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Article

Influence of Adaptive Human–Machine Interface on Electric-Vehicle Range-Anxiety Mitigation

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Abstract: The electrification of vehicles is without a doubt one of the milestones of today's automotive technology. Even though industry actors perceive it as a future standard, acceptance, and adoption of this kind of vehicles by the end user remain a huge challenge. One of the main issues is the range anxiety related to the electric vehicle's remaining battery level. In the scope of the H2020 ADAS&ME project, we designed and developed an intelligent Human Machine Interface (HMI) to ease acceptance of Electric Vehicle (EV) technology. This HMI is mounted on a fake autonomous vehicle piloted by a hidden joystick (called Wizard of Oz (WoZ) driving). We examined 22 inexperienced EV drivers during a one-hour driving task tailored to generate range anxiety. According to our protocol, once the remaining battery level started to become critical after manual driving, the HMI proposed accurate coping techniques to inform the drivers how to reduce the power consumption of the vehicle. In the following steps of the protocol, the vehicle was totally out of battery, and the drivers had to experience an emergency stop. The first result of this paper was that an intelligent HMI could reduce the range anxiety of the driver by proposing adapted coping strategies (i.e., transmitting how to save energy when the vehicle approaches a traffic light). The second result was that such an HMI and automated driving to a safe spot could reduce the stress of the driver when an emergency stop is necessary.

Keywords: range anxiety mitigation; human factors; driver acceptance; electric vehicle; human–machine cooperation; human–machine interfaces; user experience; Wizard of Oz autonomous driving

1. Introduction

The concept of range anxiety (or range paradox) emerged in the late 1990s regarding the concern of being unable to reach the destination or the next charging spot while traveling in an EV [1]. It is the stressful experience of a present or anticipated range situation, where range resources and personal resources are in fact available to effectively manage the situation, but they are perceived to be insufficient [2]. When concern due to remaining range becomes legitimate, the emotion is fear that is associated with immediate danger rather than a state of anticipated uncertainty [1]. A consequence of range anxiety is that, although EV drivers usually need approximately 160 km of available range (autonomy) per charge [3], drivers often prefer vehicles with considerably higher available autonomy (~350 km) [4]. This demand (which seems avoidable) comes from the following [1],

- worry of being immobilized due to low vehicle battery in the future or present,
- what happens if such a situation emerges,
- not being able to find a solution to the situation, and
- being stranded in an uncomfortable situation.

As such, manufacturers can either improve their vehicle's range-related parameters or invest in an alternative system to lower range anxiety, making EV competitors to gasoline and diesel cars [5]. The four important physical parameters that could make a difference in range anxiety level are the following [5],

- battery capacity (kWh),
- energy consumption (mostly affected by car weight; kWh/km),
- charging rate (kW), and
- minimal state of charge (%).

Despite that each of these parameters could be individually optimized, their effects are inversely proportional between them. As an example, implementing a larger battery also increases the weight (so, energy consumption) and charging of the vehicle. This is why range anxiety cannot be eliminated by purely quantitative means [5], which motivated the present study to investigate other innovative solutions.

The H2020 ADAS&ME project is based on human behavior that occurs in every driving session that may lead to critical situations and crashes. The purpose of the project is to demonstrate how the use of cooperative intelligent transportation systems and automated safety functions, together with unobtrusive driver monitoring, can compensate for human errors, and enhance safety and driving comfort. To achieve this goal, a holistic approach was taken in the project that considered automated driving in conjunction with information on driver state. The work is based around seven use cases aiming to cover a large number of critical driving scenarios (https://www.adasandme.com/about-adasme/use-cases/) for conventional vehicles, trucks, buses, motorcycles, and electric vehicles.

Therefore, in the Use Case B (UCB) of the ADAS&ME project, the decision was to address the EV range anxiety issue through a dedicated HMI that uses an intelligent vehicle power management system, routing analysis, and traffic mitigation combined with a WoZ autonomous driving simulation, in which participants think that the vehicle is operating autonomously.

The paper is structured as follows. Section 2 reviews how range anxiety is perceived, the literature on range anxiety mitigation methods, and elaborates why an intelligent HMI could contribute to the acceptance of EVs. Section 3 focuses on user-group selection criteria, the test protocol, the proposed coping strategies, and the used materials. Section 4 describes the implementation of our experiment. Section 5 details the user experience, and whether the felt anxiety was reduced by our HMI. Finally, Section 6 presents our conclusions and future work.

2. Literature Review

2.1. Range-Anxiety Expression

Estimating the anxiety level of the driver is crucial for UCB. However, in open roads, there are other anxiety sources besides the remaining range. The environment, the driving task, or even the HMI itself might contribute to anxiety creation. Therefore, we need to verify whether the perceived anxiety is due to range. The experience of range anxiety is expressed on the following levels [2].

1. Cognitive level: negative cognition associated with range, like concerns about running out of energy and not being able to reach the destination.
2. Emotional level: changes in effect associated with a range situation, like feeling of nervousness or even fear.
3. Behavioral level decreasing immediate anxiety by increasing perceptions of safety and control [6,7], i.e., certain activities like tapping with fingers on the steering wheel, changing driving style to save energy, or frequently checking relevant displays, e.g., range and navigation display or yelling, honking, and aggressive gesturing [8].
4. Physiological level: under parasympathetic control, i.e., blood pressure, heart rate, heart rate variability, galvanic skin response (skin conductance), cortisol level, and pupil diameter, and under sympathetic and parasympathetic control, i.e., respiratory frequency [9,10].

In light of previous information, range anxiety detection should be accomplished in two distinct steps. First, detecting basic anxiety. This might be done by the cognitive, emotional, and/or physiological levels of expression (i.e., heart rate, breath rate, and speech analysis). Although these clues are fundamental to detecting anxiety, they are not capable to define its actual source. Therefore, information from the behavioral expression level is used to conclude if the detected anxiety is related to range or not (i.e., frequency of checking the remaining range indicator, the actual speed compared to speed limitation, air-conditioner status compared to temperature).

2.2. Range-Anxiety Mitigation Methods

Numerous methods were designed to mitigate driver range anxiety, even for gasoline vehicles [11,12]. This said, being able to fill the fuel tank of a gasoline vehicle only in minutes, and the large availability of fuel stations are drastically mitigating range anxiety in those vehicles.

The most evident EV-oriented range anxiety mitigation methods are directly related to charging infrastructures. Cui et al. [13] underlined the importance of locating different types of charging stations to satisfy the different charging demands of different users. Salah et al. [14] mentioned knowing that any charging station could charge any EV is a contributing factor to reduce range anxiety. Therefore, that work emphasizes the need for unifying charging infrastructures.

Parallel to the work done in traditional charging infrastructures, some novel charging possibilities were also studied. For instance, a vehicle-to-vehicle social charging system proposes to charge the EV in need of urgent charge energy by other EVs with more energy than they need. Therefore, all other EVs become alternative charging points [15]. Without a doubt, if this kind of energy-sharing system becomes available on enough vehicles, and if their drivers willing to cooperate, this could massively decrease range anxiety. However, in immediate terms, the deployment of this system seems far.

To reduce the time spent for charging EVs, Sarker et al. [16] suggested providing battery-swapping stations where users can drop their empty battery and install a charged one. In the same direction, the Charging While Driving (CWD) system is another technology designed to reduce the time spent charging. This contactless-charging technology allows charging the battery with inductors installed in the roads [17]. Again, these technologies, once deployed on enough vehicles and road infrastructures, would massively contribute to mitigating range anxiety. This said, in the upcoming couple of years, it seems difficult and very expensive to see their massive deployment.

It is also crucial to provide accurate and reliable information on the remaining range of the EV [4,18]. Much work has addressed the range anxiety mitigation issue by providing more accurate remaining range/state of charge (SoC) estimation by combining Global Positioning System (GPS) points and charging stations [19]. Moreover, Jung et al. [20] mentioned that “displaying error-prone information ambiguously might be advantageous rather than hiding it from users”. Providing the knowledge of error-prone information improves the trust of the drivers and consequently decreases range anxiety.

A fully autonomous EV might compute when the vehicle needs to be charged and it can adapt the trips accordingly (i.e., selecting autonomously when and where to charge and adapting the driving style to reach to the destination). Therefore, the range anxiety might disappear in the passengers of fully autonomous EVs faster than regular EVs. However, even in this case, the trust to the system should be established and the users should be informed on the awareness of the autonomous vehicle.

Even though all of these methods contribute to range anxiety mitigation, the experience of the driver towards using the EV remains the main and easiest factor to reduce range anxiety [2,18]. Moreover, according to the Low Carbon Vehicle Technology Project (LCVTP), EV drivers would like to have intelligent feedback and accurate coping strategies. In the LCVTP study, 80% of the participants declared: “It is important for me to understand how my driving behavior can maximize economy” [21].

