This paper is “in press” (Transportation Research Part F: Psychology and Behaviour)

The Safe-Range-Inventory (SRI):

An assistance tool for optimizing the charging infrastructure for electric vehicles

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Abstract

Electric Vehicles (EVs) are propagated as an essential solution for reducing the carbon footprint of traffic activities. One essential barrier to the adoption of electromobility strategies in everyday life is the very limited driving range of typical EVs. A dense and reliable network of electric charging stations would enable safer and longer ranges. Modern fast-charging technologies provide additional possibilities to tactically and quickly re-charge EVs, but high implementation costs make it necessary to establish a mixed infrastructure consisting of cheap-but-slow and expensive-but-fast charging stations. We utilized the so-called Safe-Range-Inventory (SRI), a multidimensional assessment tool for capturing multi-facets of subjective range safety assessments. Using scenarios with different infrastructure settings, we revealed that the addition of just one fast-charging option drastically lowers range anxiety even under relatively short emergency range conditions. Additional fast-charging options did not have strong positive effects on the assessments but would amass very high costs. The SRI can assist in the planning of electric charging infrastructures in order to find the right balance between range safety and installation and maintenance costs.

Keywords: electric vehicle; battery; charging; fast-charge; AC/DC; infrastructure

1. Introduction

Since the “Kyoto Protocol to the United Nations Framework Convention on Climate Change”, now just known as the *Kyoto Protocol*—an international treaty from 1997 which has been signed by nearly all nations worldwide—there has been global pressure (Bohringer, 2003), and also quite a substantial effort, to reduce carbon footprints[1] within the public transport system (Grunewald & Martinez-Zarzoso, 2016). The measures to reach such a goal are manifold; in the traffic area, most of the attention is directed towards (a) the increase of efficacy, (b) alternative energy sources, wherein the development and implementation of suitable battery-driven electric vehicles (EVs) has been the main focus (Lindly & Haskew, 2002)—we now commonly label this mobility sector “electromobility” (e-mobility).

Despite sophisticated and appealing EV models now having been on display for a while with

- low noise emission (Yao, Wang, Song, & Zhang, 2014),
- potentially zero emission (Gerssen-Gondelach & Faaij, 2012),
- sometimes breathtaking acceleration rates, low energy consumption (for instance according to the nowadays established New European Driving Cycle, abbreviated NEDC) (Gerssen-Gondelach & Faaij, 2012),
- zero emission potential when renewable energy sources are used (Gerssen-Gondelach & Faaij, 2012)
- relatively low well-to-wheel greenhouse gas emissions compared to regular petrol cars (e.g., below 70 g CO_2 km^{-1} if electricity for EV charging would largely be generated using natural gas) (van Vliet, Brouwer, Kuramochi, van den Broek, & Faaij, 2011),

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[1] Total amount of greenhouse gases produced by human activities and expressed in tons of carbon dioxide (CO_2).

- other plus points such as privileged ways of travelling (e.g., on bus or express lanes, see, Fontes et al., 2014),

EVs still face clear acceptance problems with most people (Tamor, Moraal, Reprogle, & Milacic, 2015).

The main reasons for this reluctance to adopt an electric-powered strategy are mostly related to the price of EVs (Junquera, Moreno, & Alvarez, 2016) and, especially, the limited driving range typically available for EVs (Franke, Neumann, Buhler, Cocron, & Krems, 2012). On the one hand the typical low range, which for most EVs is currently limited to approximately 160 km per full charge (focusing on non-luxury-cars, Ellingsen, Singh, & Stromman, 2016), prevents less complicated travelling of long distances. It is quite interesting to note that most drivers do not travel such long distances by car at all or do so quite rarely – most range needs are accommodated by that 160 km limit (Franke & Krems, 2013; Pearre, Kempton, Guensler, & Elango, 2011)[2] — but many people who are skeptical towards e-mobility quite frequently assert their strong view that much longer distance capabilities are needed (Dimitropoulos, Rietveld, & van Ommeren, 2011). This typical psychological effect is based on a variety of outcomes which cannot be easily compensated for by simply arguing against them – mostly people are just not accustomed to running a car until the end of its energy reserves (e.g., near-to-empty fuel) and so they interpret even a quite high mileage as a threat (Kurani, Turrentine, & Sperling, 1994). People typically also over-estimate the number of long-distance trips and also overemphasize the need to reach every destination with one single vehicle (for instance their own car). This makes them rather inflexible in changing their travel strategy. Furthermore, they tend to be overly anxious about the potential consequences of a car breakdown caused by

