Motorcyclists' Real Use of Vehicle Dynamics

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ABSTRACT

The abnormally high mortality rate of Powered Two-Wheelers (PTW) is probably related to their vulnerability, but also to their behavior and interactions with other road users. There is a need to collect exposure data on PTWs to better understand uses and determinants involved in the mechanisms of accidents since there are almost no naturalistic studies on motorcyclists as on motorists. This paper aims to characterize the actual use dynamic capabilities of PTWs by motorcyclists through objective measures. In 2016-2018, an experiment was carried out to acquire Naturalistic Riding Data from 26 private motorcycles implemented with an Event Data Recorder. For 18 months, in three regions of France, the devices collected aggregated data on each ride thanks to accelerometers and gyrometers, and continuous speeds and trajectories, thanks to GPS. This paper presents the global distributions of accelerations, rotation rates and speed, and the extreme values reached at least once. It also illustrates the variability of behaviors: smooth driving versus sporty driving. 6500 travels were exploited, representing 88000 km. The motorcyclists endure rarely high levels of dynamic demands; especially in acceleration and deceleration, they exceed +-4 m/s² only 0.5% of the time. As far as cornering is concerned, their roll rate exceeds 20°/s only 0.8% and their yaw rate 2.1% of the time. Excluding time spent at standstill or at very low speed (less than 5 km/h), motorcyclists spend 80% of their time below 90 km/h and 3.2% of the time above 130 km/h, with 0.3% of the time above 150 km/h. The behavior varies greatly from one motorcyclist to another, even on the same itineraries. These data characterize the dynamics of motorcycles and discriminate different behaviors of riders.

INTRODUCTION

Accident risk and severity are significantly higher for Powered Two-Wheelers (PTW) riders than for other motorized road users. In 2019, motorcyclists accounted for 18% of road fatalities in Europe [1], although they represent less than 2% of traffic. Several studies on the causes of accidents show that the most common cause is human behavior. For example, Singh [2] reports that in the National Motor Vehicle Accident Causation Survey conducted in the United States between 2005 and 2007, in a sample of 5,470 accidents, the primary reason was attributed to the driver in 94% of cases. Studies of natural driving appear to be essential for a better understanding of accident mechanisms and for improving the safety of road infrastructure ([3], [4], [5]). To date, such studies are rare for motorcyclists.

The aim of this study is to update the data on the use of dynamic capacities of a motorbike thanks to the contribution of new data on exposure during natural driving. The data was acquired using a specific algorithm implemented in road data recorders (EDR) installed in a fleet of private motorcycles. The real-time collection of such data allows to establish the global distribution of speeds, accelerations and rotation rates, which are characteristic of the dynamics of the motorcyclist-motorcycle duo. The dynamic parameters are first analysed in terms of time spent with medium or high loads, in the longitudinal direction (acceleration/braking) and in the lateral direction (cornering). The analysis then focuses on the highest values reached at least once by the riders. The overall dynamic behaviour of the entire fleet is analysed as well as the driving behaviour of individuals is compared (calm/sporty driving). Then, a specific route driven several times by two motorcyclists is presented, where the differences in the dynamic parameters are due to the different longitudinal and lateral behaviours.

MATERIAL AND METHODS

Observational data were collected using on-board recorders on 26 private motorcycles over an 18-month period in three regions of France. This study focused on aggregate data provided for all trips, which crosses accelerometric and gyrometric data as well as speed levels. Approximately 6,500 trips could be analysed, in correspondence with the GPS trajectories, which make it possible to calculate the distances travelled. The overall distance covered during these trips is approximately 88,000 km.

The principle of this synthesis data comes from work on cars based on the concept of the friction circle [6] and presented in detail in [7,8]. The data is not stored as a function of time, but as matrices, aggregating the time spent in a combination of two given loads. For cars the longitudinal and lateral accelerations are considered with intervals of 1 m/s². For PTW, as the lateral acceleration in the motorcycle reference frame is near zero due to the particular dynamics of this vehicle, which leans during cornering, other parameters were used to translate the lateral dynamics, in particular the roll and yaw rates, with intervals of 10°/s. The raw accelerations are acquired at a frequency of 100 Hz and are noisier for a PTW than for a car. Therefore, filtering was applied in real time using a 30-point rolling average.

