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The Electric Vehicle: A New Driving Experience

Involving specific Skills and Rules

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Abstract

The arrival of the electric vehicle (EV) on the market is one consequence of government measures to improve air quality and reduce CO² emissions. However, the EV has specific properties of use associated with its limited range and relative silence compared to normal vehicles, influencing the mobility behaviours of drivers and requiring them to develop some new driving abilities. This paper examines the behavioural modifications brought about by daily use of an electric vehicle at three different levels of driving activity: strategic, tactical and operational. The study collected and analyzed the self-reported behaviours (via questionnaires and travels dairies) of 36 Parisian private drivers, each of whom drove for six months an electric MINI E prototype. The results of the study show that driving an EV requires a learning phase to acquire the skills and knowledge necessary to operate the vehicle. At the strategic level of driving, drivers take into account the restricted range of the EV, implement a daily charge process, and develop new behaviours related to trip planning. The study also examines driver behaviour at the tactical level, in terms of driver interactions with other road users to deal with the silent nature of the EV, and at the operational level of driving, in terms of braking behaviour to master the regenerative braking function of the EV. The paper discusses the interactions between these three levels of driving activity.

Highlights

- Self-reported behaviours engaged in by drivers during daily use of an electric vehicle are reported
- Behaviour modifications emerged progressively with time at all driving activity levels
- Driving at the strategic level is enhanced by the establishment of rules in order to optimize range management
- At the tactical level adaptive driving behaviours arise to compensate for the lack of vehicle noise
- Optimal driving styles arise at the operational level by mastering the regenerative braking function
- Dynamic interactions between the three levels of driving activity are highlighted

Keywords

Electric vehicle; driver behaviour; road safety; intelligent transport systems; behavioural adaptation; human factors.

1 Introduction

New international roadmaps for reducing CO₂ emissions are being accompanied by substantial financial investment in the development of sustainable transport. A large amount of funding has been allocated by private investors and governments to finance the development of renewable energy and multimodal transport systems that are energy-efficient and use cleaner fuels (United Nations, 2012; MDB Working group on Sustainable Transport, 2015). In this context, the electric vehicle (EV) is a relevant mode of transport: it is a practical alternative to conventionally fueled vehicles if the production of electricity used is not polluting. This has resulted in the provision of government

incentives (Valls, Royal, Sapin, Macron, & Eckert, 2014) to make the purchase of EVs more attractive (e.g., in France in 2015 a 6300 euros bonus increasing to 10 000 euros if associated with the destruction of an old diesel vehicle; against a 5000 euros bonus in 2011), and an increasingly varying range of EV models being offered by manufacturers to meet the specific needs of users, for both private and fleet vehicles (vehicles with 2 or 5 seats, varying range, etc).

Electric vehicles have specific properties, however, that are novel for drivers of conventionally fuelled vehicles. Drivers have to pay attention to the impact of the absence of vehicle noise at low speed (Cocron and Krems, 2013; Sandberg, Goubert, & Mioduszewski, 2010). They have to master the regenerative braking function that uses deceleration to charge the vehicle (Cocron et al., 2013). Drivers have also to deal with the limited range of the car and to plan for the charging of the electric batteries (Franke, Neumann, Bühler, Cocron, & Krems, 2012). Moreover, previous research shows that people are not yet used to managing electricity in the vehicle. They lack knowledge about electricity and batteries, and that affects their understanding of the EV and the best way to interact with it (Caperello & Kurani, 2012; Cocron et al. 2011; Strömberg, Andersson, Almgren, Ericsson, Karlsson, & Nåbo, 2011). Given these issues, and for the successful deployment of EVs, it is important to understand to what extent driving activity is modified by the specific features of the EV: that is, what behaviours arise in order to interact with it efficiently from an economical and safe point of view. We review briefly below relevant research findings in this area.

1.1 Driving tasks

The model of the driving task proposed by Michon (Michon, 1978, 1985; see also Van der Molen & Bötticher, 1988) provides an efficient framework for describing the specific driving activity engaged in by drivers during daily use of the EV. Michon modeled driving as a hierarchical categorization of all the tasks the driver must make throughout a trip. The model is useful in classifying new tasks that derive from the use of EV technology and changes to existing tasks, as well as the behaviours implemented to manage them.

In Michon's model (1978, 1985), three main levels of tasks are differentiated. At the *strategic* level the tasks performed relate to trip planning. Decisions concern the choice of a relevant route to reach a destination according to constraints such as the time the driver has, the amount of time allocated to the trip, the choice of the vehicle; and so on. Here, the driver might evaluate the most comfortable and quickest route (based on roadwork, traffic jams, etc), and any potentially dangerous situations (driving at night, driving in rain) (Wilde, 1982; Wilde, Gerszke, & Paulozza, 1998). There is the possibility at the strategic level that driving an electric car will change the way trips are planned because of its limited range. In current generation EVs, range is very restricted compared to that of a conventionally fuelled vehicle and energy becomes a daily factor to manage, as trips are limited in terms of distance. New strategic tasks are thus generated: drivers will have to take greater account of their travel itineraries, of unforeseen events, of the location of charge stations, and so on. The few studies that have explored feedback from long-term EV users confirm that daily use leads to the emergence of new behaviours. This is not immediate and requires a learning process, during which drivers understand how the EV range fits into their lifestyle, and adapt their trip planning accordingly. Generally, it seems that drivers modify their driving behaviours, such as speed and trip routes, adopt safe driving strategies to avoid critical range situations (Franke et al., 2012; Pichelmann, Franke, & Krems, 2013; Rolim, Gonçalves, Farias, & Rodrigues, 2012; Woodjack, Garas, Lentz, Turrentine, Tal, & Nicholas, 2012) and develop a charging routine (Bunce, Harris, & Burgess, 2014). Finally, the *strategic* level is modified for some drivers by the emergence of more trips done with the EV (Rolim et al., 2012). Thus, there is evidence that daily use of an EV brings about some new driving behaviours at the strategic level of driving.

