Comparison of bend-taking on thermal and electric motorcycles: qualitative studies

Clémentine PIGNAT[*,1,3], Pauline MICHEL[2], Bruno LARNAUDIE[2], Bastien VINCKE[2], Sergio RODRIGUEZ[2], Abdelhafid EL OUARDI[2], Flavien DELGEHIER[2], Franck MARS[3], Stéphane ESPIÉ[1], and Abderrahmane BOUBEZOUL[1]

[1]Université Gustave Eiffel, SATIE, 91190, Gif-sur-Yvette
[2]Université Paris-Saclay, ENS Paris-Saclay, CNRS, SATIE, 91190, Gif-sur-Yvette
[3]Nantes Université, CNRS, LS2N, 44322, Nantes

Wednesday 11th December, 2024

Keywords : **motorcycle riding behavior, motorcycle riders, bend-taking, adaptation to electric motorcycles, specificities of electric motorcycles**

1 Introduction

Powered two-wheeler (PTW) riders are overrepresented in road accidents. In France, although PTW riders make up less than 2% of traffic, they account for 22% of those killed and 34% of those seriously injured (ONISR, 2024). As a result of environmental concerns and the announced ban on the sale of thermal vehicles in the European Union from 2035, the number of electric vehicles (EVs), and particularly of electric motorcycles (EMs), is set to increase in road traffic. However, EVs have specific features regarding dynamics and sensory feedback, which influence vehicle control. This raises the question of the transition from thermal to electric vehicles and the necessity for drivers to adjust how they control their vehicles, which could be problematic, especially for experienced drivers of thermal vehicles.

Difficulties drivers and riders encounter when transitioning to EVs could be linked to changes in environmental information gathering, leading to changes in driving behavior. Indeed, the differences between thermal and electric vehicles are numerous. EVs are silent, generally have no gearbox, little vibration, and have different dynamics due to high engine torque from the first seconds of acceleration (Toman et al., 2021). The dynamics of EVs could be problematic during re-acceleration out of bends, with the risk of losing grip.

The absence of engine noise also raises questions since studies have shown that when car drivers were entirely deprived of auditory feedback, their perceived driving speed was lower than their actual speed (Evans, 1970; Merat & Jamson, 2011). When drivers were partially deprived of auditory feedback, their driving speed increased (Horswill & Plooy, 2008; Knowles et al., 2012). Another study showed that when an auditory feedback was available to the driver, they perceived their speed as higher than it was (Bringoux et al., 2017). In simple terms, speed is perceived by the driver according to a combination of sensory cues: visual information from the optic flow, vestibular information induced by the

[*]Corresponding autor : clementine.pignat@univ-eiffel.fr

dynamics of the vehicle, and auditory information, resulting mainly from the engine and the airflow in the case of motorcycles. This information is further supplemented by perceived vibrations (such as road contact and engine vibrations). For vehicles with manual gearboxes, knowing the engaged gear provides additional information.

Because of the silence of the vehicle, the absence of engine vibrations and the lack of gearbox, the "electric" rider would have fewer sensory cues available to them. During the transition from thermal motorcycles (TMs) to EMs, control difficulties could arise, putting the rider in danger (for example, overspeeding when approaching a bend).

The eMC2[1] project, which the studies presented in this article are part of, examines the safety implications of switching from TMs to EMs. The project focuses on two main concerns: on the one hand, the differences in riding characteristics, i.e. of vehicle dynamics, between TMs and EMs, and on the other hand the differences in sensory cues available to riders, and aims to measure and analyse the impact of these differences on motorcycle users' riding behaviors. We place a particular emphasis on the need for appropriate measures to ensure road safety during the transition from TMs to EMs for experienced TM riders. For this reason, we are particularly interested in the adaptation or learning phase of an EM (as a new vehicle for experienced TM riders), and in riding behaviors observed during this phase.

