Abstract:
Objective: The objective of the present research was to increase understanding of the phenomenon of range anxiety and to determine the degree to which practical experience with battery electric vehicles (BEVs) reduces different levels of range anxiety. Background: Limited range is a challenge for BEV users. A frequently discussed phenomenon in this context is range anxiety. There is some evidence suggesting that range anxiety might only be a problem for inexperienced BEV drivers, and therefore, might decrease with practical experience. Method: We compared 12 motorists with high BEV driving experience (M = 60,500 km) with 12 motorists, who had never driven a BEV before. The test drive was designed to lead to a critical range situation (remaining range < trip length). We examined range appraisal and range stress (i.e., range anxiety) on different levels (cognitive, emotional and behavioral). Results: Experienced BEV drivers exhibited less negative range appraisal and range anxiety than inexperienced BEV drivers, revealing significant, strong effects for all but one variable. Conclusion: Hence, BEV driving experience (defined as absolute km driven with a BEV) seems to be one important variable that predicts less range anxiety. Application: In order to reduce range anxiety in BEV drivers even when there is a critical range situation, it is important to increase efficiency and effectiveness of the learning process.

Keywords: range appraisal, range stress, field study, user behavior

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1 INTRODUCTION

Recently, the marketability of battery electric vehicles (BEV) has become a widely discussed issue. Range anxiety has been a perennial feature of this discussion both in media coverage (Almasy, 2010; BBC, 2013; Seeking Alpha, 2013) and scientific literature (e.g., Tate, Harpster, & Savagian, 2009). Despite frequent discussion of this psychological phenomenon, a comprehensive, empirically-based understanding of range anxiety has yet to be developed.

Literature suggests that range anxiety is a potential barrier for the widespread adoption of BEVs (e.g., Luettringhaus & Nilsson, 2012; Egbue & Long, 2012; Nilsson, 2011b). Research has found that range anxiety negatively predicts the likelihood of buying a limited-range BEV (Franke & Krems, 2013b), range satisfaction (Franke & Krems, 2013a), and users’ confidence for using the BEV for longer trips (Carroll & Walsh, 2010). Considerable resources have been invested in finding ways to reduce range anxiety in BEV users (e.g., Lundström & Bogdan, 2012). Therefore it is necessary to examine factors which may be responsible for variance in range anxiety.

There are various possible factors that may account for variance in users’ experience of range anxiety like (1) individual differences (e.g., personality traits, trust in the BEV and its functions), (2) system features (e.g., support through advanced information technology and assistant systems, availability of fast charging stations enroute) and (3) environmental factors like daytime (day vs. night) or regional structure (urban area vs. rural area). We focus on the first facet. Herein one line of evidence suggest that variables related to range anxiety are positively influenced by BEV driving experience, such as reduction in range safety buffers over the first three months (Franke, Cocron, Bühler, Neumann, & Krems, 2012a), increase of travelled distance between charging events over the first six months (Burgess, et al., 2013) and considering range anxiety not longer as a major concern after three weeks (Nilsson, 2011b). Also in the conceptual framework of range anxiety by Luettringhaus and Nilsson (2012) experience is proposed as one important factor.

The objective of the present research was to advance understanding of the phenomenon of range anxiety and to determine the degree to which practical experience predicts reduction in the different levels, on which range anxiety is expressed (cognitive, emotional and behavioral). To this end, a quasi-experimental field study research design was utilized, including experienced vs. inexperienced BEV drivers who drove a BEV in a standardized critical range situation. We assessed range anxiety on different levels.