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[2] According to a recent study conducted in Germany by the NGO Öko-Institut, even a 100 km limit is sufficient in 95 % of the cases making up a typical day (see Franke & Krems, 2013). These data have been replicated in other cultural contexts, e.g. by the FP7 research project "Grid for Vehicles" (G4V)—see for details Bunzeck, Feenstra, and Paukovic (2011). A comprehensive overview of the range needs in different countries and on different days of the week is shown on Table 1 inFranke and Krems (2013).

an empty battery[3]. Accordingly, even extended ranges realized by specific charging strategies do often cause the typical “range anxiety”. Therefore, and from a psychological perspective, range anxiety is defined as “a stressful experience of a present or anticipated range situation, whereby the range resources and personal resources available to effectively manage the situation (e.g., increase available range) are perceived to be insufficient.” (Rauh, Franke, & Krems, 2015, p. 2)

One option that consumers often have in mind is to increase the range, for instance, (1) by adding battery capacity or (2) by supplementing the electric engine with a conventional (fossil) fuel-driven one. Both ideas are only of limited value as the efficiency of the system decreases with increasing battery capacity and potentially increasing complexity of components (Jensen, Schaltz, Koustrup, Andreasen, & Kaer, 2013); also due to greater weight and / or extremely lengthened charging processes, increasing batteries additionally reduces the overall space of a car and scales up the costs of production and maintenance significantly. Supplemental fuel-driven engines can certainly extend the range, but they run counter to the idea of reducing the mechanical complexity of the overall concept. Moreover, the extra system again increases overall weight and, during activity of that supplemental system, the car produces problematic exhaust gas pollution.

Another option, especially for all-battery electric vehicles, is to implement and run a charging infrastructure that is dense enough to give sufficient opportunities to recharge at any time. This was found to be an important factor in increasing consumer willingness to buy a new EV (Junquera et al., 2016). Here, costs and usage frequency have to be balanced to be able to establish an economically sound infrastructure (Maia, Teicher, & Meyboom, 2015).

When it comes to the concrete act of charging an EV, there is a further hurdle to be faced on the path of achieving e-mobility acceptance (Flores, Shaffer, & Brouwer, 2016). Even those

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[3] The term “battery” is not validly applicable here as it is not a battery but an accumulator –a rechargeable cell – that is used. Despite this incorrect usage of the term, battery is nevertheless used by most people in any case.

who do fully accept the limited range as a given and not changeable property fear the high time costs of charging (Philipsen, Schmidt, van Heek, & Ziefle, 2016). Indeed people criticized excessively long charging times, especially when the EV is plugged into the typical single-phase 3.7 kW-230 V household socket system where it takes 8 hours or more for a longer distance EV (Gebauer, Vilimek, Keinath, & Carbon, 2016) such as the current BMW i3 model (generation I01) to recharge. Such a long charging time is in fact only realizable when we aim to using the car not for the next few hours (e.g. when charging the EV overnight). With such horror scenarios of ultra-long charging times during a trip in mind, e-mobility clearly appears to be unattractive for many people. This could certainly be changed by using sophisticated fast-charging alternatives, now available in many areas where e-mobility has already taken hold, e.g., by charging with triple phase AC up to 43 kW or by DC quick charge technology of up to 500 V with a power output of 50 kW or even 120 kW. Such sophisticated fast-charging stations even allow the full charging of a very long-running Tesla S with the largest available battery pack (i.e. 85 kWh) in less than an hour; alternative fast-charging technology, for instance in form of 50 kW DC charging, enables the full charging of a BMW i3 in approximately half an hour.