Some studies have been carried out on the adaptation from thermal to electric vehicles, though most focused on car drivers. It was pointed out that drivers, after a learning process, adapted to the specificities of electric vehicles. Among other things, studies have shown that drivers learn to master the regenerative braking of EVs and use it when it is needed and/or beneficial (Helmbrecht et al., 2014; Knowles et al., 2012; Vilimek et al., 2012). For in-depth analysis of the adaptation/learning phase and driving behaviors during this phase, several types of data could be used, but these ideas have not often been employed in studies focused on motorcycle riders: riding time, amount of braking actions, timing of braking and acceleration, steering activity (steering angle and steering jerk), riding time, etc. (Freydier, 2014; Negi et al., 2019).

The two exploratory studies presented in this article aimed to investigate the differences between riding a TM and an EM when taking bends. The first study compared the riding behaviors of novice EM riders with those of relatively experienced EM riders in order to observe a potential adaptation in these riders. The second study looked at changes in riding behavior when an experienced TM rider switches to electric for the first time. This second study was carried out with the aim of identifying transitional difficulties that may arise during the initial discovery of EM riding.

2 Method

2.1 Qualitative study 1

2.1.1 Participants

Four men participated in the study, with an average age of 48.8 years (SD = 7.7). These participants were riding professionals and instructors recruited by their hierarchy, and each rider signed a consent form. Two participants were novices in EM riding (having never ridden an electric motorcycle), while the other two were relatively experienced in EM riding. All four participants also regularly rode thermal motorcycles (TMs), with an annual mean distance of 26,000 km.

[1] https://emc2.universite-paris-saclay.fr/

2.1.2 Apparatus

All participants rode on the *La Ferté-Gaucher* race track in the *Île-de-France* region of France. Only one part of the race track was used for the study, which measured two kilometers for a lap (figure 1).

The two motorcycles used were: a thermal sport motorcycle (RSV4, Aprilia, subsequently designated as TM1) and an electric roadster motorcycle (SR/F 2020, Zero Motorcycles, subsequently designated as EM). The TM1 was chosen because its maximum torque was close to the torque of the EM (122 Nm and 190 Nm respectively).

All motorcycles ridden by the participants were instrumented specifically for the needs of these experiments, based on the instrumentation work carried out in a previous research project (Smaiah et al., 2018). Based on the extensive motorcycle instrumentation developed for this project, we are able to select the sensors needed to investigate a specific research question (Vincke et al., 2024).

Figure 1: Aerial photography (Google Earth) of the *La Ferté-Gaucher* race track used in the two studies, with distance scale.

The analysis detailed in this paper relies on the data measured by a GoPro 360° camera that was placed on the right side mirror of the motorcycles. The data (GPS location and cinematic data) was collected at a frequency of 10 Hz.

2.1.3 Design

The mixed factorial experimental design was therefore composed of a between-participants factor, "level of electric motorcycle-riding experience", and two within-participants factors: "motorization" and "riding style", for a total of six conditions (2*3). The two modes of the "motorization" factor were "thermal motorization" represented by the TM1 and "electric motorization" represented by the EM. The three modes of the "riding style" factor were "free riding", where riders were told to ride as they usually would in their daily life, "smooth riding", where participants had to minimize acceleration and braking and ride without trying to perform, and finally "dynamic riding" where they had to adopt active, sporty, and energetic riding. The two modes of the "level of electric motorcycle-riding experience" were "novice to EMs" and "confirmed EM riders". The first mode was always in free riding to allow participants to discover the race track at their own rhythm. The order of presentation of the "smooth" and "dynamic" riding conditions was counterbalanced. The "motorization" factor was not counterbalanced since the focus of the study was the transition from TM to EM.

2.1.4 Data collection / Measures

To limit the overall duration of the experimentation, questionnaires and interviews (psychological data) were conducted only when the participants had completed the riding with one type of motorization. There were two phases of interviews: one after the TM riding period and one after the EM riding period. The psychological dependent variables were submitted to a two-modality factor (thermal and electric motorization). All other data was retrieved for all experimental conditions. Given the small sample of riders, only descriptive statistics were produced and are detailed and analysed in the following.