Michon's model includes other driving tasks distributed across two additional levels that can also be modified by the management of the specific features of the EV. At the *tactical* level, the driver must analyze in real time modifications to the traffic environment and adapt actual driving behaviours and his/her interactions with other road users according to circumstances; the driver must plan actions under specific situational contexts. When driving an electric car, task activity at this level would be amplified by the need to pay more attention to interactions with pedestrians. In France, for example,

pedestrians are not accustomed to interacting with silent vehicles: there are still few electric cars on the road (only 42000 EVs were registered in France between 2011 and 2014; cf. AVERE France, 2015), and bicycles make up only 2.6% of all trips made by the French (according to the last national study on French mobility, Revue du CGDD, 2010). Because people detect several operating conditions of cars by visual and auditory cues, the lack of noise at low speeds could create new safety issues. Experiments show that the time from the first detection of a target vehicle to the instant the vehicle passes the pedestrian location is significantly decreased with an EV (Czuka, Conter, & Wehr, 2014; Garay-Vega, Hastings, Pollard, Zuschlag, & Stearns, 2010), which impacts on the ability of pedestrians to travel safely. Driving EVs at the tactical level will therefore have to take account of the silent nature of the EV, obliging the driver to adopt more attentive behaviours to other road users.

Finally, the most basic level of Michon's (1978, 1985) model of driving is the *operational* level, which relates to control of the stability of the vehicle (control of the brake and accelerator, lateral control, and so on). In driving an electric car, users in France will have to get used to driving with only accelerator and brake pedals: in France, the percentage of automatic vehicles in the vehicle fleet, with only two pedals, is marginal; manual transmission vehicles are the norm (in 2014 automatic vehicles represented less than 15% of the cars sold; cf. Comité des Constructeurs Français d'Automobiles, 2014). The presence of a feature absent in conventional cars - regenerative braking - adds an additional task at the operational level of driving: in some vehicles the car brakes when the driver releases pressure on the accelerator pedal (Vilimek et al., 2012) to enable a certain amount of kinetic energy to be recovered and transferred to the battery. This new control mechanism, regenerative braking, offers new opportunities for energy management behaviour compared to conventional cars. However, it may impact on the operational activities of the driver who needs time to become familiarized with its operation (Cocran et al., 2013).

1.2 Objectives and Context of the study

The aim of the study presented in this paper is to describe the specific behaviours engaged in by

drivers during prolonged daily use of an EV and, more generally, the driving activity that emerges. Like the few studies that have examined how drivers deal with the limited range of the EV and have highlighted the emergence of new adaptive behaviours, we postulate, by extension, that new behaviours arise at each of the levels of driving activity described above to take over the specific properties of the EV. Our hypotheses are as follows:

- We anticipate that adaptive driving behaviours will need time to arise at all driving levels; that is, will require an accumulation of experience to emerge.
- Concerning the limited range of the EV, we hypothesize that drivers not accustomed to managing energy daily (usually, s/he refuels after several weeks) will develop strategies in order to maximize the distances they can travel with the car, and identify better ways to charge the vehicle through successful experiences. Overall, they will progressively follow some new habits in planning their trips at the *strategic* level of driving.
- With respect to the EV silent feature, we hypothesize that more or less risky situations could occur and that drivers will adapt their driving behaviours at the *tactical* level to compensate for the lack of noise.
- Finally, regarding regenerative braking, we hypothesize that the repetition of similar experiences will allow the driver to acquire an optimal driving style by mastering the feature, which will modify driving behaviour at the *operational* level of driving.

In order to explore the hypotheses above, the study presented in this paper was designed as a longitudinal, self-reported, evaluation of driving changes in the context of daily use of an EV over a period of six months. A study already conducted in Germany (Cocron, Bühler, Franke, Neumann, & Krems, 2011; Cocron et al. 2011), the USA (Woodjack et al., 2012) and England (Everett, Walsh, Smith, Burgess, & Harris, 2010) - for the auto manufacturer Bavarian Motor Works (BMW) - was replicated in Paris (see also Vilimek et al., 2012). It focused on the acceptance, and new driving behaviours, of users of the EV. In this paper, deriving from the French study, only the latter aspect is considered.

2. Method

2.1 Electric vehicles

The study was part of the MINI E France Project, led by The French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR), and carried out under contract for BMW Germany. Twenty-five MINI E conversion electric vehicles, similar in external appearance to the MINI Cooper, but with only two seats and equipped with a lithium-ion battery, were utilized in the study. In everyday life, in real conditions and depending on the driving style, the average range of the MINI E is roughly 160 km (100 miles).

All the MINI E vehicles have regenerative braking, a unique function integrated in most EVs. This technology allows for the recapturing of energy otherwise lost or unutilized during braking, coasting, or downhill driving; while, at the same time, slowing the vehicle. Regenerative braking in the MINI E is integrated with the accelerator pedal, effectively allowing the driver to drive the car with one pedal; the car brakes when the driver releases pressure on the accelerator pedal (Vilimek et al., 2012). The vehicle has also a conventional brake pedal. To charge the vehicle, each participant had a wall box of 12 amps installed in his or her home by the French electricity provider EDF (*Electricité de France*). Drivers could also charge their vehicles from public charging stations located around Paris (at 27 public stations in the outer suburbs of the Paris area and 84 in Paris). A full charge took about 9 hours to complete.

2.2 Procedure and material

Data were collected from several questionnaires, from travel and charge diaries, and from focus groups. To assess changes in behaviour and acceptability occurring over time with use of the EV, data

were collected across three time intervals: at T0 month, T3 months and at T6 months. The data collection tool set was designed originally by the German research team that worked on the first MINI E study (Bühler, Neumann, Cocron, Franke, & Krems, 2011; Franke, Bühler, Cocron, Neumann, & Krems, 2012; Franke & Krems, 2013^a; Franke & Krems, 2013^b; Krems, Franke, Neumann, & Cocron, 2010).

2.2.1 Questionnaires

Two questionnaires were administered during a face-to-face interview at the beginning of the study (T0 month), before and after a short test drive of the MINI E. During the test drive each participant, accompanied by the interviewer, drove the MINI E for 30 minutes around the BMW Velizy car dealership in Paris. The first questionnaire addressed the prospective views and expectations of future users about the electric vehicle, their considerations about the ecological and technical aspects of EVs and also their driving habits with a traditional car. The second questionnaire contained items relating to their impression of the MINI E driving experience and properties.