Although the benefits of fast-charging are very clear regarding improved mobility, the costs of establishing fast-charging stations are extremely high (Li & Ouyang, 2011) which makes it necessary to optimize the number of such stations. For example, the mere material costs for a public DC fast-charging station are about 40,000-75,000 US$, whereas a public AC conventional-charging station costs about 4,000-7,500 US$ (Schroeder & Traber, 2012). Therefore, an effective balance between slower-but-more-cost-efficient and faster-but-more-cost-intensive stations seems most promising in this respect. Such a mixed infrastructure should certainly accommodate economic realities as well as users’ needs for reducing aspects of safe range anxiety—this follows the straight-forward idea that only an infrastructure which allows for reliable travelling from A to B will be appreciated and accepted (Philipsen et al., 2016).

Importantly, we will set criterion for such “reliable travelling” strictly on a psychological basis and not on simple calculation models optimizing time × costs factors, because acceptance of a technical system mainly comes from a personal assessment and not from logical reasoning (see Gattol, Saaksjarvi, & Carbon, 2011).

The present study

Previous research about the dynamics of measuring range anxiety and infrastructural needs focused on sophisticated GPS-based survey data (Dong, Liu, & Lin, 2014), range-related costs of, e.g., batteries (Lin, 2014) or plug-in hybrid electric vehicles (Kontou, Yin, & Lin, 2015). Here we present a powerful tool in the form of an easy-to-implement inventory, which refers to a psychological test where participants fill out a survey that assesses psychological safe ranges in a multi-faceted way for battery electric vehicles. The main idea is based on a two-dimensional grid reflecting psychophysical relations between physical ranges and a variety of indicators for feelings of safety. The entire set of utilized psychophysical variables makes up the so-called “Safe-Range-Inventory” (SRI) which is tested in the context of different concrete scenarios of charging infrastructures where different types and combinations of charging stations are portrayed. Specific scenarios are employed to increase the possibility to imagine a situation and thus ease-up the elaboration and understanding of such situations which assists the users in answering the items in a valid way (Carbon & Leder, 2005, 2007). The use of grid technique enables the efficient data collection of various psychophysical datasets without the necessity of asking hundreds of respective questions, which would lead to low participation rates, participants’ fatigue, and ultimately invalid data. SRI covers a variety of aspects concerning safe range assessments including anxiety as well as comfort factors.

2. Methodology

2.1 Participants

One hundred and five persons volunteered in our study. We recruited them from all over Germany via a variety of means (e.g., through newspaper advertising, internet forum or mailing lists from e-mobility clubs). All of them were regular electric vehicle users; eight participants had to be removed from further analysis due to incomplete filling in of the questionnaire, with ninety-seven participants remaining (81 male; $M_{\text{age}} = 46.3$ years, $SD = 12.1$). 62.2% of the remaining persons reported that they had used fast-charging technologies at least once before. We tested the volunteers in their home base areas, so we travelled to them for letting them participate in our study. This recruitment and testing policy allowed for the testing of persons from a variety of locations, mainly situated in Bavaria (in the south around Munich, in the north around Nuremberg), in Hesse (around the Frankfurt metropolitan area) and in North Rhine-Westphalia (around the Ruhr region). After having completed the experiment, participants received € 20 in compensation.

2.2 Stimulus & Apparatus

We used five different scenarios of an electric charging infrastructure along a fictitious route. The scenarios systematically differed in terms of the number as well as the composition of fast (specific charging times were calculated on typical 50 kW DC technology) vs. slow (specific charging times were based on typical 4.7 kW AC technology) charging stations following a scheme of ascending quality of the charging infrastructure:

a) 0 fast and 0 slow charging stations; so no charging station available at all along the entire route (0F[ast]-0S[slow]),
b) 0 fast and 3 slow charging stations (0F-3S),
c) 1 fast and 2 slow charging stations (1F-2S),
d) 2 fast and 1 slow charging stations (2F-1S),
e) 3 fast and 0 slow charging stations (3F-0S).