Citation: Rauh, N., Franke, T., & Krems, J. F. (in press). Understanding the impact of electric vehicle driving experience on range anxiety. Human Factors.
1.1 The phenomenon of range anxiety

Based on previous empirical work on users’ experience of limited range (Franke, Neumann, Bühler, Cocron, & Krems, 2012b; Franke & Krems, 2013a), we propose that range anxiety is best conceptualized as domain specific form of psychological stress (Lazarus, 1995). As a working definition, we suggest that range anxiety is a stressful experience of a present or anticipated range situation, where the range resources and personal resources available to effectively manage the situation (e.g., increase available range) are perceived to be insufficient. The experience of stress is assumed to be expressed on (1) a cognitive level, (i.e., negative cognitions associated with range like concerns about running out of energy and not being able to reach the destination), (2) an emotional level, (i.e., changes in affect associated with a range situation like feeling of nervousness or even fear), (3) a behavioral level, (i.e., certain activities like tapping with fingers on the steering wheel, changing driving style to save energy or frequent checking of relevant displays, e.g., range and navigation display), and (4) a physiological level, (i.e., increased arousal like an increased heart rate or respiratory rate). These four facets have been chosen based on similar classifications in the fields of general anxiety/stress symptoms (e.g., Clark & Beck, 2011) and range anxiety (Nilsson, 2011a).

Range anxiety can also occur in combustion vehicles. However, at present and very likely in the near future, the BEV charging network is less dense than the refueling network, charging duration is longer, there are no portable charging options as convenient as carrying a gasoline canister, and even when fully charged, a BEV has much less range (around 150 km) compared to a combustion vehicle (typically > 500 km). Therefore, one can assume that critical range situations are more likely for BEVs, and consequently, range anxiety plays a far more prominent role in BEV user experience than in combustion vehicles.

However, previous evidence suggests that dealing with BEV range in everyday use is not characterized by experience but by avoidance of range stress (Franke et al., 2012b). That is, users actively avoid critical range situations by reserving substantial range safety buffers. Their range comfort zone (i.e., comfortable range) is on average only about 80% of their actual available range (Franke et al., 2012b; Franke & Krems, 2013a). Comfortable range and range anxiety are closely related concepts: The higher the individual comfortable range, the lower the tendency to experience range anxiety in a given range situation. Hence, one possible strategy for reducing range anxiety is to expand users’ range comfort zone (i.e., reduce the preferred personal range buffer). It has been shown that comfortable range increases with BEV experience over a period of three months (Franke et al., 2012a). However, is this effect even stronger with longer periods of driving experience?

Indeed, some research indicates that after a few months, it is only possible to attain an acceptable level of competence in a specific domain; whereas, a far longer period of time is needed before an

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individual is able to develop an optimal level of relevant knowledge and competence (Ericsson, 2006).

### 1.2 A conceptual framework

Based on self-regulatory models, we have previously proposed that users’ management of range resources is best conceptualized as a control task intended to maintain a preferred state (e.g., staying within personal range comfort zone), with regulatory processes being dependent on several individual variables (e.g., range competence) as well as environmental factors (e.g., route profile; Franke & Krems, 2013a). Our conceptual framework is presented in Figure 1.

Although users will be able to stay within their personal range comfort zone in most daily range situations, there will also be situations where the available range buffer (i.e., difference between displayed range and trip distance) is smaller than the preferred range buffer (i.e., comfortable range). Individual’s comfortable range will develop based on trait variables (e.g., general control beliefs in dealing with technology) and coping resources (e.g., knowledge about influencing factors on range, skills for saving energy while driving, subjective range competence) that evolve over time. As a result of the perceived discrepancy between available and preferred range buffer, the situation will be judged as relevant to one’s wellbeing (Lazarus, 1995) and be interpreted (primary appraisal) as a challenge (because of the possibility to overcome the situation) and/or threat (because of the anticipated loss of mobility and time). This interpretation is also influenced by the appraisal of one’s currently available coping resources (secondary appraisal). When these coping resources are judged to be insufficient, the situation will be interpreted as a threat and increased stress will result. If users perceive their coping resources as sufficient and know effective coping strategies (e.g., to increase available range) the situation will be appraised as more challenging than threatening, thereby resulting in reduced stress. In sum, this model suggests that coping resources are a major factor that predicts lower range stress (i.e., range anxiety) and experience is one factor which can promote higher coping resources.
1.3 Hypotheses