After 3 months of use of the electric car (T3 months), participants were asked to complete two questionnaires on the Internet, containing items that were either existing items from T0 month, or new items. The new ones related to the experience and perceptions of participants about the use of the MINI E on a daily basis. Several topics were covered: the drive, charge, displays inside the car, the absence of noise of the vehicle, regenerative braking, and critical situations encountered. Finally, after 6 months (T6 months), participants again completed a questionnaire during a face-to-face meeting, in which the majority of items were identical to items from previous questionnaires. This long delay allowed us to consider the responses as being no longer the result of attraction to the novelty of the vehicle per se but, probably, as the reflection of the implementation of sustainable behaviours that persisted over time.

2.2.2 Travel Patterns

During the study, participants also completed travel and charge diaries, each for a period spanning one week. At T0 month, before they used the EV, they had to register in a travel diary all their trips,

detailing the trip distance, means of transport taken, the purpose of the trip, and departure and arrival times for their own conventional car. At T3 and T6 months, they completed travel diaries pertaining to all of their trips, including those with the MINI E. Users were also required to complete charge diaries detailing all battery charges that they made during a one-week period. Here, users reported on the following characteristics: place of charge, charge status at the beginning and the end of the charging process, and the reasons for the charge. Obviously, daily record keeping was desirable, but the rhythm of life of participants would not allow them to be truly exhaustive in their note taking for the entire duration of the study. So, to ensure that they recorded information accurately, it was expected that each diary should be completed for one week only. This short period of data collection yielded high-quality data, since the exercise wasn't constraining.

2.3 Participants

More than 900 people applied online to participate in this study. Applicants were invited to provide information about relevant aspects of their socio-demographic and psychographic background and were asked to indicate whether they would actually be able to use the MINI E on a regular basis, and to pay a monthly leasing fee of typically about 475 euros per month, including insurance (see Vilimek et al., 2012).

Fifty subjects were chosen based on the number of kilometers they were driving each day. The aim was to recruit drivers who would drive often enough to experience the vehicle and adapt to its novel features. They were also chosen on the basis that they lived in the Paris area, had a garage or a dedicated parking place for the car, and had access to suitable electrical power and other technical apparatus needed to drive the vehicle. Finally, the selection procedure was aimed at ensuring a minimum number of women were included in the sample and to have a majority of drivers who had had no experience with electric or hybrid vehicles.

For this paper, data for only 36 participants were analyzed because of difficulties associated with the long (6-months) duration of the study: some subjects dropped out of the study and others did not

respond to all of the administered questionnaires. Overall, the sample comprised six women and thirty men, with an average age of 44.1 years (SD = 7.98). Of these, 27.8% were driving more than 70 km per day, 30.6% had already owned a conventional MINI vehicle, 25% had experienced an electric vehicle and 19.4% had experienced a hybrid vehicle. All participants had at least one car at home; and 75% at least two. Whilst the MINI E is only a two-seat car, all participants were allowed during the study to use their own, private, vehicle(s) to carry additional passengers, or for long trips that exceeded the range of the MINI E.

3 Results

In order to study the changes reported by participants in behaviour that occurred after a long period of use of EVs, we analyze in this paper results from the post test-drive questionnaire (at T0 month, after 30 minutes of use), and from the final questionnaire (at T6 months, after 6 months of use). Moreover, the travel diaries at T0 month and T6 months are compared, and the charge diary at T6 months is examined.

The results are derived from the quantitative analysis of Likert scales and diaries. The questionnaires contained items measured on a Likert scale of six points, ranging from 1 "very strongly disagree" to 6 "very strongly agree". Other items, involving ranking by preference, also needed to be completed.

In Annex 1 we present for each six points of the Likert scale item the number and percentage of participants who responded, respectively. We also indicate the percentage of "agreement" answers that result from the aggregation of the top three values for the six points of the Likert scale (answers 4-5-6). To test whether the "agreement" percentage is significantly in the majority or minority, a one sample z-test for proportions was used to compare this value to 50%. For that we used a one-sample z-test for proportions. The percentage of agreement, margin of error and significance values derived from the z-test are detailed in Annex 1. The items with a significant result are indicated by an asterisk. Missing values on the Likert scales questions analyzed in this paper were under 1%. Concerning the diaries, only 28 participants (78%) filled out both the travel diaries at T0 month and T6 months. The

results were performed only on 26 participants, as data for two participants had to be filtered: one because her professional activity was very different on the two weeks studied (she is a nurse), the other because the MINI E was under repair for 5 days during the last period concerned. For these 26 participants, 24 filled in the charge diary at T6 months. Finally, in order to analyze the travel diaries and compare proportions performed for the T0 and T6 periods, we used Chi-Square tests. The output for this paper was generated using SAS/STAT software, Version 9 of the SAS System for Windows.

3.1 EV: easy handling but inducing new tasks while driving

The results at T0 month show, after the MINI E first test drive, that most participants consider its handling relatively easy: more than 90% of them think it is easy to use and to learn to use this vehicle (Items 1*, 2*). However, it must not be forgotten that 25% of participants had experienced an electric vehicle before the study, making this first experience with the MINI E even easier for them. Even though a majority of the participants considered driving to be easy, we note that 22% of participants consider the amount of mental workload required to drive the MINI E greater than that for a conventional car (Item 3*), and that learning to use the MINI E reportedly distracted them from normal driving activities (Item 4*).

The results also show that most participants need time to master the electric vehicle features. Sixty seven percent of participants expect (Item 5) that, while driving, they will often be concerned about the driving range. This result is confirmed by the T6 months result which shows that 50% of participants also reported that they deliberately tried to exhaust the range several times in order to see how far they could go with the MINI E (Item 6).

Concerning the silent properties of the EV, the first test of 30 minutes revealed that nearly 90% of participants (Items 7*, 8*) are reportedly aware that they will have to be particularly attentive to pedestrians and cyclists due to the low engine noise of the MINI E. Finally, regarding the regenerative braking, 100% of participants are confident in the fact they will very quickly get used to this new feature (Item 9*), while bearing in mind that their driving style will change as a result of using the

regenerative braking system (94%) (Item 10*).