Psychological data: participants completed a French version of the NASA-TLX questionnaire, which allows for a subjective assessment of workload (Cegarra & Morgado, 2009; Hart & Staveland, 1988). They also completed three other questionnaires designed by the experimenters, namely on the difficulty of the bends or on perceived differences between the two ridden motorcycles. Open-ended semi-directive interviews were also conducted (for example[2]: "Did you find it was easy to apprehend, estimate and manage your straight-line speed?"; "Did you have any difficulty measuring your acceleration and/or braking?"; "Did you find there are differences between these two vehicles? If so, which ones?").

Vehicle data: The vehicles were equipped with a GoPro 360° camera, which was used to obtain data such as GPS location, speed, longitudinal and lateral acceleration, etc.

Training data: These data have been calculated from vehicle data. Learning to drive a vehicle can be reflected by observing the evolution of variables. Here, we chose to focus on the evolution of the time spent completing a series of bends. For this purpose, a 950-meter section of the circuit was selected: the zone chosen was in the center of the circuit to avoid the influence of starting and braking during stands starts and returns (Figure 2).

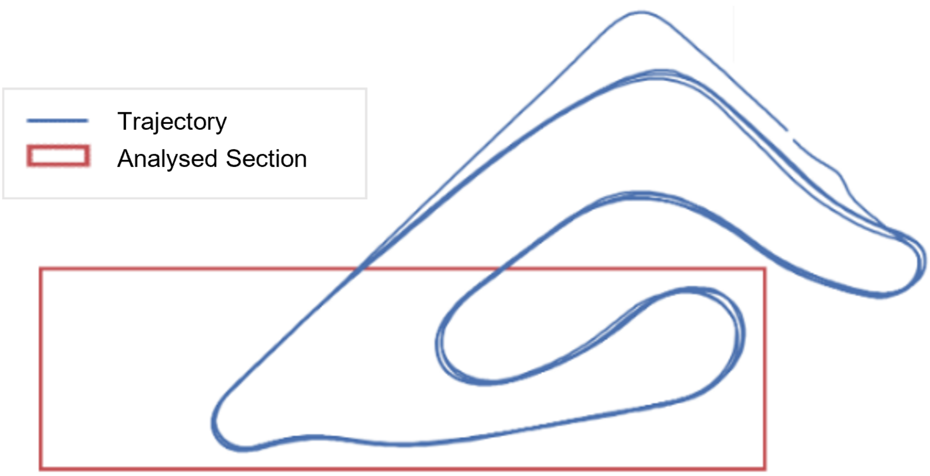

Figure 2: Trajectories for one condition and for one participant (blue line) with the analyzed trajectory section highlighted (red rectangle).

2.1.5 Procedure

The entire first block of the study was carried out on the TM1. They were asked to adopt a "free riding" mode, in other words, they could ride the vehicle as they wished, the aim being to discover the circuit over three laps. They made a stands stop where the experimenter gave instructions for the next laps. They rode three laps in the requested condition (smooth or dynamic riding), made a second stands stop and set off again for three laps in the other riding condition. They then left the TM1 in the stands, completed questionnaires and had an

[2] All examples of questions asked are translated from French for the benefit of the reader of this paper.

interview with an experimenter about the riding they had just done. The second block took place in the same way as the first, except that participants rode the EM. Once the ride was over, participants left the vehicle at the stands, completed the same questionnaires and had an interview with the same questions, this time about the EM. In a final debriefing interview, participants were asked about the differences they had perceived between the two motorcycles they had ridden, followed by open discussions about riding the motorcycles.

2.2 Qualitative study 2

2.2.1 Participants

New participants were recruited in the same way than the first study and each rider signed the consent form. Four men took part in the study and had an average age of 46.8 years (SD=6.7). All participants were novice to EM riding. These four participants also regularly rode TMs (annual mean = 21 000 km).