The objective of the present research was to understand the influence of practical BEV driving experience on the different levels of range anxiety. To this end, a quasi-experimental field study research design with experienced vs. inexperienced BEV users driving in a standardized critical range situation was utilized. Based on our conceptual model, we formulated the following hypotheses regarding user experience in a range situation involving a small or negative available range buffer (i.e., a critical range situation): We hypothesize that higher driving experience with BEVs predicts:

[H1] ... lower threat appraisal (primary appraisal).
[H2] ... lower challenge appraisal (primary appraisal).
[H3] ... higher confidence in one’s abilities (secondary appraisal).
[H4] ... higher control expectancies (secondary appraisal).
[H5] ... lower experienced stress during the test drive on the emotional and cognitive level.
[H6] ... lower experienced stress during the test drive on the behavioral level (glances towards range display).
2 METHOD

2.1 Participants

Two groups of participants, experienced BEV drivers (exp) and inexperienced BEV drivers (inexp), took part. Experience with BEV range can be defined based on various indicators whereas many of these can be assumed to be strongly correlated (Pichelmann, Franke, and Krems, 2013). For the present study we decided to use the total driven km with a BEV as an indicator, because we expected that this indicator can be most accurately estimated by the participants.

Experienced BEV drivers were recruited via a network of BEV drivers in Saxony, Germany (i.e., electromobility websites and personal contacts) and inexperienced drivers were recruited via an online screening application that was publicized in newsprint and online media. 12 experienced and 12 inexperienced drivers took part, all of them male and with no experiences with the specific BEV used in this study. The description of group characteristics for both groups is displayed in Table 1.

Despite of driving experience with a BEV there were no significant ($p > .05$) differences between experienced and inexperienced drivers on these variables.

Table 1: Description of group characteristics for experienced and inexperienced BEV drivers.

<table>
<thead>
<tr>
<th>group</th>
<th>M</th>
<th>SD</th>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
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<td>exp</td>
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<td>7.50</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>inexp</td>
<td>42</td>
<td>8.83</td>
<td>32</td>
</tr>
<tr>
<td>average daily driving distance with any vehicle in km</td>
<td>exp</td>
<td>48.33</td>
<td>53.10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>inexp</td>
<td>62.92</td>
<td>37.32</td>
<td>10</td>
</tr>
<tr>
<td>years of driving license ownership</td>
<td>exp</td>
<td>27.25</td>
<td>6.31</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>inexp</td>
<td>23.00</td>
<td>7.92</td>
<td>15</td>
</tr>
<tr>
<td>total driving experience with any BEV in km</td>
<td>exp</td>
<td>60500.00</td>
<td>48.17</td>
<td>10000</td>
</tr>
<tr>
<td></td>
<td>inexp</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>years of driving experience with any BEV</td>
<td>exp</td>
<td>7.45</td>
<td>4.41</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>inexp</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

To test whether both groups were comparably susceptible to range anxiety on a trait-level, we assessed their control beliefs in dealing with technology with the KUT (Beier, 1999) and controlled for similar KUT-values in both groups by selecting inexperienced participants based on their KUT values.

Citation: Rauh, N., Franke, T., & Krems, J. F. (in press). Understanding the impact of electric vehicle driving experience on range anxiety. Human Factors.
The KUT has been shown to be a robust predictor of smaller preferred range safety buffers (i.e., low susceptibility to range anxiety) in previous research (Franke et al., 2012b; Franke & Krems, 2013a). Indeed, after matching on this variable, both groups had very similar KUT values ($M_{\text{exp}} = 5.19, SD_{\text{exp}} = 0.77$ and $M_{\text{inexp}} = 5.09, SD_{\text{inexp}} = 0.78$ on a scale from 1 to 6, $t(22) = -0.30, p = .770, d = 0.13$).

Moreover, in order to assess whether there were between-group differences with respect to coping resources and comfortable range buffer, we assessed (1) participants’ subjective range competence (Franke & Krems, 2013a), a proxy variable for coping resources (Franke & Krems, 2013a) and (2) the individual preferred minimum range safety buffer (Franke & Krems, 2013a). Here, the results were (1) for subjective range competence $M_{\text{exp}} = 4.65, SD_{\text{exp}} = 0.68$ and $M_{\text{inexp}} = 4.15, SD_{\text{inexp}} = 0.39$ on a scale from 1 to 6, $t(22) = -2.21, p = .038, d = 0.90$ and (2) for range safety buffer $M_{\text{exp}} = 15.42, SD_{\text{exp}} = 8.65$ and $M_{\text{inexp}} = 25.42, SD_{\text{inexp}} = 11.57$ on a scale from 1 to 6, $t(22) = 2.40, p = .025, d = 0.98$.