Concerning our first hypothesis, all of these results confirm that optimizing the use of the electric vehicle is not immediate, and requires more than one experience with the vehicle to manage all specific particularities of the electric driving activity, despite a reported relatively easy handling.

The analysis of the results obtained at the end of the study, namely after 6 months of daily use of the EV, allows us to explore in detail the new driving behaviours that are established in order to master this electric driving activity. These results are presented in the following sections.

3.2 Integration of the range limitation into trip planning

3.2.1 Drivers are not accustomed to managing energy daily

After 6 months of use, 78% of participants reported they had to get used to the handling of the limited range for planning of trips (Item 11*). However, the time needed to get used to the restricted range and charging issues of the car required a maximum of a few weeks: for 44% of participants the habituation required on average 2 weeks; for 31% of participants 4 days; for 14% of them 2 hours; and, for 11% of participants, habituation was reportedly immediate (participants completed the Item “Getting used to the MINI E as means of transport -i.e. restricted range, charging- took me ... week, days, hours”)..

3.2.2 Strategies development

Regarding the establishment of strategies in order to manage the range limitation, 47% of the drivers reportedly took trips which allowed them to use less energy (Item 12). Concerning the charging process, one can observe the development of habits confirmed by 72% of users, who declared at the end of the study that charging the MINI E became a daily routine (Item 13*). In more detail, analysis of charge diaries shows that participants charged their vehicle on average 4.9 times per week (the average is derived from the aggregated values of each participant), mainly at night in 67% of cases, and at home in 79% of cases. On this last point, we can note that most drivers (94%) appreciated being able to charge their MINI E at home and therefore no longer needing to go to the gas station (Item 14*). These data are consistent with previous findings which depict similar management strategies by

the development of additional adaptations (Woodjack et al., 2012), and everyday routines (Franke & Krems, 2013^c; Franke, Neumann et al., 2012; Bunce et al., 2014).

3.2.3 Emergence of new planning behaviours

Finally, the results presented below highlight the emergence of new planning behaviours at the *strategic* level of the EV driving. Here, analysis of travel diaries reveals that the number of trips involving a car significantly increases between T0 month and T6 months: from 81% (ME = +/-2.9%) at T0 month to 90% (ME = +/-2.3%), $X^2(1, N = 1331) = 23.27, p < .0001$, at T6 months. These data are consistent with those reported by Rolim and colleagues (2012), who found that one third of their participants considered after 5 months of EV use that they made more trips (see also Woodjack et al., 2012).

In more detail, 84% (ME = +/- 11.9%) of trips are made by participants with the MINI E and 16% (ME = +/- 11.9%) with their own car at T6 months of the study. Focusing on the reasons why participants have chosen their own car instead of the MINI E, participants mention the capacity of the EV (number of passengers or storage) for 67% of the 91 trips (ME = +/- 9.7%) and the limited charge of the MINI E for 32% of the trips (ME = +/- 9.6%).

To analyze the impact of the MINI E on mobility, we chose to restrict the sample on trips that could have been done by a MINI E in the two periods; that is, trips involving a car with 0 or 1 passenger. An interesting difference appears for small distances. The proportion of trips less than 5 km is significantly more important at T6 months than at T0 month: 56% (ME = +/-4.4%) against 44% (ME = +/- 4.4%), $X^2(1, N = 968), p < .05$.

Moreover, 67% of drivers declared in questionnaires that they used the MINI E more than their traditional car for short trips (Item 15) and a third of users declared that they had used the MINI E for trips they usually did by foot (or by bike) before the study (Item 16). When we observe the proportion of trips done partially or completely by foot or bike indicated in the travel diaries, we obtain 19% (ME = +/- 2.9%) at T0 month against 12% (ME = +/- 2.4%) at T6 months. The difference is significant ($X^2(1, N = 1331) = 11, p < .001$).

This increase in small trips with use of the EV might be explained by the ecological nature of the electric car. When participants were asked to evaluate the major advantages of the electric vehicles (Annex 2), the environmental point of view (the fewer localized carbon emissions while driving and the fewer carbon emissions in general if the electricity is produced by renewable energy) was the main reason chosen, which removes any guilt of participants in using more frequently their electric vehicle. Of course, it is also possible that the increase in use of the EV is due to the novelty of the vehicle and the impact of the monthly fixed payment schedule or the cheap charging process (around 1 euro for 100 km, against 5 euros with a fueled vehicle). However, the analysis of the data between T3 months and T6 months shows that the number of trips involving only the car was relatively similar between T3 months (94%, ME = +/- 1.9%) and T6 months (90%, ME = +/- 2.3%). Thus, the initial enthusiasm can't explain by itself the increased use of the car in the long-term.

According to our second hypothesis relating to range management, , these results confirm that limited range involves re-definition of routes, development of a strategy for planning charges, and reconsideration of choice of using different modes of current transport. All of these adapted behaviours occur in a period of a few days or weeks and seem to result from the daily use of the EV. This idea is supported by the Woodjack et al. (2012) study which develops the notion of a lifestyle learning process and suggests that drivers learn about the unique attributes of an electric vehicle and incorporate these discoveries into their lifestyles, or “routinized practices”.

3.3 Dealing with the EV silent features

As noted in the introduction, another important property of the EV is its silent feature. At low speed (around 30 km/h), unlike a conventional vehicle, EVs emit no engine noise and their approach may not be perceived by pedestrians (by contrast, beyond 20-30 km/h, the rolling noise of the vehicle on the road is more and more dominant and other users more easily hear it approaching; see Czuka et al., 2014).

The data from the present study show that at T6 months, 58% of participants considered the MINI E

difficult for others to hear (item 17); and, more precisely, 28% say that occasionally they weren't noticed, or were noticed late, by pedestrians (and 11% say that they were frequently not noticed by cyclists). In response to a question about situations where road users didn't hear the EV driver (Annex 3), participants confirmed that these risky situations relating to the acoustic properties of the MINI E took place at less than 30 km/h, occurred primarily in parking areas where pedestrians did not perceive that the car had started (drivers had to honk the horn to warn them), or occurred in underground garages, on driveways, and during snowy days ("when pedestrians only looked at their feet and were therefore less aware of cars").