Current commercial electric vehicles have visual indicators aiming to mitigate range anxiety thought visual interfaces. An illustration might appear on the instrument cluster during regenerative breaking. Even though this illustration is useful, it is more of a notification than a personalized coping strategy.

Making people watch visual media [22], more specifically, scary movies [23], are known as anxiety induction methods. However, these methods are irrelevant to induce range anxiety in real driving scenarios. Rauh et al. [2] designed a protocol to induce range anxiety. According to their protocol, the remaining range in the beginning of the experience was already inferior to the trip length (the participants had been told that the EV was not fully charged due to a technical issue). They demonstrated that the experience in EV use was the major mitigator of the range anxiety.

In our study, we developed an HMI that provides coping strategies to novice EV drivers when they really need them. On the one hand, these coping strategies respond to the need of understanding how their driving behavior can maximize economy, and on the other hand, we address the range anxiety issue by accelerating the acceptance and the understanding of EV power consumption. Our anxiety induction method is mainly based on a fake remaining level showed on the same HMI. To the best of our knowledge, this is the first HMI design with open-road experimentation that combines an intelligent vehicle power-management system, routing–traffic analysis, accurate coping strategy proposals, and autonomous driving experience.

3. Method

3.1. User Panel

Participant selection aimed to recruit drivers whose everyday usage was relevant to the EV use case. Therefore, each participant needed to fill in an appliance questionnaire. Only people between 18 and 45 years old were selected, and each participant had to live in a big city. They had to have a valid driving license for at least five years. EV owners were eliminated as they already had a certain level of experience with these vehicles (similarly, EV car-sharing users were also eliminated). EV use would have biased anxiety inducement. Attention was paid to choosing frequent drivers (at least one trip per week and at least 5000 km per year). Familiarity with Advanced Driver Assistance Systems (ADAS) systems was another criterion: only drivers familiar at least with speed limiter/regulator or Adaptive Cruise Control (ACC) technologies were selected, as they were considered to be more receptive to the proposed coping strategies (instead of being disturbed from technology acclimation and complex driving scenes). Finally, people under medical treatment were eliminated as they could create a bias on our results by influencing the data acquisition models of biometric sensors. They also declared not suffering from pre-existing clinical anxiety or depression. The selected drivers signed a nondisclosure agreement, and they were remunerated for the data collection. In the end, 10 female and 12 male inexperienced EV drivers were selected as participants (age range from 18 to 45, with average of driving-license holding time of 13.3 years; standard deviation of driving-license holding time: 7 years).

In addition to the requirements of the selection process, the participants declared possessing high-end well-equipped vehicles. Some of them had company cars that were changed every year. They enjoyed driving and had only had a few minor incidents with regard to the premium nature of their vehicle. The majority were already using a navigation application from their smartphone to move around, preferred to the vehicle-integrated navigation system, which is often considered less advanced.

3.2. Ethics

All participants gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki (https://www.wma.net/what-we-do/medical-ethics/declaration-of-helsinki/), and the protocol was approved by the Ethics Committee of Universitat Rovira i Virgili—The Public University of Tarragona (http://www.urv.cat/en/) in August 2019 (project identifiable under H2020 grant agreement no. 68890).

3.3. Expert Panel

The developed protocol needed the cooperation of a team of four people, referred to as experts. Each of these experts had a distinct role. The table above explains their missions in detail:

- Technician: Mainly in charge of the preparation of the test vehicle, before the arrival of each participant and after the end of the test. These tasks ensure that the real autonomy of the EV is enough for the test, calibrating sensors and transferring the collected data to a server.
- Interviewer (placed in front-right seat): The main interlocutor of the driver. They are in charge of welcoming the participant and executing the questionnaires explained in Section 5. The expert practises active listening in a semistructured interview [24,25], and think-aloud methods used in usability testing [26].
- Observer (placed in rear-left seat): In charge of noting every relevant phrase (called a verbatim) pronounced by the driver with their observations and reactions of the driver as a human-factor specialist [27]. These were reviewed after the experiment with the aim of adjusting annotations and having better feedback.
- Annotator (placed in rear-right seat): In charge of using the HMI note-taker application (see Section 4.1) that creates annotations. The annotator is also in charge of estimating the driver state and accordingly piloting the HMI through this application (detailed in Section 4.1). The final goal of the project is implementing an automated driver-state estimator that pilots the main HMI.

All experts, except for the technician, were present in the test vehicle during experimentation. Using a left-hand-drive vehicle, the driver was seated in the front left. The interviewer was seated in the front right, the annotator was in the back right, and the observer was seated in the back left. These persons were not always the same across all user tests.

3.4. Test Protocol

This test protocol's main purpose was to create real and complex conditions, tailored to induce range anxiety to the driver, to investigate a close-to-real-life situation. This protocol began with an interview of thirty minutes, followed by a one-hour driving session on open roads and finished with another interview of fifteen minutes. The protocol was designed to be repeated by three participants per day over the course of eight days (we had 22 participants).

The order of the questions and the routes taken may have varied between participants due to the need for adapting to the technical hazards of the prototype, the state of road traffic, and in respect of indications by the participants. This did not influence our assumptions.

Protocol Phases and Theoretical Driver State

The key aspect of the established protocol was the creation of a complete experience where the participant experiments with consecutive positive, neutral, and anxious driving scenarios before facing the inevitable emergency stop scenario. The timeline of the complete user test with the expected theoretical driver state, based on pre-pilot test within the project, was the following.

0. Vehicle preparation—Before User Arrival: The technician ensured that the vehicle was ready to perform the next test. The mood of the user could hardly be evaluated. Most people are expected to wonder about what would happen in the next hour, and the feeling of uncertainty could have a negative or positive impact.
1. Welcoming: At the participant's arrival, their written consent is taken. The participant was invited to sign an audiovisual-recording agreement (for the data collection), a nondisclosure agreement, and a declaration of the validity of their driving license. Then, the participant was quickly briefed on the test without making them understand the real purpose of the test (detailed in Section 5). The interviewer had been trained to reassure the user at their arrival to be in a positive emotional

state. The most important point was to let them understand that the test was easily doable by anyone.

2. Interview: The following step was constructed with an interview with basic questions about their driving habits, followed by the Ten Item Personality Inventory (TIPI) questionnaire, which is a questionnaire to evaluate the participant's personal traits [28]. Then, the interview continued with the following questions to evaluate the state of mind of the participant on the basis of the Likert scale (see Section 5.1):

   - Today, did you get angry about something that happened suddenly?
   - Do you feel relaxed?
   - Do you feel irritable?
   - Do you feel confident?
   - Do you feel comfortable with what we are going to do?
   - Do you feel nervous?

   Likert scales are frequently used in research and marketing studies. They are a tool to understand the emotional state of the participants [29,30].
3. Sensor Equipment: The sensor equipment is quite uncommon. As users were asked to wear a headset microphone and a biophysiological signal belt on their skin (detailed in Section 4.2), it could make the user uncomfortable at the beginning.
4. Static Car Discovery: Explaining to the participant the in-vehicle sensors that collect the data mentioned in their written consent (see Welcoming phase). Simultaneously, sensors were calibrated for data acquisition by the technician (see Section 4.2).
5. Dynamic Car Discovery (Positive Scenario): On a private test track, users were invited to drive the EV freely so that they familiarize themselves with it. Afterwards, they were invited to activate a fully autonomous driving mode, always on the private test track. This fully autonomous driving mode was nonexistent and simply simulated by a WoZ system. The WoZ technology is used in experiments in which participants think that the system is operating autonomously but in reality, the autonomous feature is operated by a human [31,32]. In our case, a hidden joystick located in the front-right door, used by the interviewer (see Figure 1). This part was important to avoid learning bias during scenario-data recording by letting the new participant become familiar with the unknown technologies of autonomous driving and EV, which is judged important as safety measures before going on open roads. Users were expected to be excited to use and better understand the technology.

Figure 1. Vedecom (Partner from the H2020 ADAS&ME project: http://www.vedecom.fr) Wizard of Oz (WoZ) system. (**left**) Front-right door and system cover. Interviewer slides their right arm into that cover. (**right**) Hidden joystick inside that cover. This WoZ system does not require an additional control mechanism like dual pedals.

6. Positive Phase: While the vehicle continues to run in full autonomous mode, to establish a relaxed conversation, participants were asked to recall their best, happiest, and most incredible memories. Nothing from the discussion was collected. The interest of this phase was to induce a positive mood to have the highest valance as possible with the anxiety phase. These steps were designed to induce a positive emotional state to the participant.

