The Timeframe of Adaptation to Electric Vehicle Range

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Abstract. We explored how people learn to cope with the limited range of electric vehicles (EVs), and examined the relationship between personality traits and the amount of practice needed to achieve a maximum available range. Data from 56 participants who leased an EV in a 6-month field study were analyzed. The amount of practice needed until a participant achieved his maximum available range was assessed with four variables computed from data logger recordings: the amount of time, days, and distance the user drove the EV and the amount of days the user owned the EV. All four variables correlated strongly with each other ($r \geq .75$). The results showed that an average person needs approximately three months to complete adaptation to EV range and that speedy driving style, low need for cognition, high impulsivity, and high internal control beliefs are related to a longer adaptation timeframe.

Keywords: adaptation, electric vehicle, range, practice, need for cognition, driving style, impulsivity, control beliefs

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1 Introduction

Electric vehicles (EVs) are a promising form of sustainable transportation. However, limited range is a potential barrier for market acceptance. Recent research has focused on the interaction between the EV [1-2] and the user, with the goal of identifying approaches that could improve utilization of existing range resources. As a next step in this research, we analyze the *timeframe* in which users learn to cope with EV range and the factors that can account for variance in this timeframe. This analysis is based upon EV field study data.

2 Theoretical Background

When people use an EV, they adapt to the limited range over time [2-3]. In this paper, we define adaptation to EV range as the conscious or unconscious change in car drivers behavior that occurs after switching to an electric vehicle and influences the vehicles available range based on the definitions of adaptation in [4-5]. One facet of adaptation to EV range is the process of learning to better utilize the available battery power resources. In other words, users are expected to increase their competent range over time [1]. Adaptation can be considered complete when there is no further increase in attained available range over time (i.e., the maximum obtained range has been reached).

The amount of practice (i.e., total learning time, number of trials) has always been considered fundamental to learning and skill acquisition [6]. However, learning can also be achieved by observation (i.e., being a co-driver) [7] and periods between practice trials have also been repeatedly pointed out as important for learning performance [8-9]. Thus, coping with EV range might benefit from both, (a) time engaged in the task and (b) the idle time in between practice trials.

2.1 Contributing Factors to the Amount of Practice Needed

An overview of possible factors (e.g., internal control beliefs, subjective competence , daily practice) that are related to more successful adaptation to EV range has been presented in [1]. We assume that the following variables presented in [1] also account for variance in the length of the adaptation timeframe (i.e., the amount of practice needed to attain a maximum available range): internal control beliefs, need for cognition, ambiguity tolerance, speedy driving style, impulsivity.

Need for cognition, which can be defined as a desire to understand complex systems [10], has been shown to positively influence complex task performance [11] through higher motivation [12]. Hence, a high need for cognition might be negatively correlated with the adaptation timeframe length (i.e., EV users with a high need for cognition need less practice to improve).

High *internal control beliefs* refers to a person's perception "that the event is contingent upon his own behavior or his own relatively permanent characteristics" [13, p.1] and often demonstrates higher motivation and performance [14]. Thus, it also might be negatively correlated with the amount of practice needed.

Ambiguity tolerance can be defined as a person's perception of "ambiguous situations/stimuli as desirable, challenging, and interesting" [15, p. 179] and has often been emphasized as important for learning [16]. Thus, this characteristic might be associated with a reduced amount of practice needed to adapt to EV range.

High *impulsivity* has been shown to be negatively related to learning outcomes [17]. It might be possible that people with high impulsivity need more time to show the same performance as people with low impulsivity.

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Driving speed has been considered one of the most important determinants of driving task difficulty [18]. Hence, a *speedy driving style* might interfere with a systematic investigation of the underlying processes that influence the available range, as it requires more cognitive resources. Thus, persons with a speedy driving style might need more practice (i.e., a longer timeframe) to learn how to cope with the range of an EV.