Finally, half of all users think the lack of noise of the MINI E is potentially dangerous (item 18), which could explain why 58% of them declared that they had to get used to it (item 19), and 39% of users reported that they had to change their driving behaviour due to this silent feature (item 20). Even if they have to pay more attention to pedestrians and drive differently, the absence of noise is perceived as an advantage for drivers (on a scale of 1 - no advantage - to 100 - major advantage - drivers reported a score of 77.3, on average; $SD = 21.45$). Seventy eight percent do not want outside vehicle noise, even though the provision of artificial noise could strengthen the perception of low-speed vehicles for other road users, especially pedestrians (item 21*).

To conclude, the lack of noise at low speed seems to imply a change in the interaction between EV drivers and other road users, since usually their perception of the traffic environment is based on information from both the visual and auditory modalities. Because pedestrians can't hear the EV, they are more vulnerable and the EV drivers need to pay more attention. As we proposed in our hypotheses, drivers adapt their driving behaviours at the *tactical* level to compensate for the lack of noise.

3.4 Saving and regenerating electric energy while driving

The regenerative braking function in the EV offers new possibilities in addition to the different driving maneuvers possible in conventional cars. The analysis of the data confirms that new driving operational behaviours are quickly acquired in relation to this particular feature. Indeed, for 89% of

users their driving style changed as a result of using the regenerative braking function in the MINI E (Item 22*). The consequence is that, more generally, half of them think that with their MINI E they drove in a more flexible way than with a conventionally fueled car (Item 23), and 19% of participants report that the MINI E made them safer drivers when they drove it (Item 24*). These participants declared that they anticipated more their braking distances and tried to drive more softly, therefore inducing a more energy-efficient driving style. Thus, the regenerative braking function not only allowed drivers to regenerate electric energy while driving, but it also led some participants to adopt driving behaviours more suitable for limited range since they used it to save energy.

Another important point highlighted by the data is how much participants appreciated the regenerative feature: 100% of them liked to be able to accelerate and decelerate using just one pedal (Item 25*), and 89% missed the deceleration by regenerative braking when they drove a conventional vehicle (Item 26*). Ninety-seven percent of participants indicated that they would like to have an energy saving system in conventional vehicles that operates like the regenerative braking system in the MINI E (Item 27*).

It seems that the pleasure of, and advantages in using, regenerative braking led to a very frequent utilization of this feature, which become almost procedural. For 83% of participants, use of regenerative braking in order to avoid the use of the braking pedal was game-like (Item 28*), and they estimated that they used it instead of the brake pedal in 89.9% (SD = 8.51) of braking situations (participants completed the Item: “For what percentage of braking situations did you use the regenerative braking instead of using the brake pedal?”). Whether this actually enhances or reduces safety in situations that require emergency braking is an important issue for further research.

The reportedly automatic control of the regenerative braking was acquired rapidly. All participants estimated that this occurred quickly (Item 29*): 58% of participants estimated that they needed 1.5 hours to use it automatically; 33% of participants estimated 3 days; for 6% of participants it was reportedly immediate; and for 3% of participants assessed it to took 4 weeks (participants completed the Item: “Adapting to the regenerative braking took me...weeks, days, hours”). Similar findings for a short adaptation phase are reported by Cocron and collaborators (2013).

In summary, these results show that the driving experience of the MINI E leads quickly, based on the self-reported behaviours of drivers, to behavioural control of the regenerative braking function. As we proposed in our last hypothesis, this new feature alters the activity of driving in an operational way since the users only use a single pedal (i.e., the accelerator pedal) to accelerate and decelerate; it also plays a role in the implementation of strategic energy management as its use enhances energy conservation.

4 Discussion

4.1 Adaptive driving behaviours arise at all driving levels

The study described in this article has focused on driving activity related to the daily utilization of the EV; specifically, the MINI E. The advantage of this longitudinal study was to identify, from the self-reported behaviours of MINI E drivers, adapted driving behaviours that emerge after several months due to the special properties of the vehicle.

Concerning the limited range of the EV, the findings of our study are consistent with those of other longitudinal studies (Franke, Neumann et al., 2012; Pichelmann et al., 2013; Rolim et al., 2012; Woodjack et al., 2012), in showing that handling this limitation leads participants to maximize driving distances. In order to optimize range management, participants also defined from their experiences the best way to charge the MINI E to suit their lifestyle and their needs. Our findings support the charging routine described by Bunce and collaborators (2014) who concluded that drivers' charging behaviour became more "relaxed overtime as they developed knowledge and confidence in the battery range" (Bunce et al., 2014, p. 286). However, our work highlights some new self-reported habits that appear at the strategic level: participants establish new trip planning behaviours. They made more short trips and used the car more frequently during their travels. We proposed that this reorganization of trip planning might be due to the ecological properties of the EV: the electric driving activity is also

modified by the possibility to use cleaner fuels.

Regarding other EV features, participants reported that the silent function would involve appropriate anticipated driving behaviours. They also identified typical risky situations where they were more attentive, modifying the tactical level of EV driving. These results are in the same direction as those reported by Cocron and Krems (2013) on driver perceptions of the safety implications of quiet electric vehicles. Drivers identified similar risky situations and reported that they looked out for cyclists and pedestrians to proactively prevent critical incidents. Overall, the results presented in this article confirm that, even if learning to operate the EV is relatively simple, driving efficiently seems not to be spontaneous: a period of handling would be necessary to implement more effective behaviours at all levels of the electric driving activity.

Finally, concerning the regenerative braking function, the self-reported behaviours of drivers indicate that it rapidly enriches maneuver control at the operational level of driving. The majority of participants declared to have modified their driving style and some to have driven in a more flexible way. They also declared to use the regenerative braking function very frequently (around 90% of the braking situations) and that this acquisition was very quick. Ours results are consistent with those of another longitudinal study (Cocron et al., 2013) which reported, from onboard data logger recordings, the same rapidity in learning to use the regenerative braking, and the same frequency of use.