7. Neutral Driving: After the previous scenario, users were asked to take the control of the vehicle and go on open roads. This was the phase when users started to drive manually the EV. In neutral driving, participants only received indications related to which direction to take. The interviewer encouraged classical driving situations to provide a neutral reference for data acquisition, which needed neutral data for future exploitation.
8. Scenario Implementations: The application of the following scenarios to real-life needed the knowledge and use of local infrastructures. Therefore, we designed a circuit where the user experimented with the presented successive scenarios (shown in Figure 2). The scenarios lasted for one hour and covered nearly 30 km. The duration of the test was specifically chosen to fit a fake autonomy decrease of 1% per minute. We set the fake autonomy to 60%. These scenarios were designed to induce three steps of anxiety. The objective was to generate as much anxiety as possible without compromising road security.

   - Scenario A: This scenario lasted 20 min. The participant received no range alert, only notifications (detailed in Section 3.5) to familiarise themselves with the use of an EV and the HMI itself. The aim of this first scenario was to let the user familiarise themselves with the new EV experience by paying attention to the low noise of the car and its low autonomy. The interviewer reassures the user about the autonomy by showing tips from the HMI and how to improve battery-level management. On the basis of environmental status, the annotator launched the traffic light pop-up when the driver approached a red traffic light, and the hill pop-up when the vehicle was downhill. The estimated- and real-consumption graph was also presented while waiting on a red light. The interviewer switched from scenario A to the B when fake autonomy reached 40%.
   - Scenario B: In this phase, the remaining range started to decay, therefore the user was encouraged to find a charging station and charge the EV. This scenario started below 40% of fake range remaining, and after 20 min of driving. The interviewer had to let the user understand that they were losing too much battery, and it would be better to find a charging station to refill for at least 10 min. Even if this were not critical, the driver was still encouraged to find a charging station to charge the EV. They, then, chose one of the closest charging stations, proposed by the HMI. We knew that, at that location, the closest proposed charging station was temporarily out of service. We still let the driver go to that charging station. Once they understood that the charging station was out of service, they were encouraged to choose another charging station, which was naturally the second closest charging station. The second one was available, but the driver had been provided a charging cable that was not compatible with that charging infrastructure. The interviewer and annotators acted surprised and they argued between themselves about whose fault it was for putting the wrong cable type in the trunk. To conclude this phase, the driver was told to continue the experiment, as the remaining range was enough for the rest.
   - Scenario C: At this stage of the experiment, the remaining range was critical, and safety notifications were sent to the participant (see Section 3.5). Moreover, the participant has to deal with complex situations, such as taking the highway while having low remaining range. This scenario began after 40 min of testing, with ~20% fake battery remaining. After the incapacity to charge up the vehicle, users were expected to realize that battery breakdown was close, and to be anxious and lose their natural casualness with the interviewer (reduction of confidence on speech flow and driving skills). In this phase, the interviewer would become even more vigilant to ensure the safety of the test. As the fake range autonomy still decreased by 1% per minute, the last 10 min would be stressful for both user and interviewer. The interviewer had to play their role as an actor to not let the driver understand that autonomy was faked.

Figure 2. Navigation view of driving session. The whole session lasted 58 min for 29.5 km. Vedecom Hall A was the staring point; driver passed sequentially from points A, B, and C before the emergency stop.

9. Emergency Stop: After the range incident happened during Scenario C, the remaining range would be too critical. The vehicle had to be stopped at a safe spot. The HMI was imposed to take control of the vehicle in order to find that safe spot and complete the emergency stop. We could not implement an autonomous safety parking procedure, as using the WoZ outside of a private area could be dangerous. When 1% remaining battery level was reached, the interviewer became very directive, and asked the user to act on their warnings and park at the closest place.
10. Discussion: Once the vehicle was immobilized, the user discovered additional capabilities of the HMI (detailed in Section 3.5). Finally, the interviewer proceeded with the same questionnaire to evaluate the state of mind of the participant, again based on the Likert scale (see Section 5.3.1):

    - Do you feel relaxed?
    - Do you feel irritable?
    - Do you feel confident?
    - Do you feel nervous?

11. Revealing the purpose: Finally, the user was told about the underlying purposes of this test. Among the perceived range anxiety level, user-perceived usability (i.e., pragmatic attributes), hedonic attributes (e.g., stimulation and identification), goodness (i.e., satisfaction), and the beauty of our HMI design were interesting features to explore. To evaluate these points, participants were asked to rate the experiment and the HMI itself on the basis of some questions from the AttrakDiff scale [33,34] (detailed in Section 5.3.3). This is an important step to remove all fake knowledge induced from the user before leaving them. By being safe and confident, the user could have a proper evaluation of the real purpose of the experiment.

3.5. Adopted Coping Strategies

The HMI module was aware of the driver state and the overall driving context, and employed a series of actions to proactively or retroactively mitigate range anxiety, as well as provide assistance when available range was limited or insufficient. Anxiety-mitigation actions spanned across the entire driving session, starting with the destination selection and covering the full navigation process, including stops at charging stations and automated safety parking procedures. Actions may be static, i.e., present at all times to inform the driver, or more commonly dynamic, i.e., triggered upon some event, such as battery level dropping. Below, we summarize the various coping strategies adopted in our experiment.

- Destination-selection isochrone maps [35]: When selecting the destination, reachable areas were highlighted on the map using either normal or eco-driving style (see Figure 3, upper left).
- Estimated battery charge at arrival: After selecting the destination, and while reviewing alternative routes, the estimated battery charge at arrival was presented for each route to reassure drivers that battery charge is sufficient (see Figure 3, upper middle-left).
- Far destination: After selecting the destination, if the battery was borderline sufficient or insufficient for reaching it, a warning was displayed with a suggestion to instead find a charging station first.
- Navigation overview: The HMI provided a navigation overview with expected traffic conditions along the route to indicate that they were taken into account in battery-consumption estimation.
- Charging stations along the route: Charging stations along the route were clearly marked on the map to assume the driver that even if any battery issues arose, they could easily be solved.
- Approaching red traffic light: When the vehicle reached a red traffic light where it needed to stop, the HMI informed the driver to gradually slow down to recover energy (see Figure 3, upper middle-right).
- Approaching a hill: When reaching a hill, the driver was informed that the battery would discharge on the way up and recharge on the way down.
- Regenerative breaking: Whenever the battery was recharged, this was communicated to the driver through a visual cue within the HMI (see Figure 3, upper right).
- Estimated and real consumption graph: When the participant began to be anxious, a graph of the battery level was displayed on the HMI. On this coping strategy, we showed the overall consumption from the start and the estimation to the destination. Thus, there was no reason for the participant to worry about the range.
- Battery warning level 1: When the battery level dropped below 40% (first threshold), the driver was prompted to save energy by using the eco-driving mode of the vehicle, or even switching to automated driving.
- Search the closest charging spots icon: An icon appears on the screen to list the losest charging stations (see Figure 3, lower left).
- Battery warning level 2: When the battery level dropped below 30% (second threshold), the HMI pre-emptively introduced an option for searching for charging stations. When selected, this option displayed a list of close charging stations, with their locations highlighted on the map.
- Battery insufficient: When the battery level became insufficient, a more direct prompt to go to the closest charging station was displayed (see Figure 3, lower middle-left).
- Book charging station: The driver could directly book a charging station from the HMI and proceed there, at which point the HMI would suggest nearby points of interest (e.g., shopping mall) that the driver could visit while waiting for the charge.
- Battery critical: If all suggestions and warnings about the declining battery level were ignored and battery level became critical, the HMI communicated to the driver the intention of the vehicle to take over soon to initiate a safety parking procedure.
- Safety-parking procedure: With 5 km left on available range, the automation took over, with the HMI instructing the driver to let go of the steering wheel and pedals (see Figure 3, lower middle-right).
- Repatriation procedure: When automation took over to drive to the closest available parking spot, a repatriation procedure for the vehicle was also automatically initiated.
- Emergency assistance: The HMI enabled directly calling a taxi or for for emergency assistance, with the driver being informed in real-time about their estimated time or arrival (see Figure 3, lower right).

