roll rate, yaw rate and speeds are quite different between the two types of vehicle.

The levels of positive acceleration are clearly higher for motorcycles than for cars in terms of time spent in medium and high levels and in terms of extreme values reached. The motorcycles also brake more often and with a higher intensity, but the difference is less marked with car drivers. Overall, the drivers brake more intensely than they accelerate. On the contrary, motorcyclists accelerate more than they brake, due to the capacities of their vehicle. Whereas it is more difficult to compare the lateral dynamic behavior between cars and PTWs, the analysis of the lateral acceleration, of the roll rate and of the yaw rate provides some interesting results. As expected there is nearly no lateral acceleration in motorcycle, and nearly no roll rate in car. The levels of yaw rate are more comparable between both types of vehicle. The PTWs endure medium or high yaw rate values slightly more often than cars, but they sometimes reach very high values never endured by cars.

The comparison of speeds is more contrasted and does not confirm the common misconception that motorcyclists always ride faster than drivers do. The final analysis with a 5 km/h interval and a range of 0-150 km/h shows that the motorcyclists’ speed is higher than the car drivers’ speed. However, this result is only observed within a little fleet of equipped cars. The comparison was possible with a wider fleet of cars but with less precision, an interval of 10 km/h and a range of 0-130 km/h. These car drivers went faster than motorcyclists and spent more time beyond 120 km/h in

particular. Moreover, the levels of speed do not alone explain the higher levels of accelerations and rotation rates observed. The motorcyclists' behavior not necessary linked to high speeds, may contribute to their high road mortality.

New experiments are underway in other French departments with 15 to 25 equipped cars recording equivalent natural driving data. The results will complete the car part of the study.

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