Every condition was accompanied by a map visualizing the route and the points where charging stations were available (see Figure 1) just to illustrate the different scenarios in order to support the participants' mental images of them.

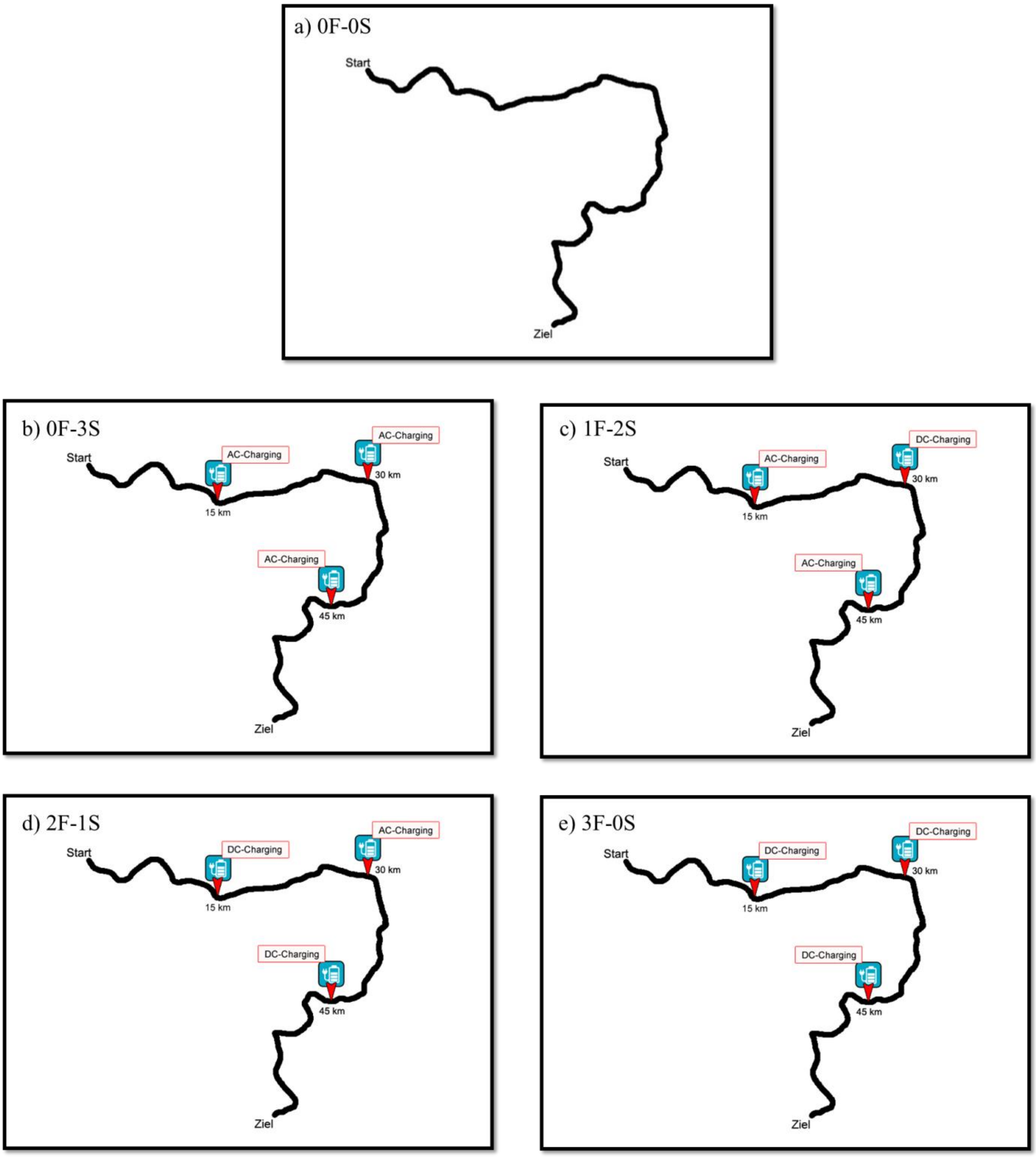

Figure 1. Depiction of the five different scenarios as shown to the participants.