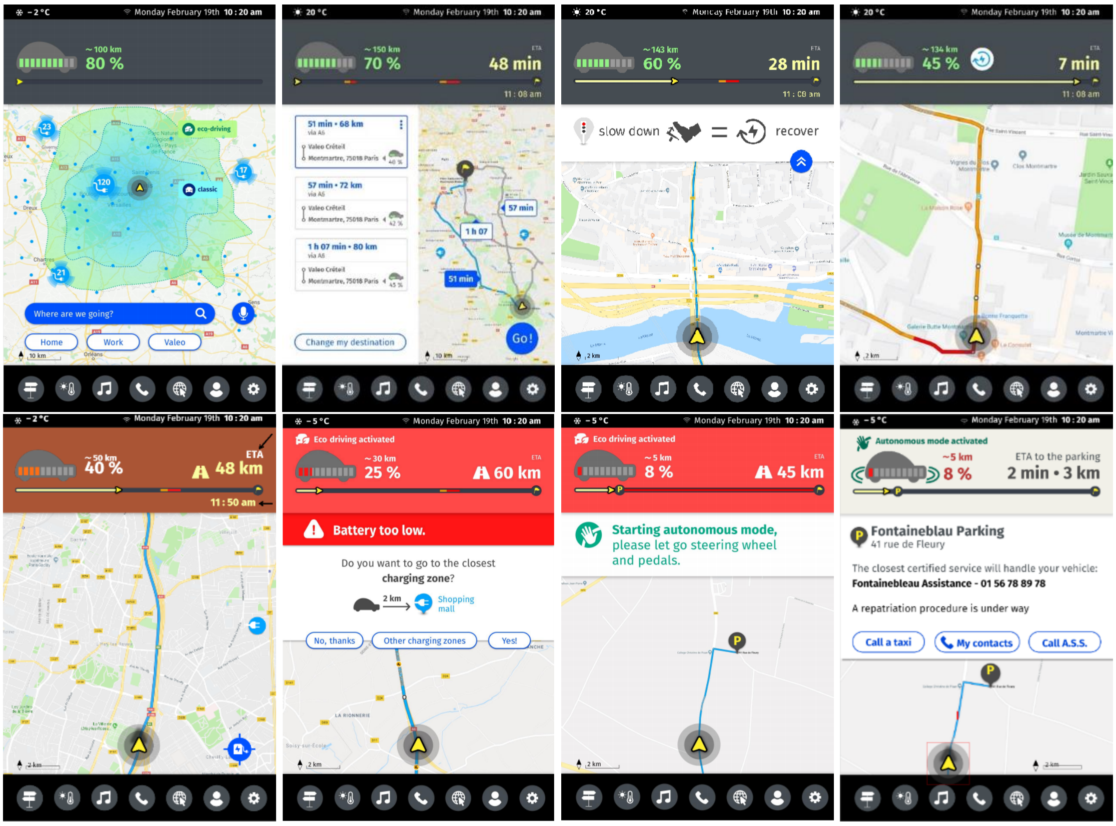

Figure 3. (left to right on upper line) (i) Isochrone maps that were reachable by using either normal driving or by activating eco-driving mode. (ii) The multiple paths leading to the destination, with individual estimation of the battery level at arrival. (iii) Traffic light coping strategy pop-up. (iv) Regenerative breaking indicator pop-up (left to right on lower line). (i) Icon to indicate the available charging stations. (ii) The Human–Machine Interface (HMI) proposed to go to the closest charging station. (iii) Remaining battery level too critical; therefore, critical range protection launched. (iv) Call assistance and call taxi proposals in battery breakdown.

3.6. Control Group

The control group was a subgroup in the participants who received neither dynamic notification (i.e., traffic light pop up and charging station icon) nor light signals. Their HMI only showed navigation-related information, the fake remaining range, and the fake remaining battery level. The main scope of this subgroup was being able to compare the efficiency and relevance of proposed contextual and sensorial interactions, which were part of the tested strategy of our HMI. Therefore, the control group of this experiment contained 5 drivers out of 22.

4. Experiment Implementation

4.1. Expert Ratings and Driver-State Estimation

The proposed data collection protocol assumed that the vehicle was able to detect the driver's range anxiety level by video/audio and physiological-signal-based trained models. The protocol also assumed that the vehicle could propose an adequate coping strategy. Even if achieving this level of automation were the final goal of the ADAS&ME project, at this data collection stage, these decisions were simply taken by a human: the annotator. They were seated in the back seat of the vehicle and had a dedicated home-made tool called an HMI note taker, visible in Figure 4.

This tool had two major roles. The first was to create time-stamped annotations for the driver's perceived subjective anxiety level by the annotator expert. In the center of the tool, two videos from the webcams (presented in Section 4.2) were visible. As the annotator was sitting in the back seat, they could not directly see the face of the driver or the front road. Anxiety may have been felt for a different reason than the remaining range. Therefore, the annotator should be able to see both the face of the driver and ahead of the vehicle. Therefore, these video fluxes were essential for the annotator to be able to observe the facial expressions, mimics, and gaze of the driver, and the road situation simultaneously. Besides these inputs, the dialogue between participant and interviewer was followed by the annotator as a contributing element in the driver's anxiety-level estimation. For example, when drivers would talk about their concerns about the range too often or if they asked for too much feedback about their driving style, the annotator would assess that the driver's state was becoming anxious. Frequency variations and pitch shifts on the driver's voice were observed. Finally, the driving style of the participant was judged to estimate if they had concerns about the remaining range (i.e., when the participants would brake before arriving to a traffic light, how fast they accelerated afterwards, and if they wanted to turn off the air conditioner). The fader switch on the left of the tool was used to record the perceived driver state from −100 (negative state) to 100 (positive state).

In addition to these video fluxes, the two gauges on the right showed the real autonomy of the vehicle, and the fake autonomy shown to the user. The annotator could modify the speed of discharge with the "+", "−", and "pause" buttons, which were located just below. After taking all these inputs into consideration, the annotator was in charge of noting the anxiety level of the driver by identifying the anxiety source. The second role of this tool was to pilot the coping strategies. On the basis of the driver's perceived anxiety level, the experimentation phase, and the remaining range, the annotator decided when to propose an adequate coping strategy, and controlled the decay of the fake battery level if any adjustment were needed. The driver was unaware of this fake automation to keep them believing that these steps were fully automatic.

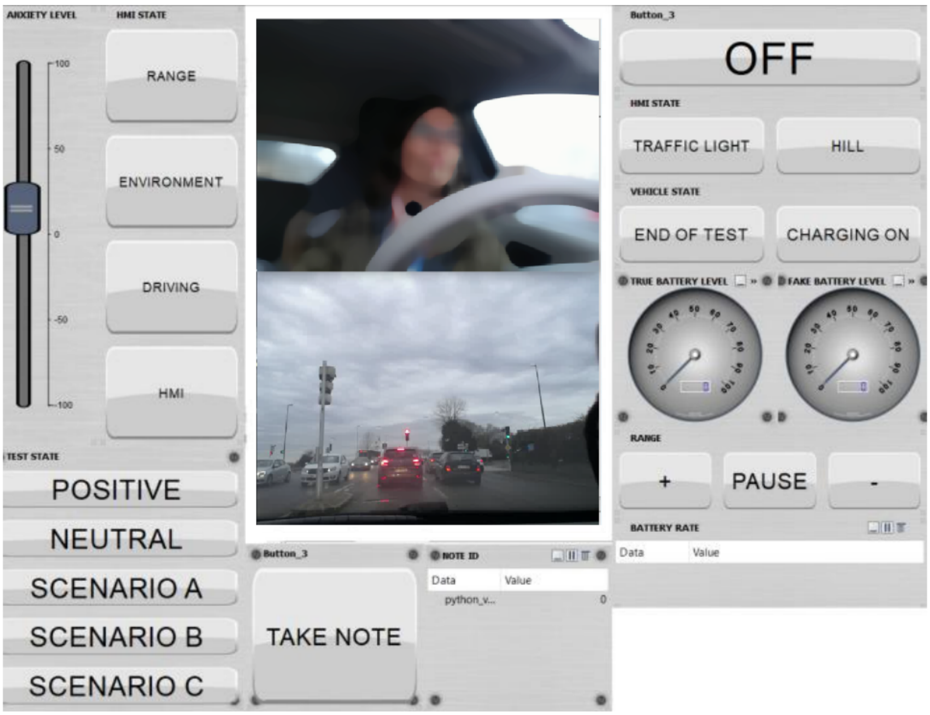

Figure 4. Human–Machine Interface (HMI) note-taker is an in-vehicle live annotation tool. This tool was used to pilot the main HMI and a annotate perceived driver state.

4.2. Additional Material

Data collection was done in a commercial EV. Even though the autonomy of this vehicle was sufficient for our data collection (approximately 100 km per charge), according to the needs of our project, the real autonomy of this vehicle was hidden from the driver.

Figure 5 is an image taken from the UCB test vehicle. The left part of the instrument cluster was hidden by a plastic cover. This was the area that was supposed to show the real autonomy of the vehicle. The HMI was displaying a fake battery level. We also recorded several additional sensors. Section 2.1 detailed the distinct expressions of range anxiety. The presented sensors were essential for detecting these expression levels. These sensors and their objectives are follows.