RESULTS

General data

The general characteristics of the trips are summarized in Table 1. The 26 motorcyclists completed an average of 249 trips. The minimum number of trips is 21 and the maximum 1068. They travelled between 309 and 9063 km, with an average of 3220 km per rider. The average trip distance is 13 km for all 6469 trips. The average trip distance for each rider is 18 km, but this average varies between 4 and 51 km between riders.

	All	Average per motorcyclist	Standard deviation	Minimum	Maximum
Number of trips	6469	249	190	21	1068
Total distance (km)	83714	3220	1841	309	9063
Average distance per trip (km)	13	18	8	4	51

Table 1: Trip and rider statistics

The 6469 trip trajectories considered in this study are shown in Figure 1. The road networks used are varied, with urban, suburban and rural areas.

Figure 1: Trip trajectories with focus on the Normandy-Centre Department, and the cities of Montpellier and Marseille

Speed levels

Overall, the motorcyclists spend 22% of their time at a standstill or at very low speeds. The distribution of speed levels was done by removing the lowest speed level, 0-5 km/h, to better see the distribution at higher speeds (Figure 2). Excluding the time spent below 5 km/h, motorcyclists spend 80% of their time below 90 km/h and 3.2% of the time above 130 km/h, with only 0.3% of the time above 150 km/h.

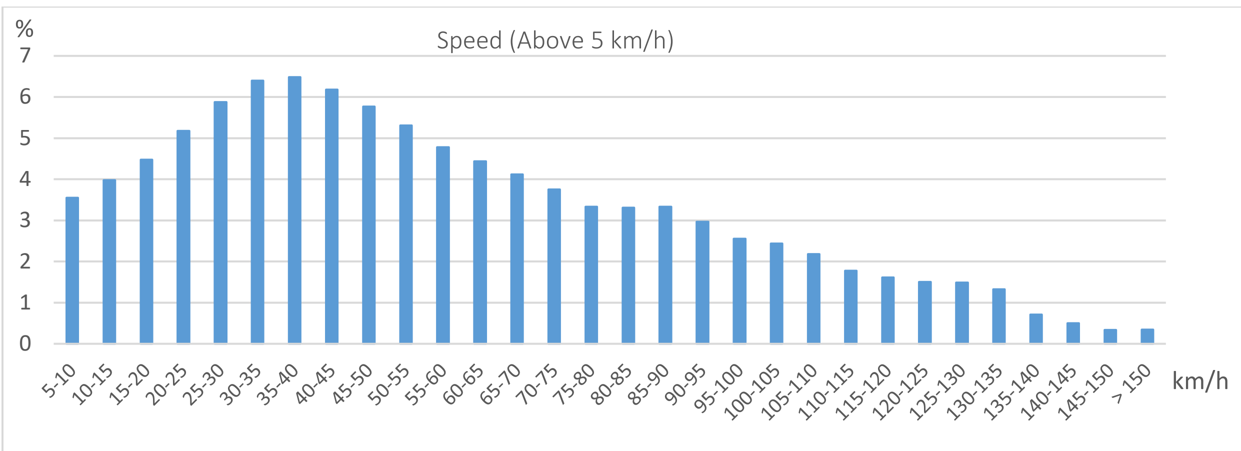

Figure 2: Global distribution of speeds in time spent above 5 km/h

These overall speed distributions must be balanced according to the road environment.

Accelerations and rotation rates

The acceleration distributions are shown in Figure 3 (top) for all trips. When braking, i.e., for negative longitudinal accelerations, motorcyclists are 8.5% of the time between -2 and -1 m/s². Below -2 m/s², the time spent braking is only 2.8% of which only 2.1% between -2 and -3 m/s² and 0.5% between -3 and -4 m/s². The percentage of time spent above -4 m/s² is only 0.2%. Motorcyclists are more often in positive acceleration, between 1 and 2 m/s² (9.2%) and between 2 and 3 m/s² (2.8%), between 3 and 4 m/s² (0.8%) and even beyond 4 m/s² (0.3%).

As expected given the vehicle dynamics specific to a PTW, there is almost never a lateral acceleration higher than 1 m/s². On the other hand, there are negative lateral accelerations between -1 and -4 m/s², 8.5% of the time, which are probably linked to the stopping phases of the PTW leaning on its stand. Specific tests were carried out to verify this hypothesis, which explains the dissymmetry in the distribution of lateral acceleration levels. The high vertical accelerations are partly related to road features (speed bumps, railroad tracks, manholes, etc.) or road defects (potholes, collapsed trenches, etc.), and partly to the transfer of the lateral acceleration to the vertical axis when the motorcyclist turns and the motorcycle leans. They are rare above 2 m/s² (2.1% of the time in total).