Each scenario was accompanied by a written description (originally given in German) of the scenario based on typical everyday-life events and typical everyday-life requirements. It consisted of two parts: a standardized introductory part that was the same for all scenarios: *“Imagine you are in a city and you have an appointment that you want to arrive punctually for. You have to take the route displayed below, which is approximately 60 km long. The traffic is at a daily average level and you need not expect any roadworks or traffic jams. You are driving with your own electric vehicle without a range extender.”*

This first part was followed by a scenario-specific text part defining the charging infrastructure along the route. As extra information, the nature of fast- vs. slow-charging technology was explained in the following way: a) fast-charging: “Charging at a fast-charging station (with DC technology) takes 20 minutes to recharge an electric vehicle’s nearly empty battery up to 80%”; b) slow-charging: “Charging at a slow, conventional charging station (with AC technology) takes 6 to 8 hours to recharge an electric vehicle’s nearly empty battery up to 80%”.

After having elaborated upon each scenario, the participants were asked to express their assessment on different facets of range safety / anxiety by means of the so-called *Safe-Range-Inventory*, which we have constructed as a multi-faceted assessment tool based on bi-axial grids. The x-axis of these grids always presents the electric vehicle’s remaining range at the start of the trip (for an example see Figure 2). The meaning of the y-axes across the inventory’s items was changed to capture range safety / anxiety in a multi-faceted way (1st facet: *I am concerned whether I will reach my destination*; 2nd facet: *I am not worried about my EV’s range along this route*, 3rd facet: *I am sure that I will reach my destination with my EV on time*.). We chose these facets in order to measure general concerns with the EV’s range (1st facet), to have valid data on a reversed item (2nd facet) and to measure whether fast and slow-charging stations might affect participant’s concerns about punctuality (3rd facet). For usability reasons, we always utilized the same 6-points Likert scale for the y-axis where the end points were operationalized as “1 = *do not agree at all*” and “6 = *fully agree*”. The grid structure (see Figure 2) allows for an economic and usable assessment as each grid actually represents a number of items, in the given case 10 single items regarding assessments for the remaining ranges between 45 km and 90 km in steps of 5 km. This specific arrangement of items within a grid helps the participant to reduce the cognitive effort and time required to complete the assessment. This helps to broaden-up the whole perspective to a multi-faceted one where different dimensions of range safety / anxiety can be assessed. The grid idea is based on established grid-assessment tools in general (Fransella, Bell, & Bannister, 2004), typically used in customer (Lemke, Clark, & Wilson, 2011) as well as emotional research, e.g. (Stevens & Levi, 2013), and in particular on the so-called *Response Grid* for EV users introduced by Franke, Günther, Trantow, Rauh, and Krems (2015).