- Vehicle Controller Area Network (CAN Bus): Contained numerous features for detecting the driver's behavioral level of range anxiety, such as the vehicle's actual speed (compared to the allowed speed) or the occurrence of hard brakes as a safety-measure metric.
- Near-infrared cameras: Two near-infrared face-tracking cameras were installed for facial expressions and gaze analysis. On the one hand, facial expression analysis provides an estimation of the emotional and anxiety level of the driver. On the other hand, the number of glances per minute to the battery indicator confirmed the source of the detected anxiety as the remaining range of the vehicle from a behavioral level.
- Shotgun microphones: Installed in front of the windshield, creating a microphone antenna. This antenna was useful to estimate the emotional anxiety level of the driver by speech analysis.
- Headset microphone: Visible through the central mirror, it was installed on the driver's face. This sensor was useful to provide a ground-truth audio recording for the microphone antenna.
- Frequency Modulated Continuous Wave (FMCW) radar: A noninvasive solution for mean heart rate and respiration rate estimation proposed in the ADAS&ME project. These data were useful for the physiological level of anxiety estimation based on biophysiological signals. The radar was mounted inside the steering wheel and was pointed at the driver's torso.
- Zephyr Bioharness 3 Belt (https://www.zephyranywhere.com/): This sensor was another ground-truth sensor for the FMCW radar.
- Webcams: Two webcams were also mounted on the vehicle. One was pointed at the road, and the other at the driver's face. These videos were essential for annotations (see Section 4.1), so they were used to estimate the cognitive level of range anxiety.
- GPS antenna: Provided information for localization and vehicle heading. The HMI needed these data.
- LED stripes: they were also embedded in the vehicle's A-pillars, piloted by the HMI. These LEDs changed color and animation according to the current HMI screen (i.e., normal driving mode, eco-mode, autonomous driving, and low battery).

Figure 5. Test vehicle and adaptive HMI on mounted tablet PC.

The exploitation of the recorded data is part of future work for this project (see Section 6.2 for further details). Nevertheless, their presence needed to be cited, as they may have been contributing factors for anxiety, especially at the beginning of the experiment.

5. Results

5.1. First Interview

Figure 6 illustrates the mean values of the given answers in the Ten Item Personality Measure (TIPI) questionnaire. The user panel was composed from highly enthusiastic people who were interested in new experiences. They also self-rated themselves as nonconventional or eccentric. Further results in the TIPI questionnaire reflected that the participants were not anxious, and were calm and emotionally stable, which were important declarations for our test.

This observation from the user group (Figure 6) is comparable to a larger population sample. Figure 7 analyses the results of the TIPI questionnaire with another data collection based on a sample of 1813 respondents [28]. The scores were regrouped under extroversion, agreeableness, conscientiousness, emotional stability, and openness headers [28]. The selected user group's personal traits were very close to a bigger population, except our user group is slightly more extroverted than the larger population.

Figure 8 shows the results of the initial questionnaire to evaluate the state of mind of the participants, who were confident, relaxed, and comfortable.

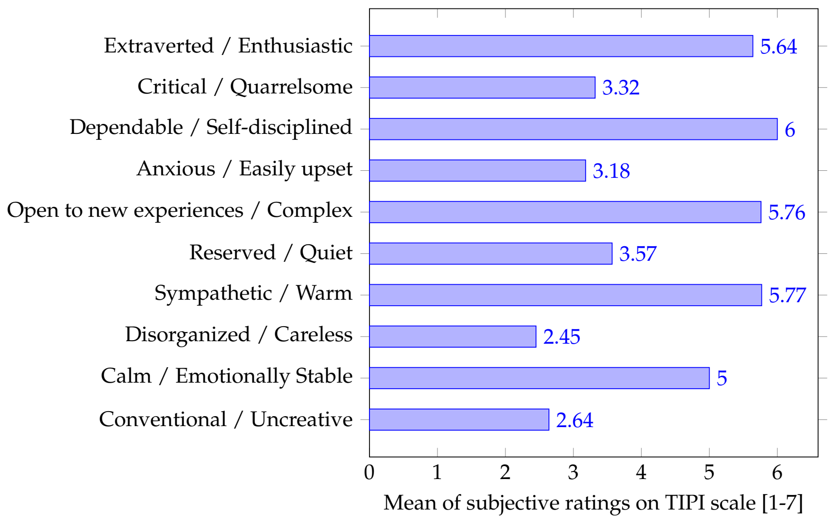

Figure 6. Twenty-two users rated how these personal traits applied to them according to Ten Item Personality Measure (TIPI) scale: strongly disagree (1), moderately disagree (2), disagree a little (3), neither agree nor disagree (4), agree a little (5), moderately agree (6), and strongly agree (7).

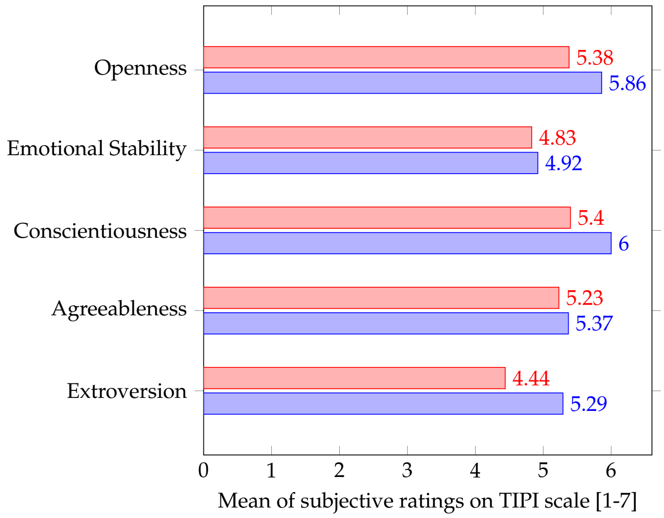

Figure 7. Comparison of TIPI results from user group with 1813 people (this study, blue; norms, red). Z-scores per personality inventory: extroversion, 0.607; agreeableness, 0.115; conscientiousness, 0.455; emotional stability, 0.112; openness, 0.467.

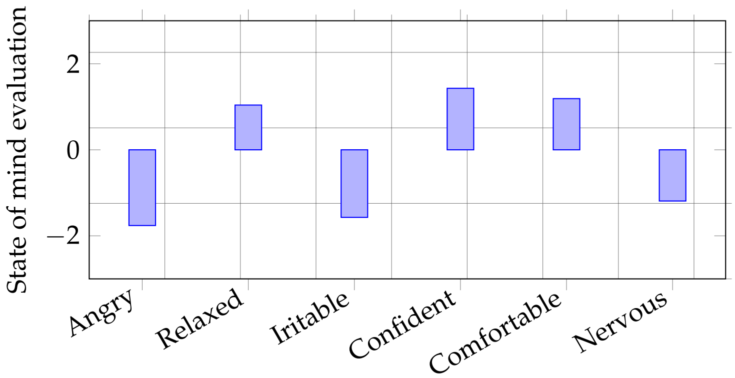

Figure 8. Mean values for responses to the following questions at the beginning of the experiment (from twenty-one participants): (1) Do you feel angry? (2) Do you feel relaxed with what we are going to do? (3) Do you feel irritable? (4) Do you feel confident? (5) Do you feel comfortable? (6) Today, did you get nervous about something that happened suddenly? (−2 for strongly disagree, −1 for disagree, 0 for neutral, 1 for agree, and 2 for strongly agree) (see Appendix B).

5.2. Scenario Evaluation—Verbatim Exploitation

This section describes the evaluation of proposed coping strategies and distinct experiment events that occurred during the protocol. For each, synthesis was presented above. The noted verbatims and the subjective anxiety annotations were used to compile these syntheses (see Appendix A).

5.2.1. Initial Phases

During this phase, we noticed that only two drivers of 22 suspected that the vehicle was not really autonomous, and that there was a second control unit somewhere in the vehicle (one of them judged that the driving was too perfect to be operated autonomously). This assessment did not concern the fake range and therefore had no impact on our results. See Table 1 for the key synthesis of initial phase.

Table 1. Synthesis in terms of user experience per event and HMI actions taken in Discovery—Positive Phase. Further details and verbatims pronounced by the participants can be found in Appendix A.1.

HMI Actions or Events	Synthesis
Dynamic Car Discovery (WoZ autonomous driving)	Even though the cover to hide the joystick seemed an unusual feature, while reviewing the participants at the end of the experimentation, they declared being unaware that the researcher was steering the car (except for two of them). Experimenting with this system was a great success. On the basis of the noted verbatims, the drivers truly believed in the autonomous capability of the vehicle, and it seems that trust in the system was established only after a couple of minutes of autonomous driving.