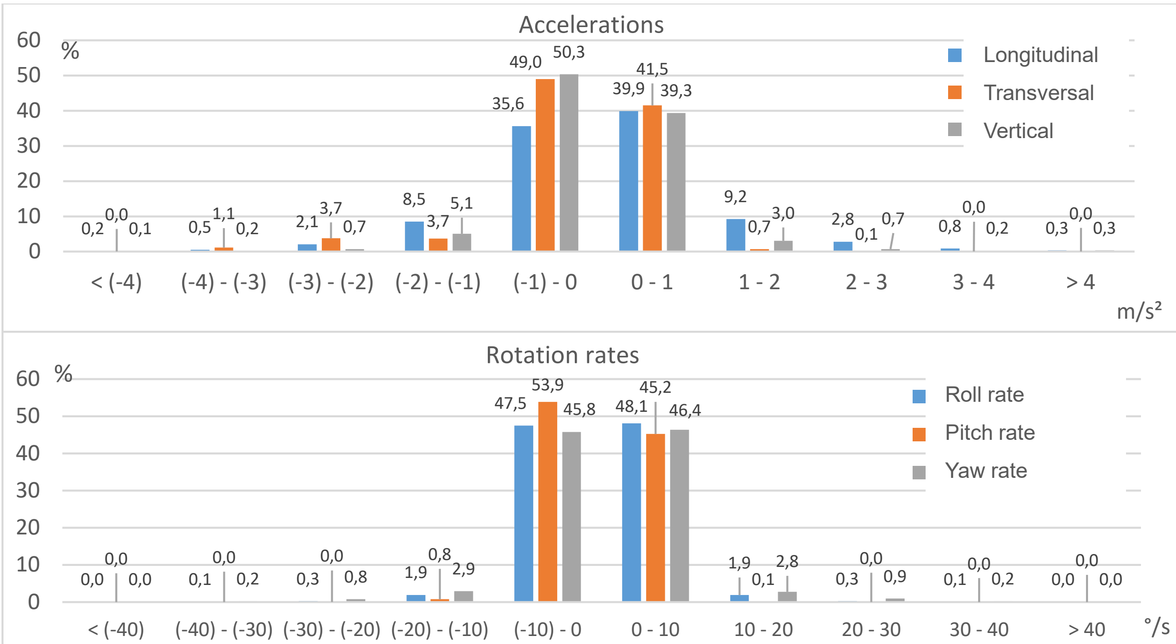

Figure 3: Global distributions of accelerations (top) and rotation rate (bottom)

The rotation rate distributions are shown in Figure 3 (bottom). In pitching, riders are very rarely above 10°/s: 0.1% of the time in positive pitch rate, i.e. braking, and 0.8% of the time in negative pitch rate, i.e. accelerating. The time spent with significant yaw rate and roll rate gives information on the behavior in cornering and changes of direction or shift. Motorcyclists are overall 3.8% of the time in roll rate between (+/-)10 and 20°/s and only 0.8% of the time above +/-20°/s. In terms of yaw rate the times spent are 5.7% between (+/-)10 and 20°/s and 2.1% above 20°/s.

Extreme values

Extreme loads are rare. To observe them, we use the 2D representation, with a [longitudinal acceleration - yaw rate] or [longitudinal acceleration - roll rate] crossover (Figure 4), which shows both braking and acceleration stresses, cornering stresses, and combined stresses, such as braking during cornering.

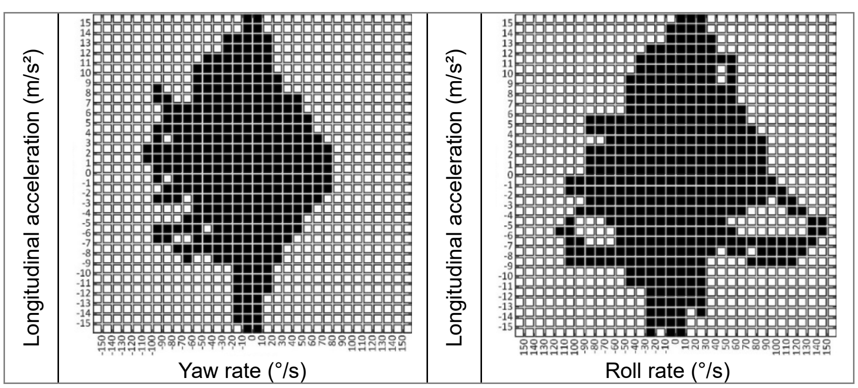

Figure 4: Crossing of loads: Longitudinal acceleration - Yaw rate (left) and Longitudinal acceleration - Roll rate (right)