2.2.2 Apparatus

Participants rode motorcycles on the race track previously shown. For this study, modifications were made to help riders consider the circuit as a two-way road. To induce bend-taking equivalent to that on an open road, cups were added to the circuit to mimic the center line separating the two lanes. The two motorcycles used were a thermal roadster motorcycle (ER6, Kawasaki, subsequently designated as TM2) and the EM. This change has been carried out so that the motorcycle types could be more comparable in terms of the type of vehicle driven and riding posture than in terms of maximum engine torque (see discussion).

All motorcycles ridden by the participants were instrumented specifically for the needs of these experiments, based on the instrumentation work carried out in a previous research project (Smaiah et al., 2018). Based on the extensive motorcycle instrumentation developed for this project, we are able to select the sensors needed to investigate a specific research question (Vincke et al., 2024). The analysis detailed in this paper relies on the data measured by a GoPro 360° camera that was placed on the right side mirror of the motorcycles. The data (GPS location and cinematic data) was collected at a frequency of 10 Hz.

2.2.3 Design

The experimental design was composed of two within-participants factors with two modalities: the ”motorization” factor and the ”riding style” factor, for a total of four conditions (2*2). The two modes of the “motorization” factor were “thermal motorization” represented by the TM2 and “electric motorization” represented by the EM. The two modes of the “riding style” factor were “smooth riding” and “dynamic riding”. The participants were always instructed to ride ”smoothly” first for each motorcycle and they always started by riding the TM2. This is because the focus of this study was the transition from TM to EM.

2.2.4 Data collections / Measures

The dependent variables were the same as in the first study.

2.2.5 Procedure

The procedure was relatively similar. Participants were introduced to the track (three laps) on their own motorcycles used daily in their work. Then, participants parked their motorcycles and went into the interview room to answer various questionnaires. In block one, participants rode the TM2 (three laps in smooth riding, then three laps in dynamic riding), then went to answer the questionnaires. Block two took place in the same way, but with the EM. The study ended with a debriefing interview.

3 Results of the studies

Although the dependent variables were similar in both studies, it was not possible to mutualize their results due to protocol changes. They are to consider and discuss separately.

3.1 Learning

The results showed few inter-individual differences in terms of lap times between the participants, whereas there were no real differences between EM and the TMs (TM1 and TM2): the lap times were relatively similar (figure 3). The main trend was that time per lap decreased with each lap. Some riders showed a decrease in time from lap 1 to lap 2 and an increase for lap 3 (S3-TM, S4-EM and S8-TM-EM). S6 bucked the trend, increasing his time with each lap when riding the EM. The best time (i.e. shorter time) was obtained by S1-EM (mean=40.4 s).

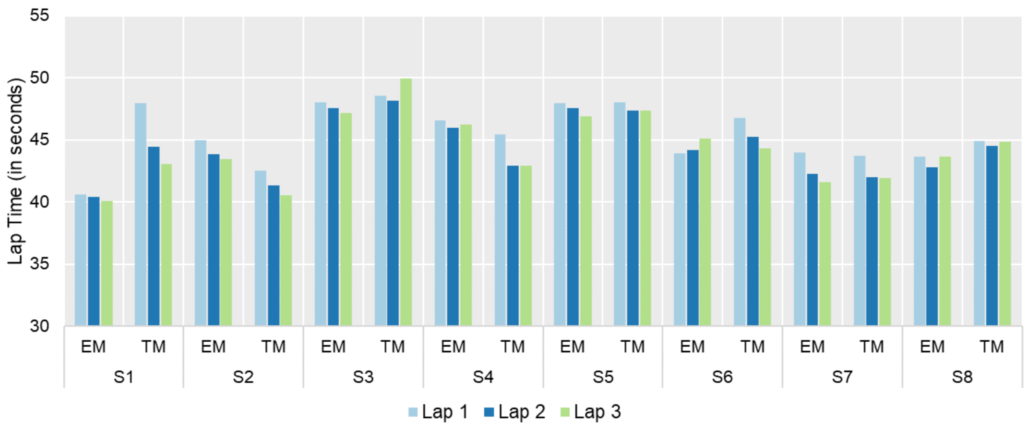

Figure 3: Evolution of lap time (in seconds) in the selected part of the race track, for the "dynamic riding" mode, per motorcycle and per subject for the two studies. S = subject.