2.2 Research Objective, Goals and Hypotheses

The objective of the present study was to better understand the timeframe of adaptation to EV range. First, we aimed to assess the amount of practice required to complete adaptation. Second, our goal was to test the expected relationships between contributing factors and the amount of practice needed for a complete adaptation to EV range. We expected the required amount of practice to be negatively correlated with (1) high internal control beliefs, (2) high need for cognition, (3) high ambiguity tolerance and positively correlated with (4) high impulsivity and (5) a speedy driving style.

3 Method

3.1 Field Study Setup

The present research was part of an EV field trial in Berlin, Germany. The trial was set up by BMW Group and Vattenfall Europe and funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. The trial consisted of two 6-month user studies (S1, S2) with 40 private users each. It was part of an international EV field trial [19]. The EV had a maximum range of around 250 km under ideal conditions and around 170 km under daily conditions. Subjective data were collected by interviews and questionnaires. Objective data were recorded by the BMW Group with car-based data loggers which recorded variables such as speed, trip length, range, and state of charge. Further methodological details can be found in [20-22].

3.2 Participants

Potential participants applied to lease an electric vehicle for a 6-month period via a public online application form. From this pool of potential early adopters of EVs, participants were selected who met several inclusion criteria (e.g., possibility to install charging infrastructure) and increased heterogeneity of basic sociodemographic and mobility-related variables. Participants were only included in the analyses if objective data could be safely allocated to subjective data, had sufficient logger data, and had completed the necessary questionnaires. The final sample consisted of 56 participants with a mean age of 48.23 years (SD = 9.72), including 9 women.

3.3 Criterion for the End of the Adaptation Timeframe

We operationalized completion of adaptation to range as the time at which users achieved their maximum available range. This score was calculated based on pre-processed logger data provided by the BMW group. The available range was assessed as the displayed remaining range for every data point of each participant. Each data point represented a driven distance of one kilometer. Values that referred to situations with the battery not fully charged were extrapolated to full charge range. As we expected a high measuring error for remaining range for low states of charge, all data points were excluded with a state of charge ≤ 5%. Because of the influence of temperature on range [23], data points with temperatures outside the interval of 0 to 30 °C were excluded. Finally, each estimated available range was divided by the mean available range for its temperature and multiplied by the mean estimated available range for 15°C (the middle of our temperature range) to further minimize the influence of temperature. Hence, for each user the data point with the maximum temperature-adjusted estimated available range was considered the end point of his/her adaptation.

3.4 Measures of the Amount of Practice Needed

Four variables were computed to measure the amount of practice the user needed to complete the adaptation to EV range: (1) the total distance driven by the participant until the criterion (see 3.3) was met, (2) the total time driven by the participant until the criterion was met, (3) the number of days the user owned the EV, and (4) the number of days on which the participant used the EV. While the first two variables are very precise measures that can differ because of standing times and speed profiles (e.g., traffic lights, jams), the last two variables also account for the idle time between practice (see 2.2). A factor analysis was conducted to combine all four variables into a general factor measuring the amount of practice needed to adapt to EV range, referred to as *practice needed* throughout the remainder of this paper. The principal component analysis identified a single factor solution according to the Kaiser-criterion (first factor eigenvalue = 3.57, second = 0.29, factor loadings for every variable > .85). The z-standardized four variables yielded a Cronbach's alpha of .96.

3.5 Measures of Contributing Factors

Internal control beliefs, ambiguity tolerance, and speedy driving style were assessed in S1 and S2; whereas, need for cognition and impulsivity were only assessed in S2. We used the 8-item *Internal Control Beliefs in Dealing with Technology Scale* [24] (n = 54), the 8-item *Ambiguity Tolerance Scale* [25] (n = 55), the speed scale of the *Driving Style Questionnaire* [26] (n = 55), and the *Need for Cognition Scale* [27] with 16 items (n = 30). For impulsivity, we used a single-item measurement from the German socio-economic panel [28] (n = 32). Cronbach's alpha was > .74 for all multi-item measures.