4.2 Adaptive driving behaviours emerge progressively: The Rasmussen Model explanation

Each property of the MINI that is to be managed (range, silent feature, regenerative braking) does not present itself at the same frequency during the driving activity; and so, the period of handling will vary. In the Human Behaviour model of Rasmussen (1983), behaviours are distinguished according to their familiarity with the task for which they are implemented. When the situation is novel and unexpected the individual will plan his/her actions from all his/her knowledge according to the aims established. However, when similar situations occur on several occasions, the individual develops rule-based behaviours or procedures learned through successful experiences. Finally, Skill-based

behaviours are developed through practice of repeated situations, involving primarily the automation of sensorimotor tasks.

In the case of the management of the limited range, we propose that drivers seem to develop with practice strategies which become rules and procedures over time, adopting the most appropriate behaviours to save energy: drivers take greater account of the distance of their trips; they acquire daily charge processes; and they reconsider their choice of using different modes of current transport. These rules and procedures can explain why, at the end of the study, more than half of participants (58%) perceived the range as less constraining than they thought it would be at the beginning of the study (Item 19).

Concerning the accumulation of risky silent situations due to the fact that the pedestrian does not hear the car coming (in parking lots or garages, or on snowy days), the Human Behaviour model of Rasmussen leads us to propose that electric vehicle drivers progressively identify rules to follow which change their driving behaviour to overcome pedestrian conflicts. Drivers are confident to the point that they prefer to enhance their attention and identify these rules and procedures with practice, rather than to add artificial external noise on the car.

Finally, regarding the regenerative braking, EV users declared a very frequent use: according to them, around 90% of the braking situations were supported by this function. So, through daily use of it, the driving experience seems to lead quickly to acquisition of procedural skills; that is, an automatic control of the regenerative braking. This would have the effect that participants modify their driving style to obtain the most appropriate behaviours to save energy while driving in order to guarantee the range of the vehicle.

Globally, as was expected, behaviour modifications emerged progressively at all driving activity levels (Michon, 1978, 1985) in order to optimize daily mobility and to make EV use safer. Behaviours arise in the driving activity of EV, and transform it as driving skills and rules are acquired over time.

4.3 Proposition of a Transversal Modulation

An interesting finding revealed by our study is what we may term the “Transversal Modulation” that each level of the electric driving activity induces on the other levels. For example, the strategic level will benefit from the development of the driving skills at the operational level. According to the self-reported behaviours of drivers, the consequence of the regenerative braking is the implementation of strategic energy management because its use enhances energy conservation and, so, offers new strategic possibilities. Otherwise, because driving in a more flexible way allows the driver to save more energy, operational skills will also positively influence the tactical level of the EV driving by decreasing the potential for a critical event. Finally, as proposed by Rasmussen (1983), mastering driving skills allows for a reduction in mental workload and the ability to devote attention to other events: operational skills will thus allow for the allocation of more attention at the tactical level. In the same vein, tactical rules followed by the driver to increase their attention to pedestrians force them to modify their driving to anticipate pedestrian behaviours. Tactical rules influence the operational level by inducing a driving style that is more flexible. Finally, strategic rules may also influence other levels of driving activity: because the driver selects trips less costly in terms of energy, the driver decreases the operational management of the range.

In view of these transversal relationships between levels involved in the electric driving activity, the period of handling the range issue requires the driver not only to adopt effective strategic behaviours, but also skills and rules at the other driving levels. Our participants declared that they got used to the restricted range and charging issues of the car in a maximum of two weeks. But, in reality, the time required should be longer for optimal management: our results show that driving at the strategic level would be optimized by behaviours which emerge from the management of the other levels. In the experiment of Pichelmann and collaborators (2013), the authors concluded (via a data logger which recorded the maximum available range of EV drivers during daily use), that a person needs approximately three months to complete adaptation to EV range. The difference between their result and the self-reports of our participants shows that several factors are at work to optimize range management, and one could conclude that the emergence of effective range optimization behaviours

continues for a long period of use, well after the time at which the driver thinks s/he has mastered the range issue.

Finally, we acknowledge that this study has some limitations. The sample of participants is not representative of the whole population, but rather of potential early adopters of EV s (exemplified by their previous experience of electric or hybrid vehicles). Hence, the findings are not truly representative of the French population at large. Furthermore, the study is a self-reported assessment of driving changes provided by participants of the study; and, hence, it is possible that there may be some discrepancies between self-reported and actual behaviours. Nevertheless, the findings of the study improve further our understanding of driver adaptation to electric vehicles.

5 Conclusions

The findings from this study are generally consistent with previous research that has described how EV users deal with range and mobility during daily use of this kind of vehicle. However, our study goes further by categorising new behaviours that arise at each of the levels of the driving activity (strategic, tactical and operational) and by proposing the Transversal Modulation that each level of electric driving activity seems to induce on other levels.

The aim of the next phase of our research program will be to design and develop training aids for drivers of the electric car, which highlight and accelerate the acquisition of the rules and EV skills that optimize the efficiency and safety of EV driving. This training assistance would detail the ideal behaviours to have in order to drive in an eco-driving manner, thereby helping to reduce drivers' concerns related to limited range, optimise safety, and provide a basis for the more widespread uptake of EV's within the general vehicle fleet.

