Applied Ergonomics 57 (2016) 28–35

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Individual differences in BEV drivers' range stress during first encounter of a critical range situation

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ARTICLE INFO

Article history:
Received 24 February 2015
Received in revised form
28 August 2015
Accepted 21 September 2015
Available online 9 October 2015

Keywords:
Battery electric vehicle
Range anxiety
Range stress
Individual differences

ABSTRACT

It is commonly held that range anxiety, in the form of experienced range stress, constitutes a usage barrier, particularly during the early period of battery electric vehicle (BEV) usage. To better understand factors that play a role in range stress during this critical period of adaptation to limited-range mobility, we examined individual differences in experienced range stress in the context of a critical range situation. In a field experiment, 74 participants drove a BEV on a 94-km round trip, which was tailored to lead to a critical range situation (i.e., small available range safety buffer). Higher route familiarity, trust in the range estimation system, system knowledge, subjective range competence, and internal control beliefs in dealing with technology were clearly related to lower experienced range stress; emotional stability (i.e., low neuroticism) was partly related to lower range stress. These results can inform strategies aimed at reducing range stress during early BEV usage, as well as contribute to a better understanding of factors that drive user experience in low-resource systems, which is a key topic in the field of green ergonomics.

1. Introduction

For several years to come battery electric vehicle (BEV) drivers will probably have to deal with situations where they face long-distance trips that are nearly as long as the total available range of their BEV. This is because it will take considerable time before BEVs offer a usable range equivalent to that of combustion vehicles at a comparable price (i.e., even with the projected developments in battery technology). Moreover, larger batteries of BEVs result in a larger ecological footprint (Hawkins et al., 2012; Karabasoglu and Michalek, 2013; Yuan et al., 2015) and reduce the potential of BEVs to enhance sustainability of road transport. Hence, to ensure that BEVs can make a large contribution to sustainable transport, the best strategy may not be increasing battery range to match combustion vehicles but rather tailoring it to a level that fits users' mobility needs (i.e., travel patterns). However, in this context human factors issues around the range-related user experience must be addressed. For instance, what circumstances ensure an optimal BEV user experience (i.e., trips free of range anxiety), including trips with a distance almost equal to the range of the BEV?

Range anxiety is a phenomenon that is frequently named among barriers to widespread adoption of BEVs (e.g., Birrell et al., 2014; McIlroy et al., 2014; Nilsson, 2014). Yet, the term range anxiety is used with many meanings and lacks a clear psychological foundation. It is used to refer to different psychological states such as experienced discomfort or workload, avoidance behaviors, or even anticipation of such states (e.g., before buying a BEV). Our research focuses on user experience while driving in relatively highly critical range situations, as such situations represent the most prototypical context for range anxiety and constitute a significant usage barrier. Previously, we suggested that the concept of stress provides a good psychological foundation for the phenomenon of range anxiety in such a context (Rauh et al., 2015). In the following we therefore use the term range stress when writing about the present study, and the term range anxiety when writing about the phenomenon of range anxiety in general.

Research has shown that practical experience with BEVs is typically linked to an adaptation process (Burgess et al., 2013; Pichelmann et al., 2013; Franke et al., 2015a, in press; Wikström et al., 2014). Following this adaptation process, range stress occurs relatively infrequently in experienced BEV drivers (Franke et al., 2012b; Franke and Krems, 2013), even under conditions of high range demand (i.e., daily long-distance mobility profiles; Franke et al., 2014; Franke et al., in press).

However, this pattern of results also implies that for

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http://dx.doi.org/10.1016/j.apergo.2015.09.010
0003-6870/

inexperienced BEV users, it is particularly challenging to deal with limited range. Indeed first results show that inexperienced BEV drivers experience more range stress than experienced BEV drivers in a standardized critical range situation (Rauh et al., 2015). Clearly, offering a good range-related user experience from the earliest stage is vital. Range stress in the early stage of BEV usage (e.g., during a first extended test drive or while testing a BEV for longer trips in a car-sharing setting) might particularly contribute to a less positive first impression of BEVs and, hence, constitute a purchase barrier.

Therefore, a crucial question for human factors research is: Which factors should be targeted to avoid range stress in the early period of BEV usage? Or stated differently: Which factors are related to lower experienced range stress during the first encounter of a critical range situation? Better understanding of factors underlying individual differences in range stress could (1) contribute to a theoretical understanding of user interaction with limited resources and could (2) inform the development of strategies aimed at enhancing the range-related user experience in early-stage BEV usage.