4 Results

4.1 Timeframe of Adaptation

Data obtained from each measure of the amount of practice needed and the criterion for the end of the adaptation timeframe were screened for outliers according to [29]. The Kolmogorov-Smirnov test was conducted to investigate if the variables deviated significantly from a normal distribution. All variables were normally distributed and only one outlier for the end of the adaptation timeframe criterion was detected. Nevertheless, this value was retained in analyses, as it was apparently not due to an error in data recording and also subjective data from the user supported a very high range value.

The mean of the maximum estimated available range was 192.63 km (SD = 26.82). All four variables measuring the timeframe of adaptation that were computed from the data logger recordings were strongly correlated ($r \geq .75$) with each other. The average participant needed 2397.80 driven kilometers (SD = 1708.74), 72.88 driven hours (SD = 47.81), 97.39 days of ownership (SD = 45.66 days), and 62.32 days to drive the car (SD = 35.25 days) before reaching the maximum estimated available range. Figure 1 shows the box plots for all four measures of the amount of practice needed.

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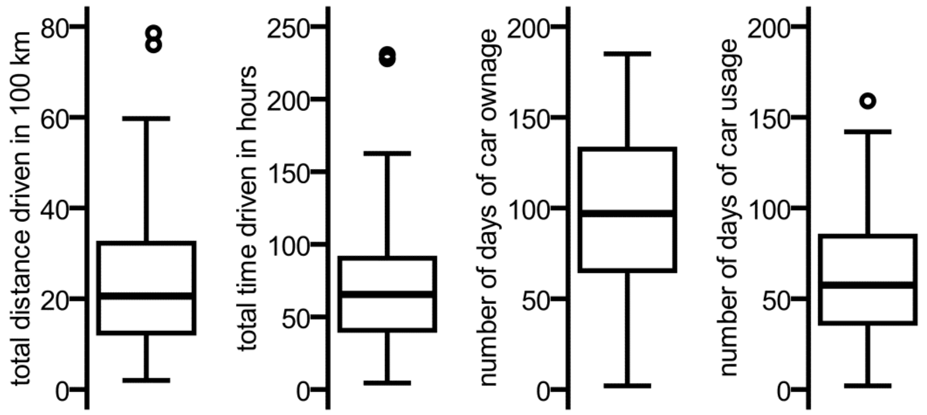

Fig. 1. Box plots of participants' amount of kilometers driven, amount of days driven, number of days of car ownership, and the number of days on which they drove the car until the end of their adaptation timeframe to EV range.

4.2 Contributing Factors to the Amount of Practice Needed

To screen for distortion of correlations between the practice needed and contributing factors caused by highly influential values, scatter plots were inspected. They did not show any disproportionately influential values. One-tailed correlation tests were conducted, because we had directional hypotheses. Correlations were interpreted in accordance with Cohen [30] as weak ($|r|$ = .10), moderate ($|r|$ = 0.3), and strong ($|r|$ = 0.5).

In order to interpret our results regarding factors contributing to the timeframe of adaptation to EV range, we only used the magnitude of the correlation coefficients. The significance level was not used to determine whether the findings supported our hypotheses, because of the small sample size.

Hypothesis 1, which predicted a negative correlation between high internal control beliefs and the amount of practice needed, was not supported by our results. Instead, a weak positive correlation (r = .27, p = .025, n = 54) was observed, indicating that high internal control beliefs are related to a higher amount of practice needed. Future research should examine this result further.

Hypothesis 2, which predicted a negative correlation between high need for cognition and the amount of practice needed, was supported by our results, as we found a weak negative correlation (r = -.26, p = .080, n = 30).

Hypothesis 3, which predicted a negative correlation between high ambiguity tolerance and amount of practice needed, was not supported by our results, as the correlation coefficient was close to zero (r = .03, p = .409, n = 55). As the concept of ambiguity tolerance in relation to learning was mostly researched in the context of academic learning, it might be possible that it is less relevant for adaptation to EV range.