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Annex 1

| Items | Detailed answers | | | | | | Percentage of agreement answers | | |
|---|------------------------|-------------------|-----------------|--------------|----------------|---------------------|---------------------------------|--------|------|
| | Very strongly disagree | Strongly disagree | Mostly disagree | Mostly agree | Strongly agree | Very strongly agree | Agree | z | P |
| Please indicate your level of agreement with the following statements: | Number & percentage | | | | | | Cum % & ME | | |
| Easy handling but inducing new tasks while driving | | | | | | | | | |
| 1 The MINI E is easy to use | 0 | 0 | 2 | 13 | 21 | 0 | 94% | 5.328 | .001 |
| <i>T0 month</i> | 0% | 0% | 6% | 36% | 58% | 0% | 7.5 | | |
| 2 It was easy to learn how to use the MINI E | 1 | 0 | 2 | 17 | 16 | 0 | 92% | 5.004 | .001 |
| <i>T0 month</i> | 3% | 0% | 6% | 47% | 44% | 0% | 9 | | |
| 3 The amount of mental workload required to drive the MINI E is greater than that for a conventional car | 13 | 11 | 4 | 8 | 0 | 0 | 22% | -3.336 | .001 |
| <i>T0 month</i> | 36% | 31% | 11% | 22% | 0% | 0% | 13.6 | | |
| 4 Learning to use the MINI did not distract me from normal driving activities | 0 | 3 | 5 | 16 | 12 | 0 | 78% | 3.336 | .001 |
| <i>T0 month</i> | 0% | 8% | 14% | 44% | 33% | 0% | 13.6 | | |
| 5 While driving I will often be concerned about the driving range | 1 | 1 | 10 | 14 | 8 | 2 | 67% | 2.004 | .053 |
| <i>T0 month</i> | 3% | 3% | 28% | 39% | 22% | 6% | 15.4 | | |
| 6 I deliberately tried to exhaust the range several times in order to see how far I could go with the MINI E | 1 | 4 | 13 | 12 | 4 | 2 | 50% | 0.000 | .398 |
| <i>T6 months</i> | 3% | 11% | 36% | 33% | 11% | 6% | 16.3 | | |
| 7 Due to the low engine noise of the MINI E, I will have to be particularly aware of pedestrians | 1 | 0 | 3 | 8 | 9 | 15 | 89% | 4.668 | .001 |
| | | | | | | | 10.3 | | |

| | | | | | | | | | |
|--|----|----|----|-----|-----|-----|-------|-------|-------|
| <i>T0 month</i> | 3% | 0% | 8% | 22% | 25% | 42% | | | |
| 8 Due to the low engine noise of the MINI E, I will have to be particularly aware of cyclists | 1 | 0 | 3 | 4 | 14 | 14 | 89% | 4.668 | .001 |
| <i>T0 month</i> | 3% | 0% | 8% | 11% | 39% | 39% | 10.3 | | |
| 9 I will get used to the regenerative braking system pretty quickly | 0 | 0 | 0 | 4 | 14 | 18 | 100% | 6.000 | .001 |
| <i>T0 month</i> | 0% | 0% | 0% | 11% | 39% | 50% | 0.000 | | |
| 10 My driving style will change as a result of using the regenerative braking | 0 | 1 | 1 | 10 | 13 | 11 | 94% | 7.5 | 5.328 |
| <i>T0 month</i> | 0% | 3% | 3% | 28% | 36% | 31% | | | |

Integration of the range limitation into trip planning

| | | | | | | | | | |
|--|-----|-----|-----|-----|-----|-----|-------|--------|------|
| 11 I had to get used to the handling of the range (planning of trips etc.) | 0 | 1 | 7 | 13 | 9 | 6 | 78% | 3.336 | .001 |
| <i>T6 months</i> | 0% | 3% | 19% | 36% | 25% | 17% | 13.6 | | |
| 12 When I can, I do trips which allow me to use less energy | 8 | 5 | 6 | 11 | 3 | 3 | 47% | -0.329 | .744 |
| <i>T6 months</i> | 22% | 14% | 17% | 31% | 8% | 8% | 16.3% | | |
| 13 Charging the MINI E became a daily routine to me | 3 | 0 | 7 | 7 | 8 | 11 | 72% | 2.664 | .05 |
| <i>T6 months</i> | 8% | 0% | 19% | 19% | 22% | 31% | 14.6 | | |
| 14 Appreciate being able to charge at home and therefore no longer needing to go to the gas station | 0 | 1 | 1 | 1 | 11 | 22 | 94% | 5.328 | .001 |
| <i>T6 months</i> | 0% | 3% | 3% | 3% | 31% | 61% | 7.5 | | |
| 15 For short trips, I used more the MINI E than my traditional car | 9 | 1 | 2 | 7 | 11 | 6 | 67% | 2004 | .053 |
| <i>T6 months</i> | 25% | 3% | 6% | 19% | 31% | 17% | 15.4 | | |
| 16 I used the MINI E for trips I usually do by foot (or by bike) before the study | 14 | 4 | 6 | 9 | 3 | 0 | 33% | -2.004 | .053 |
| <i>T6 months</i> | 39% | 11% | 17% | 25% | 8% | 0% | 15.4 | | |

Dealing with the EV silent features

| | | | | | | | | | |
|---|-----|-----|-----|-----|-----|----|------|--------|------|
| 17 The MINI E is difficult for others to hear | 2 | 3 | 10 | 17 | 1 | 3 | 58% | 0.996 | .242 |
| <i>T6 months</i> | 6% | 8% | 28% | 47% | 3% | 8% | 16.1 | | |
| 18 The low noise outside of the MINI E is potentially dangerous | 6 | 6 | 6 | 14 | 4 | 0 | 50% | 0.000 | .398 |
| <i>T6 months</i> | 17% | 17% | 17% | 39% | 11% | 0% | 16.3 | | |
| 19 While driving the MINI E, I mostly had to get used to the lack of noise | 1 | 2 | 12 | 14 | 6 | 1 | 58% | 0.996 | .242 |
| <i>T6 months</i> | 3% | 6% | 33% | 39% | 17% | 3% | 16.1 | | |
| 20 I had to change my driving behavior due to the lack of outside noise of the MINI E | 5 | 7 | 10 | 11 | 3 | 0 | 39% | -1.332 | .164 |
| <i>T6 months</i> | 14% | 19% | 28% | 31% | 8% | 0% | 15.9 | | |
| 21 I would not mind if my MINI E had an idle noise so that others can hear me at any time (while standing, with engine on) | 11 | 6 | 11 | 7 | 0 | 1 | 22% | -3.336 | .001 |
| <i>T6 months</i> | 31% | 17% | 31% | 19% | 0% | 3% | 13.6 | | |