3.2 Semi-directive interview

After the session of EM riding, in the first study, to the question "*Did you find it easy to capture, estimate and manage your straight-line speed?*", one participant replied: "*Yes because I have already ridden the electric motorcycle. [...] The electric it goes less fast at the end of the straight line than the thermal one when accelerating in the dynamic riding condition. [...] There is a 30 or 40 km/h gap at the end of the straight line. [...] I looked at the meter at one point and saw 170 km/h. [...] And with RSV4, I think in perception of things, 190-200 km/h, or even more.*"[3]. Actual speeds were calculated from recorded data and compared with the perceived and observed (i.e. read on the speedometer) speeds by this participant. The maximum speed reached by this subject with the EM was 176 km/h and that reached with the TM1 was 182 km/h, a deviation of 6 km/h.

3.3 Workload

A comparison of the workload associated with riding the motorcycles was carried out for the second study. The workload when riding the EM was rated higher by participants than when riding the TM2 (figure 4.A). The lowest workload was associated with their usual motorcycle (mean=7.0; SE=0.4) followed by that associated with the TM2 (mean=7.2; SE=0.8) followed by that of the EM (mean=8.7; SE=1.6). Details of each item are shown in 4.B. The

[3] All comments made by the participants during the interviews were translated from French for the benefit of the reader.

results showed that the EM almost systematically generated a higher workload than the TM2 and the control motorcycle (mental activity, physical activity, time pressure, effort and frustration). The greatest differences between EM and TM2 were found for physical pressure, effort, frustration (delta=9%) and time pressure (delta=7%).

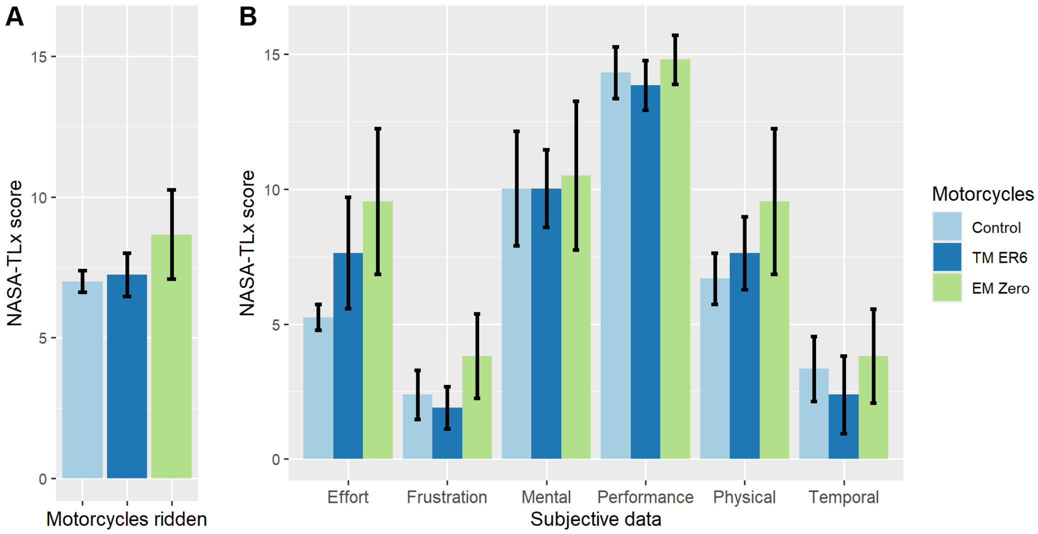

Figure 4: A. NASA-TLX mean score (and standard error) as a function of the motorcycle ridden for study two. B. Mean score obtained for each item (and standard error) of the NASA-TLX as a function of the motorcycle ridden for study two.