Hence relevant differences related to BEV driving experience (e.g., with respect to coping resources and comfortable range buffer) were maximized and differences regarding confounding variables (e.g., general driving experience, relevant trait variables) were minimized.

### 2.2 Field experiment setting

The BEV used in this study was a converted MINI Cooper (MINI E) with an average driving range around 170 km under everyday conditions. The BEV had regenerative braking to recover energy during deceleration. Range information was displayed via a digital remaining range display in km (range estimation based on charge level and energy consumption over the last 30 km) placed behind the steering wheel. An additional charge level display was covered to standardize the presentation of range information. Moreover, users were able to obtain information about their energy consumption via a visual 10-bar indicator (display indicates if energy is consumed or recovered). In addition, there was a portable navigation system, which showed the route and the remaining km the participants had to drive. Furthermore, a small video camera was installed, which recorded the gaze direction of the participants.

To induce range stress participants were told that they were going on a 67.70 km accompanied round-trip (represented by mobility needs in Figure 1) while the BEV was not fully charged (see next paragraph). A map of the route was shown to the participants depicting a trip consisting of a short training track (1.6 km) and 3 sections (A to C). Part A (27.80 km) and Part B (17.60 km) were characterized by hilly country roads and small villages. Part C (20.70 km) included a German Autobahn, which participants were informed would lead to the highest consumption levels compared to the other sections of the round-trip. Actually, participants only drove through section A, were than debriefed and afterwards took the shortest way back. Section A was designed to lead to a

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particularly high consumption level, being mostly uphill (driving uphill is positively correlated with a high consumption, participants started at 298 m above sea level and drove up to 505 m above sea level at the end of pat A).

Participants were told at the beginning that the BEV was not fully charged because of unexpected technical problems. The state of charge (representing mobility resources in Figure 1) that all participants started with was on average 50% for the experienced drivers ($SD_{exp} = 3.09$), corresponding to an average range of 85 km ($SD_{exp} = 5.27$) and 49% for the inexperienced drivers ($SD_{inexp} = 3.06$), corresponding to an average range of 84 km ($SD_{inexp} = 6.23$). The starting configuration was designed to lead to a critical range situation during the test drive for all participants, where the remaining range was insufficient for the trip length.

All participants drove the roundtrip under comparable conditions (represented by environmental factors in Figure 1): Average ambient temperatures were $M_{exp} = 20.83^\circ C; SD_{exp} = 3.66$ and $M_{inexp} = 17.25^\circ C; SD_{inexp} = 4.46$; battery temperature at the beginning of the trip was $M_{exp} = 20.55^\circ C; SD_{exp} = 7.10$ and $M_{inexp} = 20.08^\circ C; SD_{inexp} = 5.42$; there was low traffic on the route (rated ten times by the experimenter on a 7-point ordinal scale ranging from 0 – no other car on the route to 6 – traffic jam/stop and go ($Md_{nexp} = 1.24, IQR_{exp} = 0.56$ and $Md_{inexp} = 1.42, IQR_{inexp} = 0.57$). All participants drove with the same configuration of auxiliary consumers (same air conditioning system setting, radio off, low beam on) and the same experimenter accompanied every trip.

The navigation system, which permanently displayed total km driven and km left, as well as the digital remaining range display enabled the perception of relevant variables (e.g., average available range buffer; see Figure 1).

After the introduction of the participants to the BEV (e.g., information on range and regenerative braking, video of a BEV user), there were two periods of data collection: 1) while driving range stress and range situation variables were assessed at 10 data collection points at fixed locations within section A, and 2) after driving (after completing section A and before participants were debriefed), range stress was assessed retrospectively for section A.