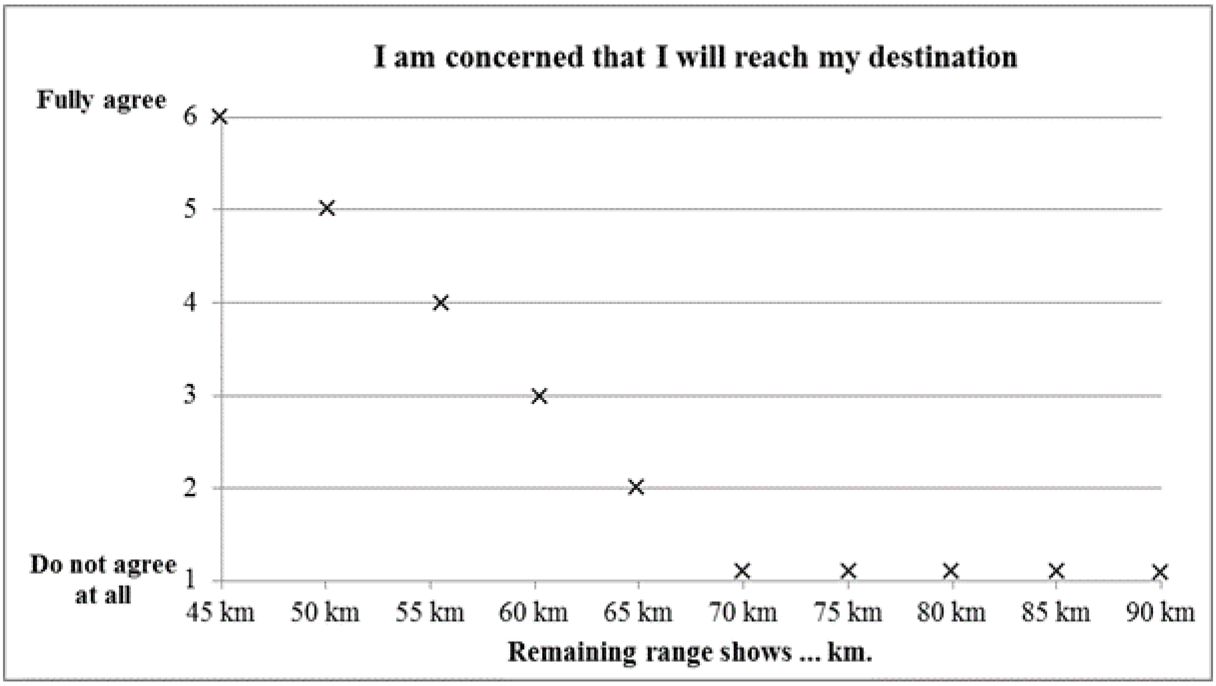

Figure 2. An example of a fictional grid from the Safe-Range-Inventory (SRI) referring to the facet *concerns about reaching the destination*. Participants simply had to tick their assessment for each remaining range (at the start of their trip).

The logic of the SRI’s facets is to relate specific subjective concerns to remaining driving ranges. By the use of bi-axial measurements, participants are asked to assess single facets such as “*I am concerned whether I will reach my destination”* in relation to the actual driving range. Each facet related to the very same 6-point Likert scale *(1 = do not agree at all, 6 = fully agree),* depicted on the y-axis. The remaining driving range was depicted on the x-axis with a range from 45 km to 90 km (see Figure 2). Before rating the items, participants were additionally instructed about how to fill in the bi-axial measurement by reading the following passage: *“The horizontal axis (x-axis) displays the remaining range your electric vehicle has before you start the trip. Please mark points or draw a line that best describes how your attitudes change depending on the remaining range of your vehicle.”*

2.3 Procedure

Every participant had to specify his or her range anxiety under five different conditions reflecting different facets of range safety / anxiety. First, participants’ task under every condition was to imagine traveling a distance of 60 kilometres (approx. 37 miles) with an electric vehicle. Each condition was distinguished only by the amount of available fast charging stations and conventional charging stations, respectively. The conditions were shown in a fixed order (see Table 1; for details see material section). After participants had answered all items under each condition, the experiment was finished. The whole procedure took about 10-15 minutes. We conducted the study from June until July 2014 when less than 20,000 all-electric vehicles had been registered by the Kraftfahrt-Bundesamt (KBA; i.e. Federal Motor Transport Authority) in Germany, which equals a percentage of about 0.05% of the total – about 44 million – registered cars in Germany (Kraftfahrt-Bundesamt (KBA), 2015).