At the extremes, acceleration and braking can exceed +/-15 m/s². These values are beyond the values encountered in particular in emergency braking tests. It is possible that on some motorcycles the vibration level is still quite high even after filtering, and that such extreme values are sometimes reached. In lateral, the maximum yaw and roll rates are close to +/-90°/s apart from the non-standard combined stresses. These representations will make it possible to differentiate the driving styles of motorcyclists.

Variability of driving profiles

To discriminate the type of driving, indicators of the loads have been calculated. These indices represent the number of black cells in relation to the total number of cells in a crossed representation as in Figure 4. The average and extreme values of these indices are summarized in Table 2. On average, the load indices are 13.5% (with yaw rate) and 14.8% (with roll rate) and vary from the "softest" rider to the "sportiest" rider between (6.1%, 2.2%) and (23.7%, 22.8%).

	Longitudinal acceleration versus Yaw rate	Longitudinal acceleration versus Roll rate
Global fleet (all trips)	31.3%	39.2%
Average per driver	13.5%	14.8%
Motorcyclist with the smoothest riding style	6.1%	2.2%
Motorcyclist with the sportiest riding style	23.7%	22.8%

Table 2: Loads Indicators (Overall Fleet, Smoothest/Sportiest Rider)

To assess differences in practiced speeds, the profiles of the smoothest and sportiest riders were compared with the overall practiced speed profile of the entire fleet (Figure 5).

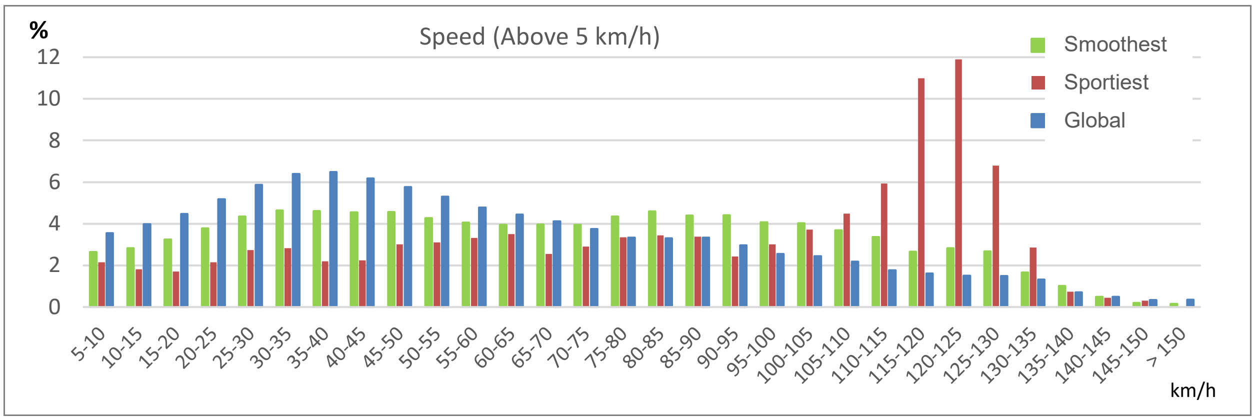

Figure 5: Comparison of the global speed profile, and the smoothest and sportiest driving profiles

The speed profiles are quite varied, with the smoothest motorcyclist riding more often than all riders below 70 km/h, and the sportiest rider riding much more often between 105 and 135 km/h. There was little difference in the amount of time spent above 135 km/h, but it can be seen that the smoothest motorcyclist was most often riding at these higher speeds. The distribution of the indicator [longitudinal acceleration - yaw rate] (Figure 6) shows that the sportiest rider is an extreme case and that the majority of motorcyclists' indicator is between 10 and 18%. There are only two motorcyclists' indicators below 10%.