### 2.3 Scales and measures to assess levels of range stress

All questionnaire items used a 6-point Likert scale from (1) completely disagree to (6) completely agree, unless otherwise stated. The measures used in the present study are described below in the order of their appearance in Figure 1.

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**Citation:** Rauh, N., Franke, T., & Krems, J. F. (in press). Understanding the impact of electric vehicle driving experience on range anxiety. *Human Factors.*
2.3.1 Range appraisal

Range Appraisal consists of two facets: primary and secondary appraisal (see middle section of Figure 1). The 16-item PASA questionnaire (Gaab, 2009) was used after driving to assess facets of stress appraisal with reference to Lazarus’ transactional model of stress (Lazarus & Folkman, 1984). The instruction framed the items around the experienced range situation after finishing section A of the test drive.

In the PASA, primary appraisal is assessed with the subscales threat and challenge, secondary appraisal is assessed in terms of control expectancies and self-confidence in one’s abilities. Cronbach’s Alpha ranged from .50 to .92 for the four subscales. A mean score was computed for each.

2.3.2 Range stress

Range stress was assessed on the cognitive and emotional level as well as the behavioral level (see right section of Figure 1).

Cognitive and emotional level. Two items were asked ten times while driving at pre-defined locations, with the distance between two measurements ranging from 2.17 km to 4.11 km. The items dealt with actual concerns about range (“Do you have concerns regarding the remaining range?”) and the degree of stress experienced as a result of the range display, and thereby, the remaining range (“How stressed did you feel by the changes in the range display on the last part of the trip?”). Items were read aloud by the experimenter and participants indicated their response on an 11-point Likert scale ranging from 0 (not at all) to 10 (very strong) while driving. The mean score over all 10 data collection points was calculated for both items. The Cronbach’s Alpha of the two items was .69 and a mean score was calculated. Furthermore participants were also asked for other aspects regarding electric driving (e.g., noiselessness, regenerative breaking) to draw their attention not too much to the range issue.

After driving, participants evaluated their range experience retrospectively by answering four further items (“While driving, I was often worried about range.”; “With the MINI E I was stressed by range”, “With the MINI E I was concerned about reaching the destination”, “While driving the MINI E, the topic of range frequently bothered me”). The Cronbach’s Alpha of the four items was .77 and a mean score was calculated.

Behavioral level. As a behavioral indicator for stress, glances towards the range display while driving were coded based on video data. Range was displayed behind the steering wheel. No other information was displayed at this location (e.g., speed was displayed in the middle of the vehicle’s dashboard). The camera was mounted just above the steering wheel. The camera picture was

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divided into two quadrants: (1) the area above the horizontal centerline (i.e., glances towards the street) and (2) the area underneath the horizontal centerline (i.e., glances towards the remaining range display).

The video material was coded by two independent raters. They counted participants’ glances towards the range display (i.e., glances underneath the horizontal centerline that were not far to the left or right) for each of the 9 intervals between the 10 data collection points. Two short fixations of the area of interest interrupted by a fixation of another area (e.g., area above the horizontal centerline) were counted as two glances.

Both raters showed high agreement with a correlation of $r = .97$ for total counted glances per participant. Hence, we averaged the ratings of the two raters. The number of glances for each interval was divided by the individual time the participant needed to complete this route segment (hence range display glances per minute). Four participants (2 experienced drivers, 2 inexperienced drivers) had missing values due to technical problems, hence $N = 20$. The mean score over all 10 data collection points was calculated.
3 RESULTS

Hypotheses were tested using one-tailed t-tests (directional hypotheses) with an alpha of .05. Assumptions for t-tests were satisfactorily met. Cohens’s d was calculated as a measure of effect size. All results are displayed in Table 2.

Table 2: Results pertaining to range appraisal and range stress matched to the hypotheses.