The objective of the present research was to better understand factors involved in range stress experienced by BEV drivers during their first encounters with critical range situations. To this end, data from a field experiment were analyzed in which inexperienced BEV drivers drove a BEV in a critical range situation. Participants rated their experienced range stress during the trip (i.e., while encountering the critical range situation). To our knowledge, this study is the first to examine individual differences in experienced range stress during critical range situations in early stage BEV usage.

2. Interacting with limited resources

In many fields of everyday life, abiding by notions of environmental sustainability requires that we manage natural resources efficiently. In other words, we must utilize resources such that current usage does not compromise future usage of resources (see World Commission on Environment and Development, 1987; or the earlier notions of von Carlowitz, 1713). If we apply these goals to the transport sector we must (1) maximize the usage of renewable energy for propulsion as well as production of transport systems, and (2) maximize energy efficiency, as well as minimize degradation of natural resources during production and usage of transport systems. This explains why electric vehicles are highly appealing. They have a great potential to enhance sustainability of our transport system.

However, the user is a critical parameter in the equation of the net sustainability of electric mobility systems (Franke et al., 2012a), and research shows that it is relatively challenging for users to efficiently deal with range resources in BEVs (Carroll, 2010; Franke et al., 2012b; Franke and Krems, 2013).

Green ergonomics (Thatcher, 2013; Hanson, 2013) offers a useful approach to address such challenges because it is concerned with the design of “low-resource systems” (Thatcher, 2013). According to Thatcher (2013), green ergonomics interventions have great potential to enhance eco-efficiency of products. Dealing with limited resources can increase workload (i.e., in monitoring and controlling resources), and green ergonomics can provide interventions (e.g., interface design) that reduce this cognitive burden (Thatcher, 2013). Also in the field of limited-range BEVs, it has been argued that increasing battery capacity is only one method of solving the challenge of limited range, and strategies focusing on human factors should not be disregarded (Franke et al., 2012b). In particular, a better understanding of how users handle stress-inducing critical range situations will help derive ergonomics interventions that enhance the range-related user experience.

3. Present research

The objective of the present research was to better understand factors involved in BEV drivers’ experience of range stress during first encounter of a critical range situation. The following hypotheses were tested:

3.1. [H1] Route familiarity

Uncertainty has been widely discussed as a key stressor (e.g., Greco and Roger, 2003; Paterson and Neufeld, 1987). Different types of uncertainty (e.g., Lipshitz and Strauss, 1997; Milliken, 1987; Monat et al., 1972), which have diverse effects on experienced stress and coping, have been identified. Yet, it can be concluded that higher uncertainty about the (future) state of the environment (i.e., state uncertainty, see Milliken, 1987), which makes anticipation and anticipatory coping more difficult, can lead to higher experienced stress. Consequently, if drivers are more familiar with the road that lies ahead (i.e., if they can better anticipate the future state of the environment), they should experience less range stress. Accordingly, we expect [H1] that higher route familiarity is related to lower experienced range stress.

Interestingly, reducing route uncertainty is also employed in many system concepts that aim to enhance the range-related user experience and reduce range stress of BEV drivers. These efforts typically aim at including as much information as possible on route characteristics in range prediction and route guidance (e.g., Demestichas et al., 2012; Neaimeh et al., 2013).

3.2. [H2] Trust in the range estimation system

A range estimation system can be conceived as a kind of automated system that takes over the task of predicting distance-to-empty based on detected state of charge (i.e., energy in the battery), and additional information that helps characterize past, present and future energy consumption. However, this prediction algorithm cannot guarantee complete accuracy for every situation. This may in turn induce uncertainty and mistrust.

Much research has focused on user interaction with automated systems (Parasuraman, 1997; Hoff and Bashir, 2014). Trust in automation is a key variable in this regard (Hoff and Bashir, 2014; Lee and See, 2004; Xu et al., 2015), and has been found to contribute to a better user experience (Lee and See, 2004). Hence, trustworthiness is a key design criterion for any automated system.

The quality of the range estimation system is a prerequisite for a good range-related user experience of BEV drivers. In particular, it has been pointed out that range displays must be reliable and trustworthy (e.g., Birrell et al., 2014; Strömberg et al., 2011; Neumann and Krems, in press). In connection with the above-mentioned research, it is important to note that *subjectively* experienced trustworthiness is the crucial factor in determining user experience and behavior (see e.g., Muir, 2007). However, the relationship between experienced trustworthiness of a range estimation system and experienced range stress has not yet been empirically tested. Consequently, we expect [H2] that higher trust in the range estimation system is related to lower experienced range stress.

3.3. [H3] System knowledge

A fundamental proposition of the transactional model of stress (Lazarus and Folkman, 1984) holds that stress is a result of a misfit between a person's abilities and the demands imposed by the environment. Hence, abilities (skills, knowledge) are crucial for stress resistance. Therefore, relevant knowledge regarding the