5.2.2. Scenario A

Numerous comments were received on the GPS system. The provided zoom amount on the map and the system reactivity were judged to be close to the state of the art, as participants were already used to smartphone applications. Therefore, this created an additional distraction to the drivers, at least at the beginning of the driving session.

Regarding range, some users were surprised by the battery-discharge speed. Some other users considered this to be the normal discharge of an EV, as they had had no previous experience on this technology. However, the remaining battery percentage gave confidence to the drivers, as they made an analogy with the remaining battery percentage of a smartphone. The users judged the interface as “pleasant” and “modern”, which was important to our design. Further details and verbatims pronounced by the participants can be found in Appendix A.1.

5.2.3. Scenario B

After this phase, a majority of drivers aimed to adopt a smoother and more economical driving behavior, visible especially as softening accelerations and maximising recovering energy while braking. See Table 2 for the key synthesis of the Scenario B.

Table 2. Synthesis in terms of user experience per event and HMI actions taken in Scenario B. Further details and more verbatims from this scenario are available in Appendix A.2.

HMI Actions or Events	Synthesis
“Hill” and “Traffic light” pop-ups	The “Hill” coping strategy was perceived as an eco-driving mode. Some of the drivers judged this information to be useless, but still adapted their driving style as proposed to save energy. The “Traffic Light” coping strategy was understood (i.e., when to start the regenerative break when approaching to traffic light) and appreciated by all. However, some participants assigned it more complex meanings, such as the fact that the HMI was connected to the traffic light, and according to the remaining time to change the state, it anticipated the need to brake.
HMI color changes to orange	HMI changed the color of the upper bar to orange when there was less than 40% battery left. This caught the attention of the drivers on the vehicle’s autonomy.
Charging station proposal appearance on HMI	In this stage of the experiment, the remaining battery level was enough to reach point B. Therefore, the HMI did not offer a proposition to go to a charging station. It only activated a button that showed the closest charging stations. The drivers asked if they could charge the battery. Some of them detected by themselves how to find the closest charging stations through the HMI. They paid more attention to these details, especially when the vehicle was stopped at traffic lights for example (as this was the first time that they were using that interface).
Looking for a charging station	This step only applied to drivers who did not feel the need to charge the battery. The experts started a short discussion between them about the remaining level of the battery as passenger concern to induce range anxiety in the driver. The driver questioned if they were correctly remembering the battery percentage at the beginning of the experiment. Majority of the participants remembered correctly the initial battery percentage (60%). Some of them told it was a little less than 60%. None of them claimed that the battery was charged more than 60%.

5.2.4. Scenario C

In this phase, the participants asked numerous questions and for advice on how, for example, to diminish power consumption and adapt their driving style. They also turned off the air conditioner, and their gaze was very often directed at the remaining-battery indicator on the HMI with the aim of better observing its variation. They also proposed to search for charging stations again. See Table 3 for the key synthesis of the Scenario C.

Table 3. Synthesis in terms of user experience per event and HMI actions taken in Scenario C. Further details and more verbatims from this scenario are available in Appendix A.3.

HMI Actions or Event	Synthesis
Autonomous Mode Safety Procedure	This message often created confusion. The fact that the vehicle would inevitably take control was judged "surprising". At the same time, this message reassured the drivers, as being blocked in the middle of a highway was not an acceptable option. Some drivers who believed the possibility that the vehicle would drive fully autonomously (like in the WoZ experiment from the positive phase) desired to push the battery to its extreme limits.
Calling Assistance and Taxi	The assistance functionality was particularly appreciated by the drivers. It was also perceived as a "premium" functionality, in phase with the "technological progress of this century". During the experiment, we prioritized making a fake phone call with the technician, who was supposed to rescue us with another vehicle, instead of using the "call a taxi" functionality. The presence of this choice, however, was noticed and appreciated as well.

5.3. Final Interview on User Experience

5.3.1. State of Mind on Emergency Stop

The participants were asked the same questions from the state-of-mind evaluation (see Section 5.1) at the end of the test while waiting for a fictitious repair during the emergency stop. Figure 9 illustrates the answers given by participants. Even though the level of confidence and relaxation decreased when compared to the first assessment, it was noticeable that the drivers unanimously declared not being nervous despite being immobilized in an emergency stop. The control group rated themselves a little less relaxed, but a little more confident compared to the test group. The test group probably judged themselves a little bit more responsible on the EV power management, as they were informed on the effect of their driving style on the power consumption.

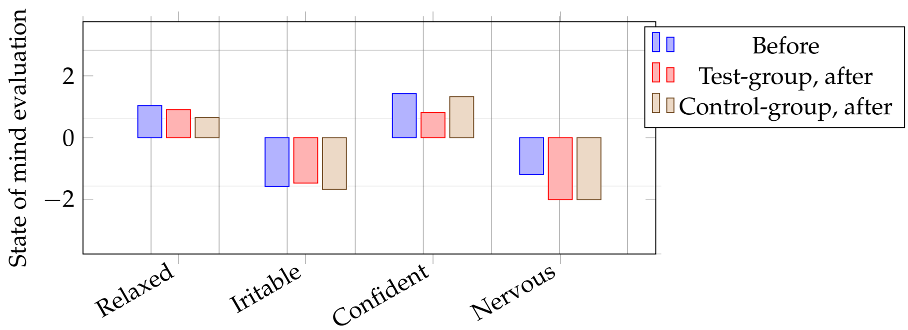

Figure 9. Mean values for responses of the following question, from twenty-one participants at the beginning of the experiment (in blue), for eleven test-group drivers at the emergency stop (red), and three control-group drivers in emergency stop (gray): (1) Do you feel relaxed? (2) Do you feel irritable? (3) Do you feel confident? (4) Do you feel nervous? (−2 for strongly disagree, −1 for disagree, 0 for neutral, 1 for agree, and 2 for strongly agree) (see Appendix B).

5.3.2. Revealing the Purpose

Despite the nature of the experiment, at the end of it, no one had any doubts about the credibility of this protocol. One of our final questions was "What did you feel when the battery suddenly decreased?" Only by asking this specific question did the participants understand that the battery decrease was planned. They were amazed to learn the truth about the real autonomy.

To avoid teaching participants that public charging infrastructure cannot be relied on (on the basis of what happened with Scenario B: 8), they were also told that charging unavailability was set up on purpose as part of our protocol.

5.3.3. User Feeling on HMI

The aim of this experiment was to teach novice EV users how they can learn this technology better and faster. Therefore, it was important to understand how the messages were perceived. To do so, participants rated the HMI itself on the basis of some questions from the AttrakDiff scale. According to the results of this questionnaire (Figure 10), users judged the HMI and the transmitted messages as simple and clear. The experiment was pleasant and enjoyable to all, which confirmed that receiving coping strategies and global information from an HMI over EV use was comprehensible and interesting in terms of user experience. The control group rated the HMI to be simpler and less original, but much more pleasant and enjoyable. On the other hand, the test group found it clearer and more exciting.

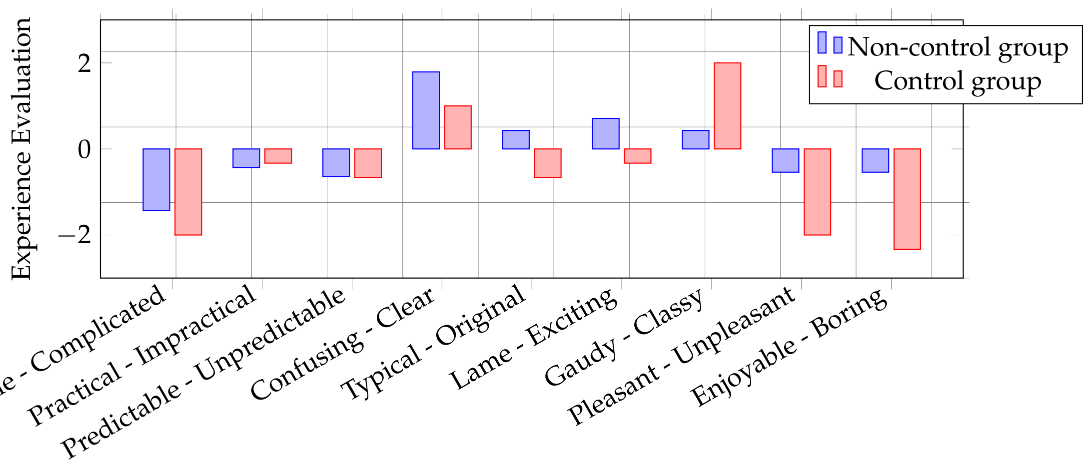

Figure 10. Mean values of AttrakDiff questionnaire responses, given by fifteen test-group (blue) and three control-group (red) participants (see Appendix B).