3.4 Perceived disturbance

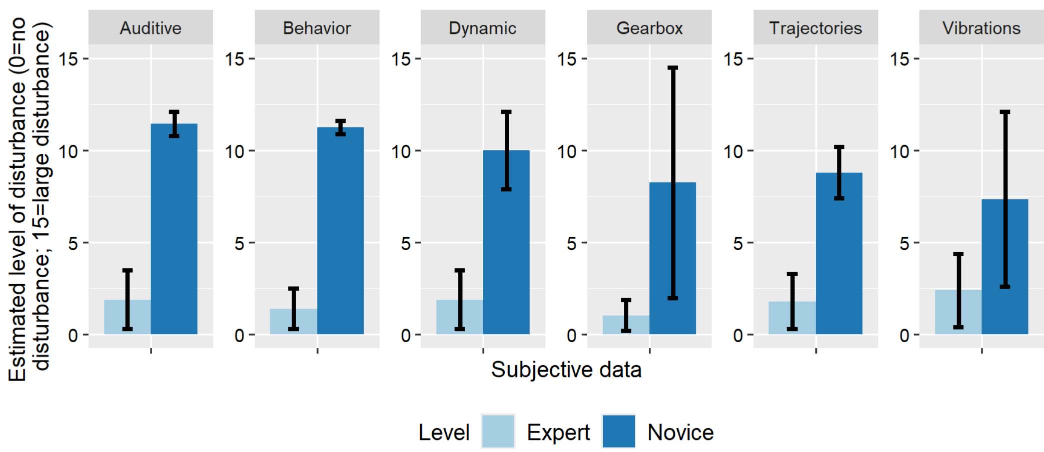

Figure 5: Average level (and standard error) of riding disturbance for professionals as a function of the level of expertise in EM riding. Auditory = engine noise, behavior = vehicle behavior, dynamics = vehicle dynamics, gearbox = presence of gearbox, trajectories and vibrations = engine vibrations.

These results come from the questionnaire completed by the participants at the end of the first study (figure 5). They were asked whether they thought the difference in the item in question (e.g. auditory feedback) had affected their riding. The trends showed that, for all items, motorcyclists who had already ridden an EM found the differences between the EM and the TM1 posed few riding difficulties, unlike novices. For example, for the auditory feedback change, experienced riders were unperturbed, unlike novices (delta=63.7%).

4 Discussion

4.1 Learning

Adaptation to the different motorization was similar, with trends showing an improvement in lap times for each motorization. These improvements suggest that learning to ride EMs is fast for professionals. This conclusion is supported by the times of S1, who was the most experienced electric motorcycle rider. Indeed, he performed best when driving the EM, showing how well he adapted to electric motorization over time. Experienced electric motorcycle riders drove the EM faster than novices, with a 3.1 s lower lap time. These results are in line with the literature, since motorcyclists who had already ridden an EM showed better performance (Negi et al., 2019).

4.2 Semi-directive interview

One participant talked about the perception of speed in a straight line. He perceived a speed difference of over 30 km/h, whereas the actual difference between the speeds was 6 km/h; in other words his perceived speed was lower than his practiced speed when riding the EM. This misperception of speed is in accordance with the literature, as the results of (Bringoux et al., 2017) (study carried out on a car-driving simulator) suggested that speed reached had been perceived as higher than it actually was when the sound was present. This remark raises an important point for road safety since riders would probably tend to underestimate their speed when driving an EM if they didn't look at their speedometer, or on the contrary, would tend to need to look more frequently at their speedometer, which would decrease time looking at the road and could increase the number of accidents.