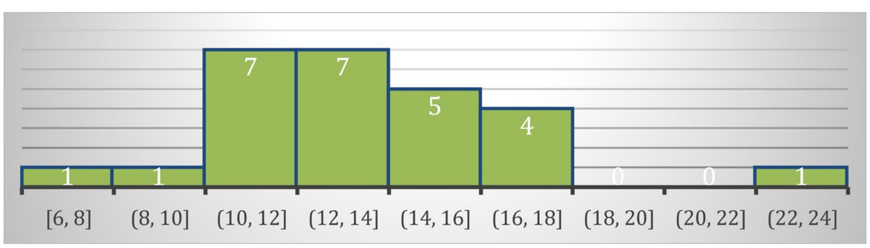

Figure 6: Distribution of load indicators Longitudinal acceleration vs Yaw rate

Figure 7 illustrates the diversity of driving profiles in more detail, with the intersection [longitudinal acceleration - yaw rate] for the 26 motorcyclists. For each rider, the distance travelled and the corresponding stress indicators are given.

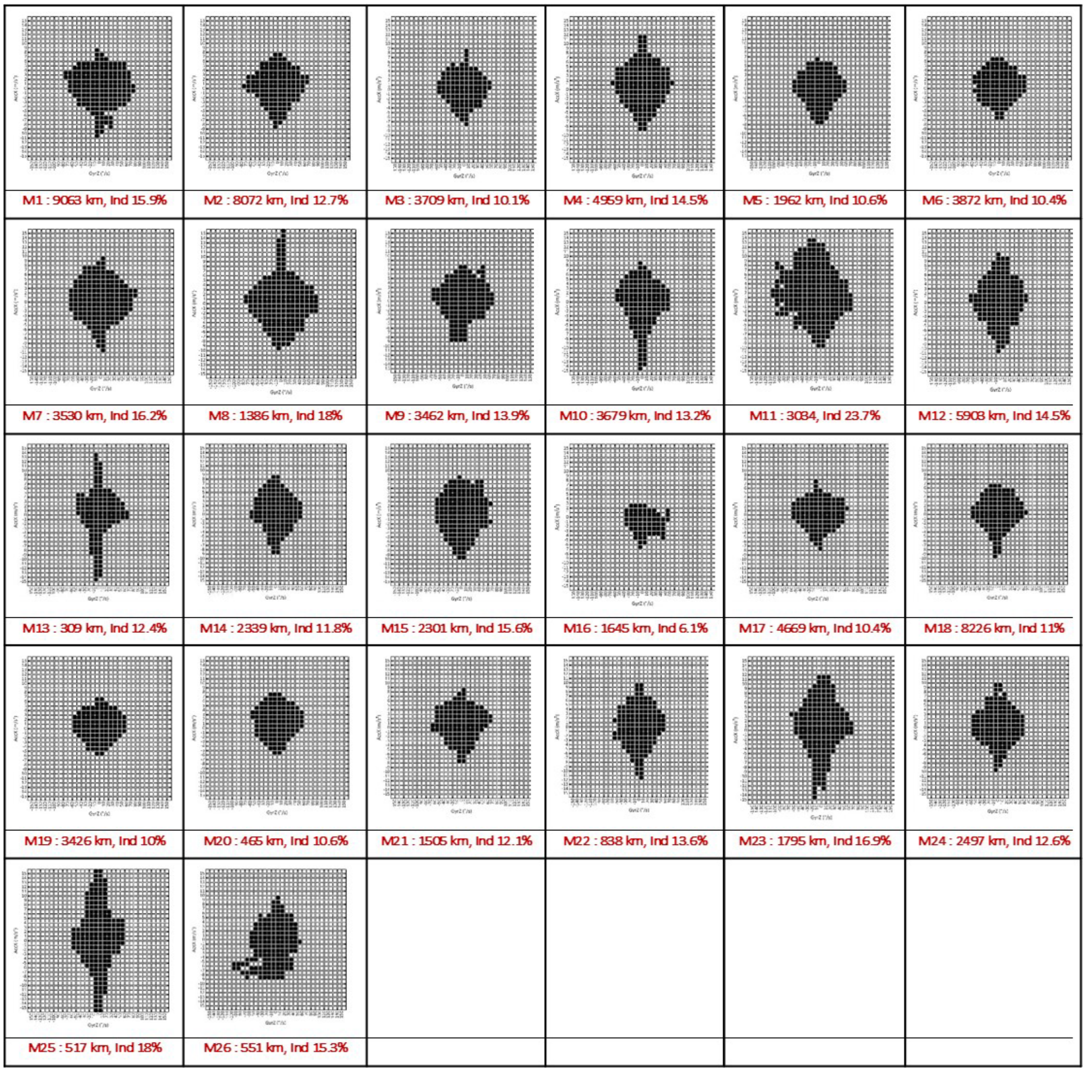

Figure 7: Extreme stress levels of the 26 riders - Longitudinal acceleration vs. Yaw rate