3. Results

For each facet we calculated an ANOVA for repeated measures using the within-subject factors condition (0F-0S; 0F-3S; 1F-2S; 2F-1S; 3F-0S) × remaining range (45 km - 90 km; in steps of

5 km). Therefore, we regressed scores made in every facet onto *condition*, *remaining range*, and their interaction. Results are provided facet by facet below. Note that we will concentrate on the comparison of each condition. A detailed analysis of variance within each single condition can be found in Table 1 and under Appendix A.

1st facet: *I am concerned whether I will reach my destination*

Analysis revealed a main effect for condition, $F(4, 93) = 74.79$, $p <.001$, $\eta_p^2 = .76$, remaining range, $F(9, 88) = 74.79$, $p < .001$, $\eta_p^2 = .70$, and – most importantly – their interaction, $F(34, 63) = 74.79$, $p < .001$, $\eta_p^2 = .90$. Pairwise comparisons (Bonferroni corrected; see for details Table 1) showed that under a low remaining range status at the beginning of the trip (45 km) the addition of charging stations, independently of fast or slow recharging ones (0F-3S; 1F-2S; 2F-1S; 3F-0S), significantly decreased participants' concerns about reaching their destination in comparison to the no-charging-station condition (0F-0S), all *t*s> 10.85 and *p*s<.001 (Figure 3). Furthermore, comparing the 0 fast and 3 slow charging stations condition (0F-3S) to the conditions wherein fast-charging stations were installed (1F-2S; 2F-1S; 3F-0S) revealed an additional reduction of participants' concerns about reaching their destination with an EV, all *t*s > 4.34 and *p*s < .001. Analysis between the three fast-charging conditions uncovered that only the 3F-0S condition significantly decreased participants' concerns compared to the 1F-2S condition, $t(96) = 2.91$, $p = .045$, and the 2F-1S condition, marginally $t(96) = 2.80$, $p = .062$. However, there was no effect comparing the 1F-2S condition to the 2F-1S condition, $t(96) = 0.33$, $p = .62$.

Using pairwise comparisons (Bonferroni corrected) under a remaining range status that was equal to the length of the route to be taken (60 km), results showed a similar pattern of effects. First, all other charging conditions again decreased participants' concerns about reaching their destination in comparison to the no-charging-station condition (0F-0S), all *t*s>

9.02 and *p*s<.001. Second, comparing the 0F-3S condition to fast-charging conditions decreased participants' concerns about reaching their destination for the 1F-2S condition, marginally *t*(96) = 2.31, *p* = .070, the 2F-1S, *t*(96) = 3.13, *p* = .003, and the 3F-0S condition, *t*(96) = 5.29, *p* < .001. Analysis between the three fast-charging conditions uncovered that only the 3F-0S condition significantly decreased participants' concerns compared to the 1F-2S condition, *t*(96) = 3.37, *p* = .011, and the 2F-1S condition, *t*(96) = 2.99, *p* = .035. However, there was no effect comparing the 1F-2S condition to the 2F-1S condition, *t*(96) = 0.65, *p* > .10.

All effects were diminished when the remaining range status was higher (here 90 km) than the length of the route (60 km) to be taken (for an overview the Figure 3).