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Group</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>df</th>
<th>p</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>PASA</td>
<td>exp</td>
<td>12</td>
<td>1.19</td>
<td>0.30</td>
<td>3.05</td>
<td>15.06</td>
<td>.004</td>
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<td></td>
<td></td>
<td>inexp</td>
<td>12</td>
<td>1.85</td>
<td>0.69</td>
<td>4.93</td>
<td>14.98</td>
<td>.002</td>
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<tr>
<td>H2</td>
<td>PASA</td>
<td>exp</td>
<td>12</td>
<td>3.75</td>
<td>1.15</td>
<td>-0.141</td>
<td>22</td>
<td>.445</td>
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<tr>
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<td></td>
<td>inexp</td>
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<td>3.69</td>
<td>1.10</td>
<td>1.01</td>
<td>22</td>
<td>.318</td>
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<tr>
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<td>PASA</td>
<td>exp</td>
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<td>22</td>
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<tr>
<td></td>
<td></td>
<td>inexp</td>
<td>12</td>
<td>4.40</td>
<td>0.46</td>
<td>-2.19</td>
<td>17.27</td>
<td>.022</td>
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<td>H4</td>
<td>PASA</td>
<td>exp</td>
<td>12</td>
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<td>0.66</td>
<td>2.01</td>
<td>17.85</td>
<td>.030</td>
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<td>inexp</td>
<td>12</td>
<td>4.29</td>
<td>1.18</td>
<td>-2.63</td>
<td>17.46</td>
<td>.009</td>
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<td>range</td>
<td>exp</td>
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<tr>
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<td>stress</td>
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<td>1.78</td>
<td>17.66</td>
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<tr>
<td></td>
<td>while</td>
<td>exp</td>
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<td>driving</td>
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<td>12</td>
<td>5.18</td>
<td>1.59</td>
<td>-2.63</td>
<td>17.46</td>
<td>.009</td>
</tr>
<tr>
<td></td>
<td>(whole</td>
<td>trip)</td>
<td>exp</td>
<td>12</td>
<td>3.25</td>
<td>1.34</td>
<td>2.25</td>
<td>22</td>
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<tr>
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<td>1.05</td>
<td>-2.63</td>
<td>17.46</td>
<td>.009</td>
</tr>
</tbody>
</table>

Note. t-tests are one-tailed. Df with decimal places indicate that Levene-test for equal variances was significant and correction was applied.

3.1 Range appraisal

In support of H1, experienced drivers interpreted the situation as less threatening than inexperienced drivers, revealing a strong and significant effect. Yet, results did not support H2, as there were no differences between the two groups regarding the PASA subscale challenge.

Citation: Rauh, N., Franke, T., & Krems, J. F. (in press). Understanding the impact of electric vehicle driving experience on range anxiety. Human Factors.
In support of H3, experienced drivers had a higher self-confidence in one’s abilities than inexperienced drivers, revealing a strong and significant effect. Finally, in support of H4, experienced drivers had higher control expectancies than inexperienced drivers, revealing a strong and significant effect.

When completing the PASA, users thought they had to drive an additional 38.30 km section (section B + C), including one part on the German Autobahn, which they were informed would require the highest consumption, while having an average remaining range of $M = 33.12$ km, $SD = 6.48$ km. However, for experienced drivers, this range was $M = 36.08$ km ($SD = 6.24$) and for inexperienced drivers it was $M = 30.17$ km ($SD = 5.44$; significant difference, $t(22) = -2.48, p = .022$). Hence, experienced drivers had a higher available range buffer after driving, probably due to their more efficient eco-driving performance during the test drive. Yet, for both groups the range buffer was negative meaning that both were exposed to a critical range situation. Consequently, we assume that the range situation assessed after driving is still sufficiently comparable for experienced and inexperienced drivers, although it is possible that the observed effect might have been smaller if the groups had identical available range buffers after driving.