Saving and regenerating electric energy while driving

| | | | | | | | | | |
|---|-----|-----|-----|-----|-----|-----|-------|--------|------|
| 22 My driving style changed as a result of using the regenerative braking function in the MINI E | 1 | 0 | 3 | 13 | 11 | 8 | 89% | 4.668 | .001 |
| <i>T6 months</i> | 3% | 0% | 8% | 36% | 31% | 22% | 10.3 | | |
| 23 With my MINI E I drove in a more flexible way than with a conventional car. | 4 | 4 | 9 | 9 | 7 | 3 | 52% | 0.240 | .387 |
| <i>T6 months</i> | 11% | 11% | 25% | 25% | 19% | 8% | 16.3 | | |
| 24 The MINI E made me a safer driver when I drive it | 5 | 4 | 20 | 4 | 2 | 1 | 19% | -3.672 | .001 |
| <i>T6 months</i> | 14% | 11% | 56% | 11% | 6% | 3% | 12.9 | | |
| 25 I liked the fact that I could accelerate and decelerate using just one pedal in the MINI E | 0 | 0 | 0 | 6 | 9 | 21 | 100% | 6.000 | .001 |
| <i>T6 months</i> | 0% | 0% | 0% | 17% | 25% | 58% | 0.000 | | |
| 26 When I drive a conventional vehicle I am missing the deceleration by regenerative braking | 1 | 1 | 2 | 6 | 11 | 15 | 89% | 4.668 | .001 |
| <i>T6 months</i> | 3% | 3% | 6% | 17% | 31% | 42% | 10.3 | | |

| | | | | | | | | | |
|---|----|----|-----|-----|-----|-----|-------|-------|------|
| 27 I would like to have an energy saving system in conventional vehicles that operates like the regenerative braking system in the MINI E | 0 | 0 | 1 | 14 | 10 | 11 | 97% | 5.664 | .001 |
| <i>T6 months</i> | 0% | 0% | 3% | 39% | 28% | 31% | 5.4 | | |
| 28 It has become a bit of sport or game for me using the regenerative braking so that I can get to my desired position without having to use the braking pedal | 0 | 2 | 4 | 9 | 9 | 12 | 83% | 3.996 | .001 |
| <i>T6 months</i> | 0% | 6% | 11% | 25% | 25% | 33% | 12.2 | | |
| 29 I got used to the regenerative braking system pretty quickly | 0 | 0 | 0 | 7 | 15 | 14 | 100% | 6.000 | .001 |
| <i>T6 months</i> | 0% | 0% | 0% | 19% | 42% | 39% | 0.000 | | |

Annex 2

| Items | Degree of advantage | | |
|---|---------------------------------|------|------|
| <i>T6 months</i> | Percentage & Margin of Error | z | p |
| In your opinion, what are the major advantages of electric vehicles like the MINI E? | | | |
| Please indicate the degree of advantage on a scale of 1 (no advantage) to 100 (major advantage). | | | |
| Quieter inside the car | 78% | 3.36 | .001 |
| Less noise outside | 77% | 3.24 | .01 |
| Fewer localized carbon emissions while driving | 87% | 4.44 | .001 |
| | 11 | | |

| | | | |
|--|------|-------|------|
| Fewer carbon emission in general (incl. electricity generation), when charged with 'green power' (low CO2) | 68% | | |
| | 15.2 | 2.16 | .05 |
| Fewer carbon emission in general if the electricity is produced by renewable energy | 83% | | |
| | 12.3 | 3.96 | .001 |
| Support of developing the availability of renewable energies | 69% | | |
| | 15.1 | 2.28 | .05 |
| Possibility to charge during peak hours (cheap) | 65% | | |
| | 15.6 | 1.8 | .07 |
| Feeling less guilty about driving a car | 46% | | |
| | 16.3 | -0.48 | .356 |
| Fast acceleration of the vehicle | 80% | | |
| | 13.1 | 3.6 | .01 |
| Less dependence on fossil fuels such as oil | 79% | | |
| | 13.3 | 3.48 | .001 |
| Lower costs (energy costs) than for a conventional combustion engine vehicle | 78% | | |
| | 13.5 | 3.63 | .001 |

Annex 3

| Items <i>T6 months</i> | Detailed answers | | | | | Percentage of agreement answers | | |
|---------------------------|---------------------|-------------|--------|--------------|------------|---------------------------------|-------|---|
| | Never | Very rarely | Rarely | Occasionally | Frequently | Very frequently | Agree | |
| | Number & percentage | | | | | Cum % | z | P |
| | | | | | | & ME | | |

How often did other road users not see/hear you (or see/hear you too late) in the following situations:

| | | | | | | | | | |
|------------------------------------|-----|-----|-----|-----|----|----|------|-------|------|
| While starting the car. | 18 | 7 | 3 | 6 | 0 | 2 | 22% | -3.36 | .001 |
| | 50% | 19% | 8% | 17% | 0% | 6% | 13.6 | | |
| While turning the car off | 26 | 5 | 4 | 1 | 0 | 0 | 3% | -5.66 | .001 |
| | 72% | 14% | 11% | 3% | 0% | 0% | 5.4 | | |
| While parking the car | 15 | 8 | 6 | 4 | 3 | 0 | 19% | -3.67 | .001 |
| | 42% | 22% | 17% | 11% | 8% | 0% | 12.9 | | |
| While driving the car < 30 km/h | 13 | 7 | 8 | 5 | 2 | 1 | 22% | -3.36 | .001 |
| | 36% | 19% | 22% | 14% | 6% | 3% | 13.6 | | |
| While driving the car in > 30 km/h | 28 | 2 | 5 | 1 | 0 | 0 | 3% | -5.66 | .001 |
| | 78% | 6% | 14% | 3% | 0% | 0% | 5.4 | | |
| In car parks | 12 | 7 | 4 | 11 | 2 | 0 | 36% | -1.66 | .099 |
| | 33% | 19% | 11% | 31% | 6% | 0% | 15.7 | | |
| By turning | 21 | 3 | 8 | 4 | 0 | 0 | 11% | -5.87 | .001 |
| | 58% | 8% | 22% | 11% | 0% | 0% | 10.2 | | |