During the many discussions, several participants stated that the EM was more difficult to manage when approaching bends due to an underestimation of perceived speed. However, they also mentioned that the absence of a gearbox on EMs made it easier to manage the motorcycles inside bends. For example, if the rider arrived too fast in a bend, it would be easier for him to slow down with an EM: "*there's no gearshift, so we don't waste time clutching, declutching, looking for the selector, etc.*"[3] and also "*we don't have any jerks with the electric when we go back on the throttle.*"[3]. Not all novices to the EM had the same experience, some were "*more confident in corners or on the go-around because it's easier*"[3], but one of these riders slipped in a corner because he accelerated too hard and "*took the throttle back too soon*"[3].

4.3 Workload

It is generally accepted that workload depends on task complexity, attentional resources, expertise and so on. Only the workload attributed to the riding task in the second study was analyzed. Indeed, the TM1 was deemed too exclusive and demanded great concentration from the participants, causing a bias in the type of motorcycle (sport versus roadster). In the second study, this bias was corrected as both the TM2 and EM were roadsters. The expected results were an increase in workload when riding the EM, probably since the riders were unfamiliar with this type of vehicle. The results revealed differences that were in accordance with this hypothesis, since the lowest workload was associated with their usual motorcycle, and was almost similar to that associated with the TM2 (which has characteristics in common with their personal motorcycle), whereas the EM induced a mental workload 7% higher.

4.4 Perceived disturbance

The results showed that motorcyclists who had already ridden an EM were less perturbed than novices by the change in motorization. This lesser disturbance was to be expected, as these riders had become accustomed to and adapted to the effects of electric motorization.

The motorcyclists did, however, agree on one point concerning vehicle dynamics: it was repeatedly said that the EM, not having a gearbox or clutch, would be easier for beginners to handle.

4.5 In-depth data analysis

The extensive instrumentation we are privileged to have in this project has enabled us to collect other data that have not yet been analyzed for lack of time, but will be presented at the conference. These data will enable a more detailed analysis of the transition between TM and EM. Indeed, they include information such as steering angle and motorcycle roll angle, and as such they could provide a better understanding of adaptation to this new motorization. Previous work has shown higher steering activity (steering wheel angle and steering jerk) in expert car drivers, difficulty in the regulation of the vehicle's speed and also a higher number of braking actions for novice drivers (Freydier, 2014; Negi et al., 2019).

5 Limits and prospects

A difficulty in generalizing the results was identified due to the high level of expertise of the participants (professional riders and instructors). Our hypothesis is that their daily and professional experience of motorcycle riding enabled them to adapt very quickly to the change in motorization, which probably limited the effects. Also, this study was carried out on a race track, which made riding less complex: full visibility of the environment, no traffic and no interaction with other vehicles or other road users. In addition, the circuit's sinuosity prevented the use of maximum motorcycle performance. These factors could limit the effect of the motorization on riding performance. It should be noted that the number of participants was low, and the number of laps for each experimental condition was limited to three, due to the very limited battery autonomy of the EM in dynamic conditions, and the relatively long recharging time. Finally, the choice of motorcycles (TM1 and EM) made at the start to have similar engine torque resulted in a consequent difference in motorcycle type and rideability. In order to study the effects of electric power without the effects of motorcycle type, the sport motorcycle (TM1) was replaced by a roadster motorcycle (TM2).

As part of the eMC2 project, longitudinal and natural studies have been conducted to examine the adaptation of TM to EM for the general population.

6 Conclusion

These first results support the presence of a rider behavior adaptation during the transition from a TM to an EM due to the motorization specificities. They also show an increase in workload when participants switch to riding the EM. On the road with non-professional drivers, the increase in workload could be even greater, raising safety issues. This observed trend, which needs to be confirmed by further studies with non-professional drivers, suggests the need for awareness-raising and even training for this change of motorization. Some of the further studies will be conducted on our riding simulator. All of these planned further studies will be conducted with a single aim: to continue investigating the transition from TM to EM in order to identify potential road safety issues.

7 Acknowledgment

This research received a grant from the *Agence Nationale de la Recherche* (ANR, France national research agency) for the eMC2 project, grant number: ANR-22-CE22-0012.