These graphs allow to quickly identify motorcyclists who brake hard, such as M10, M13, those who accelerate hard like M8, and those who brake and accelerate hard like M23 and M25. In lateral direction, the motorcyclists who stress their vehicle the most are M7, M8, and M23, as well as M11 whose graph shows that he or she stresses his vehicle the most in all directions, including in combined stresses. These longitudinal and lateral loads are related to the way the motorcyclist drives, but are also influenced by the type of roads he or she drives on. The vehicle is not stressed in the same way in an urban environment, in the suburbs, on the freeway or on a mountain road. This is why it is important to compare, whenever possible, the riding of several motorcyclists on the same route.

Comparison of riding profiles on a same route

The example shown in Figure 8 corresponds to a route of about 10 km, which was travelled 4 times by rider M7 and 3 times by rider M6. These two motorcyclists have travelled more than 3500 km each and their overall riding profile appears different (Figure 7), with M7 riding more sportily. On this route, the same holds true, with less stress in all directions for M6. In this case the differences in driving profile are confirmed by the study of a common route. The speeds practiced by these two motorcyclists on this route are also quite different, with M7 driving faster overall, which explains why he puts more strain on his vehicle, both longitudinally and transversely.

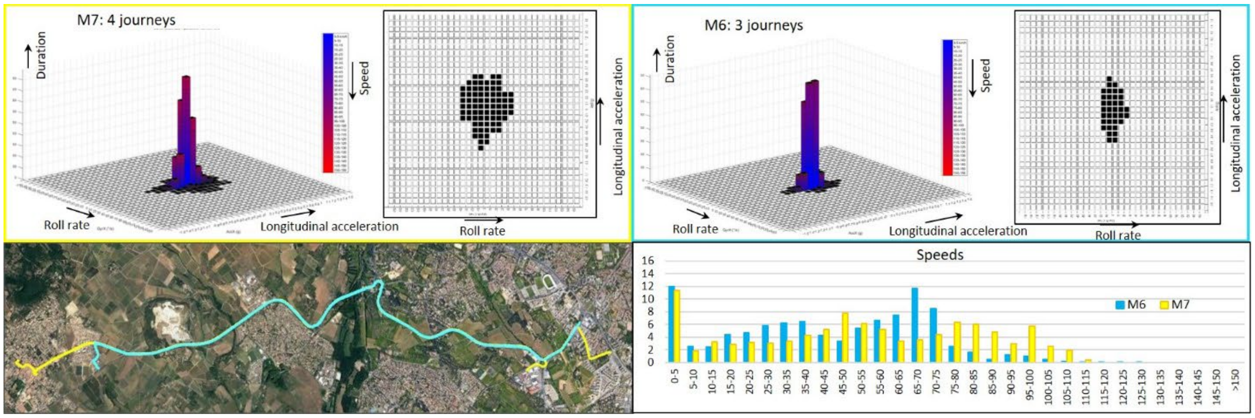

Figure 8: Route taken by two motorcyclists (M7 in yellow, 4 trips, M6 in blue, 3 trips)

CONCLUSION

This naturalistic riding data acquired over a period of 18 months with 26 private motorcycles in three regions of France, have been used to evaluate the actual dynamic loading of PTWs. About 6500 trips could be analysed, for a total distance of 88000 km. The results obtained on the complete set of data concern first the global distributions, in time spent, of the longitudinal, lateral and vertical accelerations, and of the pitch, roll and yaw speeds, then the extreme values reached at least once by the motorcyclists for these same parameters. The variability of behavior is then illustrated, ranging from smooth to sporty riding.

Motorcyclists rarely experience high levels of dynamic demands. In particular, during acceleration and deceleration, they exceed +-4 m/s² only 0.5% of the time. When cornering, their roll speed exceeds 20°/s only 0.8% of the time and their yaw speed only 2.1% of the time. Excluding time spent stopped or at very low speeds (less than 5 km/h), riders spend 80% of their time below 90 km/h and 3.2% of the time above 130 km/h, with only 0.3% of the time above 150 km/h. Behavior varies greatly from rider to rider, even on the same route. This type of natural driving exposure data allows to characterize the vehicle dynamics of motorcycles and to discriminate the different driving profiles of motorcyclists.

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