### 3.2 Range stress

*Cognitive and emotional level.* In support of H5, experienced drivers had less range stress on the cognitive and emotional level than inexperienced drivers, revealing a strong and significant effect. As mentioned above in section 3.1, there was a significant difference between both groups regarding the average remaining range after driving. Therefore, we examined the results for the ten different range measurements during the test drive, which revealed that the difference regarding the average remaining range became significant at the fifth range stress measurement (after 12 km of driving). Hence, we calculated the range stress values again for only the first four data points of the trip, where the difference regarding the average remaining range was not yet significant. As Table 2 shows also for this first part of the test drive, experienced drivers had less range stress than inexperienced drivers, revealing a medium and significant effect. Most importantly, the difference between effect sizes calculated using only the first four versus all ten data points was not substantial (see Table 2). This gives support to our conclusion that even after driving, the range situation was sufficiently comparable for both groups (i.e., both were confronted with a critical range situation). Finally, in additional support of H5, the self-evaluation of range stress after driving revealed that experienced drivers reported significantly lower values (i.e., strong effect), and therefore, exhibited lower range stress than inexperienced drivers. Consistent with the argument presented in section

*Citation:* Rauh, N., Franke, T., & Krems, J. F. (in press). Understanding the impact of electric vehicle driving experience on range anxiety. *Human Factors.*
3.1, we assume that the estimated range situation after driving is still sufficiently comparable across groups.

**Behavioral level.** In support of H6, experienced drivers looked less often at the range display than inexperienced drivers, revealing a strong and significant effect. Due to the significant difference between both groups regarding the average remaining range after driving, we also analyzed the data from only the first four data points (same as above in section cognitive and emotional level). Table 2 shows that when considering only the first part of the test drive, experienced drivers also looked less often at the range display than inexperienced drivers, revealing a strong and significant effect.

## 4 DISCUSSION

The present study was conducted to better understand the phenomenon of range anxiety and to investigate the degree to which practical driving experience predicts the reduction of different levels of range anxiety. As expected, results indicated that experienced BEV drivers had substantially less negative range appraisal (with the exception of challenge appraisal) and lower range stress than inexperienced BEV drivers. Hence, as indicated in our conceptual model, experience seems to have an effect on range anxiety at the cognitive, emotional, and behavioral level.

### 4.1 Implications

With respect to methodological implications, the present study demonstrated that it is possible to construct situations in field-experimental settings that allow for the examination of range anxiety (i.e., induce range stress), given that range anxiety appears to occur relatively infrequently in everyday BEV use. As indicated by analysis of verbal protocols, it seemed that all participants believed our cover story for the trip length and available range. From our perspective, it is important to include both range-related facets (i.e., greater communicated trip distance and communication of unexpectedly lower range) to yield this effect. Overall, we conclude that the current experimental design is suitable to create a critical range situation and can be effectively applied to further study range appraisal and range stress.

Furthermore, our results suggest that practical BEV experience might be one possible way to reduce range anxiety in BEV users. Previous research indicates that most range adaptation seems to occur within the first three months of BEV use (Pichelmann, et al., 2013). Furthermore, there is some evidence suggesting that users obtain different levels of learning success within this time period, due to different variables such as the active exploration of critical range situations (Franke et al., 2012a), daily range practice (Franke et al., 2012b; Franke & Krems, 2013a), domain specific knowledge

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(Franke & Krems, 2013a), and subjective range competence (Franke et al., 2012b; Franke & Krems, 2013a). Therefore teaching users relevant knowledge and skills (e.g., knowledge about factors influencing range, strategies for saving energy while driving, range competence) could be one fruitful approach to reduce the experience of range anxiety, but further empirical studies have yet to investigate these assumptions. Accordingly, we suggest facilitation of the learning process by motivating the driver to intensively explore (and understand) the range of the BEV. This could be accomplished, for example, with the help of advanced driver assistant systems that incorporate concepts from the field of gamification. This might help to shorten the learning processes, thereby reducing range anxiety. However, given the strong effect sizes observed here (experience of $M = 89.40$ months) compared to the moderate effect sizes found regarding the effect of experience over the first three months in terms of comfortable range (Franke et al., 2012a) and range preferences (Franke & Krems, 2013b), it seems that additional, meaningful learning occurs after the first months. Hence, strategies aimed at decreasing range anxiety should ideally be designed to be in effect for longer than just the first three months.