6. Conclusions

This work claims that range anxiety could be successfully created within the proposed protocol, using a wizarded tablet system. It can also be concluded that an efficient HMI is an effective way to deal with the problem of range anxiety, even in cases of an inevitable emergency stop. The proposed coping strategies are important contributions to the driver's understanding of EV power management. Therefore, by mitigating range anxiety, such a contextual and adaptive HMI could contribute to the acceptance of EV technology. Independently to the range anxiety, the WoZ method for simulating autonomous vehicle was successful as participants believed vehicle was fully autonomous. The automated safety parking procedure could also be noted as an efficient coping strategy.

Obviously, the proposed coping strategies must be relevant in EV energy saving. However, designing easily understandable interactions is important to contribute to the adoption of the coping strategies. This is the main reason why the more easily a coping strategy was understandable, the more it was appreciated (i.e., in our study, the traffic-light pop-ups were understood easily, and therefore they had been adopted instantaneously). Another contributing factor in the coping-strategy proposal was, instead of letting the driver explore them, finding the right moment to present them (in our case, the estimated- and real-consumption graph was not consulted that often). Not only does the right timing augment the understandability of the proposition, it also contributes to its adoption as the driver discovers it when it is really needed. This kind of contextual information is highly appreciated and seems to efficiently contribute to reducing the driver's state of anxiety.

6.1. Discussion

Even though the coping strategies were appreciated, the drivers were consoled by the presence of experts (experimenters) in the vehicle. Therefore, we consider that our test had a bias: the drivers could have been more anxious if they were alone in the vehicle. Then, the proposed coping strategies could have been evaluated in stricter conditions. Another bias concerns the experimental nature of the interface, with a level of service below the state of the art for navigation systems, which might have played a role in the users' perception during driving activity.

The GPS navigation system was also underestimated, which is a key element of driving experience and a significant part of the screen. This part needs to be refined in future experiments to overcome this type of frustration, which can be a significant source of anxiety and biased-data acquisition.

Future HMI developments against range anxiety (or with the aim of accelerating the adoption of new technologies) should consider these points. It would also be effective to give positive/negative feedback to drivers whenever the driver tries to apply the freshly learned coping strategies. Having positive feedback would encourage the drivers to test other strategies, and negative feedback would be useful to correct misplaced energy-saving tendency.

The limited number of participants (both in test and control group) is a weakness of our study. Even though the selected user group and their high similarity with the norm group on the TIPI questionnaire reflected generalizability in terms of effectiveness from such an intelligent HMI, the future works should consider an age and gender comparison between the user and norm groups to ensure better generalizability and conduct experiments with more participants. Another weakness of our study was the comparison between the control and main groups. For instance, EV power consumption between these two groups could be provided as comparison data.

6.2. Future Work

Section 4.2 described the installed sensors in the test vehicle. However, in this experiment, those data were not used. Future work in the UCB of the ADAS&ME project is to automate the anxiety-detection and coping strategy proposal tasks. Therefore, the next steps are developing artificial intelligence algorithms on the basis of driver-gaze, facial expression, speech, and biophysiological signal analysis. These modules would then detect basic and range anxiety of the driver. The very purpose of the UCB is to replace the HMI Notetaker tool (presented in Section 4.1) and the annotator expert by the developed module.

The size and location of the HMI are sensitive parameters, allowing for dynamic and accessible reading of information. However, it is necessary to remain vigilant during the animations to avoid distraction from the driving activity. Further ergonomic tests should be developed in light of the literature to assess this impact.

Multimodal inputs remain a key factor to create better interaction between human and vehicle. In this scope, the presented HMI used a synthetic voice assistant to explain the coping strategies, and it piloted the embedded LEDs into the A pillars of the test vehicle. In our case, the synthetic voice was not appreciated, and the direct sunlight on the embedded LEDs made them nearly invisible in some cases. Future HMI designs should take better consideration of these additional interaction possibilities.

Finally, the personalization of driving and associated feedback is a major focus for coming years, involving the development of individual learning algorithms to adapt to user reactions, acceptance rate, and suggestion learning.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Verbatim and Note List

This appendix section represents some interesting verbatims by the experiment participants. The original phrases were pronounced in French, and the following are their English translation.

Appendix A.1. Discovery—Initial Phase

Table A1. Some verbatims pronounced during Discovery—Positive Phase.

HMI Actions or Events	Verbatim
WoZ autonomous driving	"It reacts nearly like a real human. It detects even little potholes and pays attention to them!"
Positive Phase	Talking about these moments opened a better dialogue between participant and interviewer. The shared memories were often linked to road trips with friends or family. It also attenuated the anxiety of the participants, which might have been caused by being in an experiment.
Neutral Driving	The experience of driving an EV was generally judged as "impressive", "surprising", and "pleasant". The main factors that contributed to those judgments were the noisiness of the vehicle and its power (the torque motor).

Appendix A.2. Scenario B

Table A2. Some verbatims pronounced during Scenario B.

HMI Actions or Events	Verbatim
Initial range decrease	The first traces of anxiety were perceived from the participants who paid attention to the variation of the vehicle's autonomy. They tried to calculate future consumption by comparing the EV's battery consumption to a smartphone's battery consumption. "We consumed a lot from the beginning of the experiment! We were at 59% at the beginning, and now we are at 42%. It discharges fast, I'll try to adapt my driving style."
Hill pop-up	"This applies to the power consumption of a gasoline vehicle also, right? I already knew that."
Traffic light pop-up	• "It asks me to save energy. Do I have an aggressive driving style?" • "When I brake, it charges!"
HMI color changes to orange	"I was supposed to arrive at the destination with 11% battery left. I am not sure anymore that I can."

Table A2. *Cont.*

HMI Actions or Events	Verbatim
Charging-station-proposal appearance on HMI	• "Do you really think that we need to charge the vehicle? It seems OK to me." • "I have an important phone call just after. I hope this will not last too long!"
Looking for a charging station	"The user interface is not bad at all for checking if the driving path is adapted in terms of distance and needed battery level."
Charging Station 1	This first attempt to charge the EV was fruitless, as the infrastructure was out of order. Still, being stopped at that charging station gave the drivers the occasion and needed time to better explore the HMI. They then chose the second closest charging infrastructure. They felt the interface was there to help then, but they felt anxiety was increasingly perceivable. "What a pity that these charging stations are out of service. Do you know what the government plans are?"
Charging Station 2	After this second fruitless charging attempt, nervousness was palpable (weird jokes, vocal-tone changes, and anxious behaviors were observed and noted). Users were vigilant when driving after this point to adapt their driving behavior to be as economic as possible, following previous information that they had received from the HMI. "We will definitely be out of power! It has never happened to me before. We will have this experience together. I will adapt my driving style."

Appendix A.3. Scenario C

Table A3. Some verbatims pronounced during Scenario C.

HMI Actions or Event	Verbatim
Route resumption (back to institute)	The HMI showed that it was always possible to reach the destination, and most of the drivers seemed to trust it despite their concerns and were willing to continue. Those who has concerns were told to trust the system and keep going. "You should add additional pedals to the back of the vehicle, then you could turn them to charge the battery like dynamos!"
Autonomous Mode Safety Procedure	"Really? The vehicle will be fully autonomous in open roads? I want to accelerate more to discover how this technology would work in open roads!"
Emergency Stop	This procedure was requested by the experts as soon as possible when autonomy was critical if people did not stop by themselves (originally, this procedure was planned with WoZ autonomous driving). However, the concern of being immobilized on the road was relativized, as drivers were not alone in the car. Similarly, being in city roads helped them to control their anxiety level, as assistance could easily be found in case of need. "If it's like phones, it suddenly unloads, and we stopped in the middle of the road, we're in trouble!"
Calling Assistance	"Oh this is awesome! We can call the local assistance service directly from the HMI. We can even see the countdown to their arrival! I knew that this existed but I had never seen it before!"
Call a taxi	"It is nice to have this option. Now we are on city roads so it is not that essential. But in rural areas that can help a lot."

Appendix B. Missing Data Issue

The verbatims and Figure 6 are compiled from all twenty-two users. Figure 8 contains twenty-one users. Figure 10 contains results from eighteen drivers, and Figure 9 contains fifteen users. This divergence is due to the data availability.