Hypothesis 4, which predicted a positive correlation between impulsivity and amount of practice needed, was supported by our results, as we found a weak positive correlation (r = .25, p = .082, n = 32).

Hypothesis 5, which predicted a positive correlation between speedy driving style and amount of practice needed, was supported by our results, as the correlation was weak and positive (r = .22, p = .054, n = 55).

5 Discussion

The specific aims of the present study were to (1) quantify the amount of practice needed (i.e., the timeframe) until adaptation to EV range can be assumed to be completed, and (2) to identify factors contributing to the amount of practice needed. We were able to identify a timeframe of roughly 3 months of car ownership corresponding to 2400 driven kilometers, 73 driven hours and 63 days on which the car was driven. Furthermore, we found some indication for a relationship of practice needed with internal control beliefs, need for cognition, impulsivity, and speedy driving style.

5.1 Critical Examination of the Methodology

Each study lasted for six months. Hence, it cannot be determined whether a higher available range might be achieved after six months (e.g., after a year of driving). Therefore, the real timeframe of adaptation (i.e., practice needed) might be much longer. Although this possibility cannot be ruled out, there is some evidence against it. The average participant achieved his or her estimated maximum available range after 97.39 days of car ownership. If the adaptation timeframe were longer than six months, the average should be much closer to 180 days.

The criterion for the end of the adaptation timeframe (maximum estimated available range) varied on an individual basis. Hence, the findings presented might have been different if a fixed reference value (e.g., an available range of 180 km) was used for all participants as a criterion. This was not possible to test, however, as participants' achieved available ranges varied considerably. A high value might not have been achieved by some participants and a low value might have resulted in an underestimation of the length of the adaptation timeframe for persons achieving a much higher available range.

As noted previously, we consider our estimates for the timeframe of adaptation to EV range to be rather conservative, as our criterion is the absolute maximum available range. Another study, which investigated adaptation to EV range based on changes in charging behavior, identified a critical timeframe of two weeks for adaptation [19]. There are two possible explanations for this difference. First, the researched facets of adaptation to EV range differ (attained available range vs. charging behavior) across the two studies. Second, our study tried to identify the absolute end of the adaptation period; whereas, the other study analyzed when major changes in the adaptation process where concluded. Hence, different aspects of adaptation to EV range might require different timeframes for completion.

5.2 Implications for Theory, Practice and Future Research

The present study showed that field research on everyday interaction with EV range should be conducted over several months, in order to validly assess the user experience and behavior of adapted EV drivers. The absolute minimum seems to be three months, corresponding to the average necessary number of days of car ownership, but more time is recommended. Under conditions in which the EV is driven over greater daily distances than the present study (on average around 37 km), shorter study periods may be possible.

The findings concerning factors contributing to the amount of practice needed suggest a relationship between practice needed and need for cognition. Hence, in order to help people adapt as quickly as possible to their EV, they should be encouraged to concern themselves with the influences on their available range as much as possible. Furthermore, for EV novices, a steady, non-impulsive driving style appears to promote faster achievement of the maximum

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available range. As internal control beliefs seem to be linked to high available ranges, but high amounts of practice as well, an implication for practice cannot be determined now.

All of our findings require further research, especially with regard to the causal nature of the relationships between contributing factors and necessary practice. Hence, we highly recommend further cross-lagged analyses, as experimental investigation is difficult in the field of personality traits. Also, the interaction between necessary practice, contributing factors, and achieved available range should be explored in more detail.

In the present study, we have focused on a specific facet of adaptation to EV range. Charging behavior, as examined by [19], also appears to be a promising approach to understanding adaptation to EV range. In fact, we believe there are several facets of adaptation to EV range which are worth further investigation: increase of trip length over time, personal range buffer changes over time, amount of trips until recharging, EV usage in comparison with other possibilities of transportation (e.g., other cars of the household, public transportation), but also indicators like experience of stress, or range anxiety. Therefore, future research should aim to develop a more comprehensive picture of adaptation to EV range.

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