Finally, our results demonstrate that experienced BEV drivers are as challenged as inexperienced drivers by the critical range situation, but not as stressed by it. Hence, experience does not seem to have an effect on challenge appraisals in a critical range situation. However, Lazarus and Folkman (1984) stated that challenge appraisal is correlated with more positive emotions compared to threat. Moreover, studies indicate that challenge appraisals can be seen as a more positive outcome of situation evaluation, as it is linked to more confident coping expectancies and more positive emotions (Skinner & Brewer, 2002).

### 4.2 Study limitations and further research

The sample size of the present study was relatively small, because presently it is still difficult to find BEV drivers with the amount of practical experience we required. Yet, despite this small sample size, significant effects and strong effect sizes resulted. We do not see reasons to assume that our results are biased in a certain direction by the small sample size in this study.

Additionally, our experienced BEV drivers belong to a specific sample of early adopters of BEVs, who only represent one segment of all future BEV users. Hence, our sample of experienced drivers might be restricted on relevant personality variables, as early adoption is known to be associated with personality characteristics (Rogers, 2003). For the research question of the present study, this was less of a concern because both study groups were matched on control beliefs (KUT values). However, this resulted in high KUT values in our sample. Therefore, it is possible that the present study underestimated the level of stress that would typically be appraised in the given situation.

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Furthermore, in contrast to scores on stress measurement items, the values of the threat subscale of the PASA questionnaire were quite low, which indicates that participants were stressed by the situation, but not very threatened by it. Perhaps, this finding is due to the experimental setting. Participants might have been less anxious about negative consequences if the BEV were to run out of energy, because of the presence of the experimenter and the fact that the university had the ultimately responsibility. For the present study we weighted the advantages of having the experimenter present (e.g., participants were asked relevant items at the correct location during the trip, there were no critical situations like overtaking maneuvers at the moment of questioning) higher than the potential disadvantages (e.g., underestimating the stress level of participants as social support is known to decrease stress, Cohen & Wills, 1985). It is possible that threat appraisal would be higher on an everyday, unaccompanied trip and that the present study underestimates the threat and potentially the level of stress. Therefore we suggest to change from an accompanied trip to a test drive without a co-driver (i.e., the experimenter) as one potential way to further improve our experimental design.

Another possible improvement would be to investigate glance behavior in more detail (e.g., with an eye tracker) to, for example, better distinguish glances towards different displays, which are more or less relevant to assess range situation (e.g., share of glances to range-related displays relative to all glances to displays as a more specific behavioral indicator of range stress).

In addition one should always keep in mind that practical BEV driving experience is just one variable (besides others, e.g., personality traits, environmental factors) that have an influence on range anxiety. Further investigations are needed to examine which additional variables play a major role in explaining the variance in range anxiety and how they are linked with practical BEV driving experience.

Moreover, practical driving experience should be examined in more detail in further research (i.e., not only absolute km driven but also amount of experienced critical range situations or how participants coped with such situations and if it was successful).

In addition we suggest to further investigate the outcomes of the learning process (e.g., coping resources), which mediate the influence of BEV driving experience on range anxiety. Therefore, analyses of potential mechanisms are necessary to find out which variables mediate the relationship between practical experience and lower range stress appraisal (e.g., knowledge about influencing factors on range, strategies for saving energy while driving, subjective range competence).

Further research is also needed to investigate and advance our conceptual model in more depth and also incorporating related research and theorizing (e.g., Luettringhaus and Nilsson, 2012). For
instance with regard to specific facets of experience, influence of specific trait variables and coping resources or internal states of the driver as influencing factors on range anxiety.

5 ACKNOWLEDGMENTS

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6 KEY POINTS

- the present study showed that it is possible to construct situations in field-experimental settings that allow for the study of RA
- experienced BEV drivers had (relative to inexperienced BEV drivers) less negative range appraisal (except for challenge appraisal) and lower range stress in a critical range situation, revealing strong and significant effects
- our results suggest that it might be possible to influence RA, but further investigation is needed to find out if it is possible to reduce RA in the initial stages of BEV use
- the proposed conceptual model seems to be suitable for improving understanding of the RA phenomenon, but requires further detailed investigation

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7 REFERENCES


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