References

1. Nilsson, M. *Electric Vehicles the Phenomenon of Range Anxiety*; Technical Report; Lindholmen Science Park: Lindholmen, Sweden, 2011.
2. Rauh, N.; Franke, T.; Krems, J.F. Understanding the Impact of Electric Vehicle Driving Experience on Range Anxiety. *Hum. Factors* **2015**, *57*, 177–187. doi:10.1177/0018720814546372. [CrossRef] [PubMed]
3. Pearre, N.; Kempton, W.; Guensler, R.; Elango, V. Electric vehicles: How much range is required for a day's driving? *Transp. Res. Part C Emerg. Technol.* **2011**, *19*, 1171–1184. doi:10.1016/j.trc.2010.12.010. [CrossRef]
4. Franke, T.; Krems, J.F. What drives range preferences in electric vehicle users? *Transp. Policy* **2013**, *30*, 56–62. doi:10.1016/j.tranpol.2013.09. [CrossRef]
5. Knutsen, D.; Willén, O. *A Study of Electric Vehicle Charging Patterns and Range Anxiety*; Uppsala Universitet: Uppsala, Sweden, 2013.
6. Mayou, R.; Simken, S.; Threlfall, J. The effects of road traffic accidents on driving behavior. *Injury* **1991**, *22*, 365–368 [CrossRef]
7. Taylor, S.; Koch, W.J. Anxiety disorders due to motor vehicle accidents: Nature and treatment. *Clin. Psychol. Rev.* **1995**, *15*, 7211738. [CrossRef]
8. Clapp, J.D.; Olsen, S.A.; Danoff-Burg, S.; Hagewood, J.H.; Hickling, E.J.; Hwang, V.S.; Beck, J.G. Factors contributing to anxious driving behavior: The role of stress history and accident severity. *J. Anxiety Disord.* **2011**, *25*, 592–598. doi:10.1016/j.janxdis.2011.01.008. [CrossRef] [PubMed]
9. Moraveji, N.; Olson, B.; Nguyen, T.; Saadat, M.; Khalighi, Y.; Pea, R.; Heer, J. Peripheral Paced Respiration: Influencing User Physiology during Information Work. In Proceedings of the 24th ACM UIST Symposium, Santa Barbara, CA, USA, 16–19 October 2011; pp. 423–427. doi:10.1145/2047196.2047250. [CrossRef]
10. Sano, A.; Picard, R.W. Stress Recognition using Wearable Sensors and Mobile Phones. In Proceedings of the 2013 Humaine Association Conference on Affective Computing and Intelligent Interaction, Geneva, Switzerland, 2–5 September 2013; pp. 671–676. doi:10.1109/acii.2013.117. [CrossRef]
11. Barajas, L.G. Behavior-Based Low Fuel Warning System. U.S. Patent US 7,999,664 B2, 16 August 2011.
12. Tuzi, G.; Varughese, S. Low Fuel Warning. U.S. Patent US 9,163,953 B2, 20 October 2015.
13. Cui, S.; Zhao, H.; Wen, H.; Zhang, C. Locating Multiple Size and Multiple Type of Charging Station for Battery Electricity Vehicles. *Sustainability* **2018**, *10*, 3267. doi:10.3390/su10093267. [CrossRef]
14. Salah, K.; Kama, N. Reducing Range Anxiety by Unifying Networks of Charging Stations. *ICMIT* **2016**, *70*, 04003. doi:10.1051/matecconf/20167004003. [CrossRef]
15. Bulut, E.; Kisacikoglu, M.C. Mitigating Range Anxiety via Vehicle-to-Vehicle Social Charging System. In Proceedings of the IEEE 85th Vehicular Technology Conference (VTC Spring), Sydney, NSW, Australia, 4–7 June 2017.
16. Sarker, M.R.; Pandzic, H. Electric Vehicle Battery Swapping Station: Business Case and Optimization Model. In Proceedings of the International Conference on Connected Vehicles and Expo (ICCVE), Las Vegas, NV, USA, 2–6 December 2013. doi:10.1109/ICCVE.2013.18. [CrossRef]
17. Vaka, R.; Keshi, R.K. Review on Contactless Power Transfer for Electric. *Energies* **2017**, *10*, 636. doi:10.3390/en10050636. [CrossRef]
18. Yuan, Q.; Hao, W.; Su, H.; Bing, G.; Gui, X.; Safikhani, A. Investigation on Range Anxiety and Safety Buffer of Battery Electric Vehicle Drivers. *J. Adv. Transp.* **2018**, *2018*, 8301209. doi:10.1155/2018/8301209. [CrossRef]
19. Sarrafan, K.; Sutanto, D. An intelligent driver alerting system for real-time range indicator embedded in electric vehicles. In Proceedings of the IEEE Industry Applications Society Annual Meeting, Portland, OR, USA, 2–6 October 2016; pp. 1–7. doi:10.1109/IAS.2016.7731820. [CrossRef]
20. Jung, M.F.; Sirkin, D.; Gür, T.M.; Steinert, M. Displayed Uncertainty Improves Driving Experience and Behavior: The Case of Range Anxiety in an Electric Car. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, Seoul, Korea, 18–23 April 2015; pp. 2201–2210. doi:10.1145/2702123.2702479. [CrossRef]
21. Khan, T.; Williams, M.; Wellings, T.; Robertson, D.; Binersley, J. Designing the Human Machine Interface to Address Range Anxiety. *World Electr. Veh. J.* **2012**, *5*, 72–82. [CrossRef]
22. Kuijsters, A.; Redi, J.; de Ruyter, B.; Heynderickx, I. Inducing Sadness and Anxiousness through Visual Media: Measurement Techniques and Persistence. *Front. Psychol.* **2016**, *7*, 1141. doi:10.3389/fpsyg.2016.01141. [CrossRef] [PubMed]

23. Bosse, T.; Gerritsen, C.; de Man, J.; Stam, M. Inducing Anxiety through Video Material. *Int. Conf. Hum.-Comput. Interact.* **2014**, *434*, 301–306. doi:10.1007/978-3-319-07857-1_53. [CrossRef]
24. Louw, S. Active Listening in Qualitative Research Interviews. In Proceedings of the International Conference: Doing Research in Applied Linguistics, Bangkok, Thailand, 21–22 April 2011.
25. Elias Hull Porter, J. The Development and Evaluation of a Measure of Counseling Interview Procedures': Part I2 the Development. *Educ. Psychol. Meas.* **1943**, *3*, 105–125. doi:10.1177/001316444300300111. [CrossRef]
26. Alhadreti, O.; Mayhew, P. "Thinking About Thinking Aloud": An Investigation of Think-aloud Methods in Usability Testing. In *Proceedings of the 30th International BCS Human Computer Interaction Conference: Companion Volume*; BCS Learning & Development Ltd.: Swindon, UK, 2016; pp. 41:1–41:3.
27. Sonderegger, A. Influencing Factors in Usability Tests: The Testing Situation, the Product Prototype, and the Test User. Ph.D. Thesis, Université de Fribourg, Fribourg, Sweden, 2010.
28. Gosling, S.D.; Rentfrow, P.J.; Swann, W.B., Jr. A very brief measure of the Big-Five personality domains. *J. Res. Person.* **2003**, *37*, 504–528. doi:10.1016/S0092-6566(03)00046-1. [CrossRef]
29. Likert, R. A technique for the measurement of attitudes. *Arch. Psychol.* **1932**, *22*, 140.
30. Sullivan, G.M.; Artino, A.R. Analyzing and Interpreting Data From Likert-Type Scales. *J. Grad. Med. Educ.* **2013**, *5*, 541–542. doi:10.4300/JGME-5-4-18. [CrossRef] [PubMed]
31. Martin, B.; Hanington, B.M. *Universal Methods of Design*; Rockport Publishers: Beverly, MA, USA, 2012.
32. Wang, P.; Sibi, S.; Mok, B.K.; Ju, W. Marionette: Enabling On-Road Wizard-of-Oz Autonomous Driving Studies. In Proceedings of the 12th ACM/IEEE International Conference on Human-Robot Interaction (HRI), Vienna, Austria, 6–9 March 2017; pp. 234–243.
33. Hassenzahl, M.; Burmester, M.; Koller, F. AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität 1 Grundannahmen und Vorarbeiten. In *Mensch & Computer*; Springer: Stuttgart/Leipzig, Germany, 2003; pp. 187–196.
34. Hassenzahl, M. The Interplay of Beauty, Goodness, and Usability in Interactive Products. *Hum.-Comput. Interact.* **2004**, *19*, 319–349. [CrossRef]
35. Efentakis, A.; Grivas, N.; Lamprianidis, G.; Magenschab, G.; Pfoser, D. Isochrones, Traffic and DEMOgraphics. In Proceedings of the 21st ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems, Orlando, FL, USA, 5–8 November 2013; pp. 548–551. doi:10.1145/2525314.2525325. [CrossRef]