References

Bringoux, L., Monnoyer, J., Besson, P., Bourdin, C., Denjean, S., Dousset, E., Goulon, C., Kronland-Martinet, R., Mallet, P., Marqueste, T., Martha, C., Roussarie, V., Sciabica, J.-F., & Stratulat, A. (2017). Influence of speed-related auditory feedback on braking in a 3D-driving simulator. *Transportation Research Part F: Traffic Psychology and Behaviour*, *44*, 76–89. https://doi.org/10.1016/j.trf.2016.10.006

Cegarra, J., & Morgado, N. (2009). Étude des propriétés de la version francophone du NASA-TLX.

Evans, L. (1970). Speed Estimation from a Moving Automobile. *Ergonomics*, *13*(2), 219–230. https://doi.org/10.1080/00140137008931135

Freydier, C. (2014, July). *Attention divisée en simulation de conduite automobile : Influence de l'expérience et Impact de l'alcool* [Doctoral dissertation, AIX – MARSEILLE Université].

Hart, S. G., & Staveland, L. E. (1988, January). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In P. A. Hancock & N. Meshkati (Eds.), *Advances in Psychology* (pp. 139–183, Vol. 52). North-Holland. https://doi.org/10.1016/S0166-4115(08)62386-9

Helmbrecht, M., Olaverri-Monreal, C., Bengler, K., Vilimek, R., & Keinath, A. (2014). How Electric Vehicles Affect Driving Behavioral Patterns. *IEEE Intelligent Transportation Systems Magazine*, *6*(3), 22–32. https://doi.org/10.1109/MITS.2014.2315758

Horswill, M. S., & Plooy, A. M. (2008). Auditory Feedback Influences Perceived Driving Speeds. *Perception*, *37*(7), 1037–1043. https://doi.org/10.1068/p5736

Knowles, M., Scott, H., & Baglee, D. (2012). The effect of driving style on electric vehicle performance, economy and perception. *International Journal of Electric and Hybrid Vehicles*, *4*(3), 228. https://doi.org/10.1504/IJEHV.2012.050492

Merat, N., & Jamson, H. (2011). A Driving Simulator Study to Examine the Role of Vehicle Acoustics on Drivers' Speed Perception. *Proceedings of the 6th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design : driving assessment 2011*, 226–232. https://doi.org/10.17077/drivingassessment.1401

Negi, N., Van Leeuwen, P., & Happee, R. (2019). Differences in Driver Behaviour between Race and Experienced Drivers: A Driving Simulator Study: *Proceedings of the 5th International Conference on Vehicle Technology and Intelligent Transport Systems*, 360–367. https://doi.org/10.5220/0007700003600367

ONISR. (2024, May). *Accidentalité routière 2023 en France* (tech. rep.).

Smaiah, S., Sadoun, R., Elouardi, A., Larnaudie, B., Bouaziz, S., Boubezoul, A., Vincke, B., & Espié, S. (2018). A Practical Approach for High Precision Reconstruction of a Motorcycle Trajectory Using a Low-Cost Multi-Sensor System. *Sensors*, *18*(7), 2282. https://doi.org/10.3390/s18072282

Toman, P., Svoboda, J., & Pinkas, J. (2021). Study of riding specifics of the electric and conventional powered two-wheeler users. *2021 Smart City Symposium Prague (SCSP)*, 1–6. https://doi.org/10.1109/SCSP52043.2021.9447401

Vilimek, R., Keinath, A., & Schwalm, M. (2012). The MINI E Field Study - Similarities and Differences in International Everyday EV Driving. *Advances in Human Aspects of Road and Rail Transport*, 363–372.

Vincke, B., Michel, P., Ouardi, A. E., Larnaudie, B., Delgehier, F., Sadoun, R., Bouaziz, S., Espié, S., Rodriguez, S., & Boubezoul, A. (2024). Real track experiment dataset for motorcycle rider behavior and trajectory reconstruction. *Data in Brief*, *57*, 111026. https://doi.org/https://doi.org/10.1016/j.dib.2024.111026