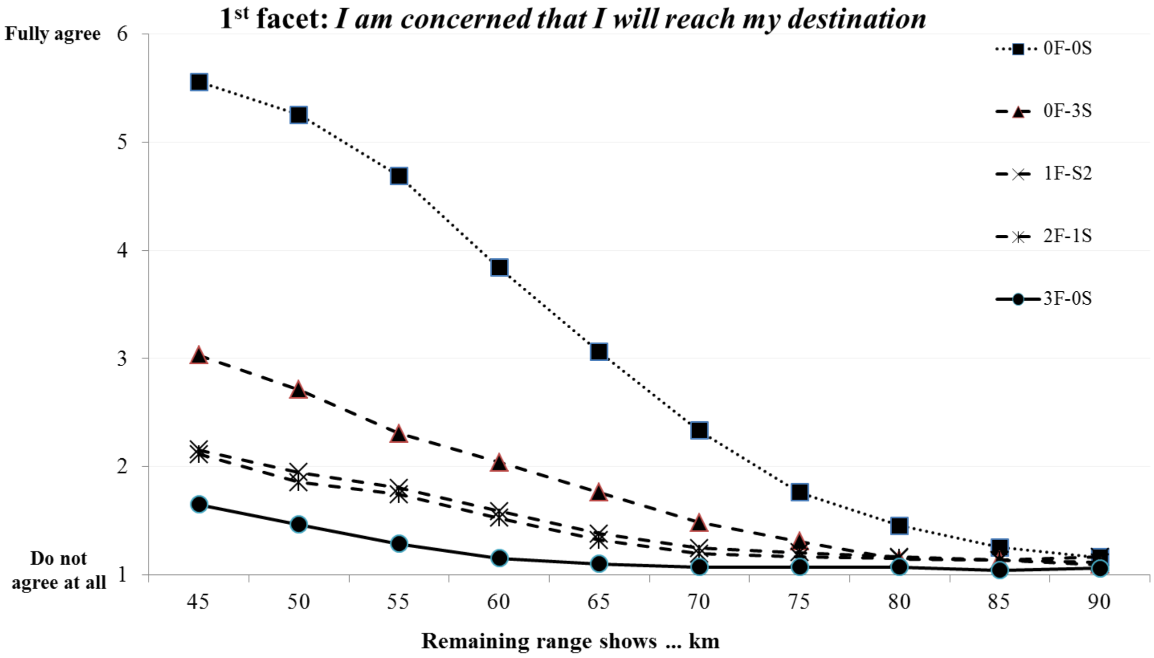

Figure 3. Results from the Safe-Range-Inventory (SRI) referring to the facet *concerns about reaching the destination*.

2nd facet: *I am not worried about my EV's range along this route*

The same analysis procedure was used as in the 1st facet.

An ANOVA for repeated measurements revealed a main effect for condition, *F*(4, 93) = 52.29, $p <.001$, $\eta_p^2 = .69$, remaining range, *F*(9, 88) = 22.65, $p < .001$, $\eta_p^2 = .70$, and, most importantly, their interaction, *F*(34, 63) = 13.06, $p < .001$, $\eta_p^2 = .89$. Pairwise comparisons (Bonferroni corrected) showed that if the remaining range status was lower (45 km) than the length of the route to be taken (60 km), the addition of charging stations – regardless of whether they were fast or slow (0F-3S; 1F-2S; 2F-1S; 3F-0S) – significantly decreased participants' concerns about the EV's range during the trip compared to the no-charging-station condition (0F-0S), all *t*s > 6.88 and *p*s < .001. Furthermore, compared with the slow-charging condition (0F-3S), analysis revealed that participants would also be more confident in reaching their destination on time using their EVs under the fast-charging conditions (1F-2S; 2F-1S; 3F-0S), all *t*s > 5.42 and *p*s < .001. By analyzing the three fast-charging conditions, results showed no significant influence on participants' concerns about the EV's range during the trip under any condition, all *t*s< 1.35 and *p*s > .10.

Using pairwise comparisons (Bonferroni corrected) under a remaining range status that was equal to the length of the route to be taken (60 km) revealed a very similar pattern of results. Having any kind of charging station along the route decreased participants' concerns, all *t*s > 7.33 and *p*s < .001. Additionally, the fast-charging conditions (1F-2S; 2F-1S; 3F-0S) decreased participants' concerns compared to the slow-charging-station condition (0F-3S), all *t*s > 3.46 and *p*s < .011. Analysis between the three fast-charging conditions again revealed no significant influence on participants' concerns about the EV's range along the route under any condition, all *t*s< 1.73 and *p*s > .10.

Similar to the 1st, all effects were diminished when the remaining range status was higher (here 90 km) than the length of the route (60 km) to be taken (for an overview see Figure 4)

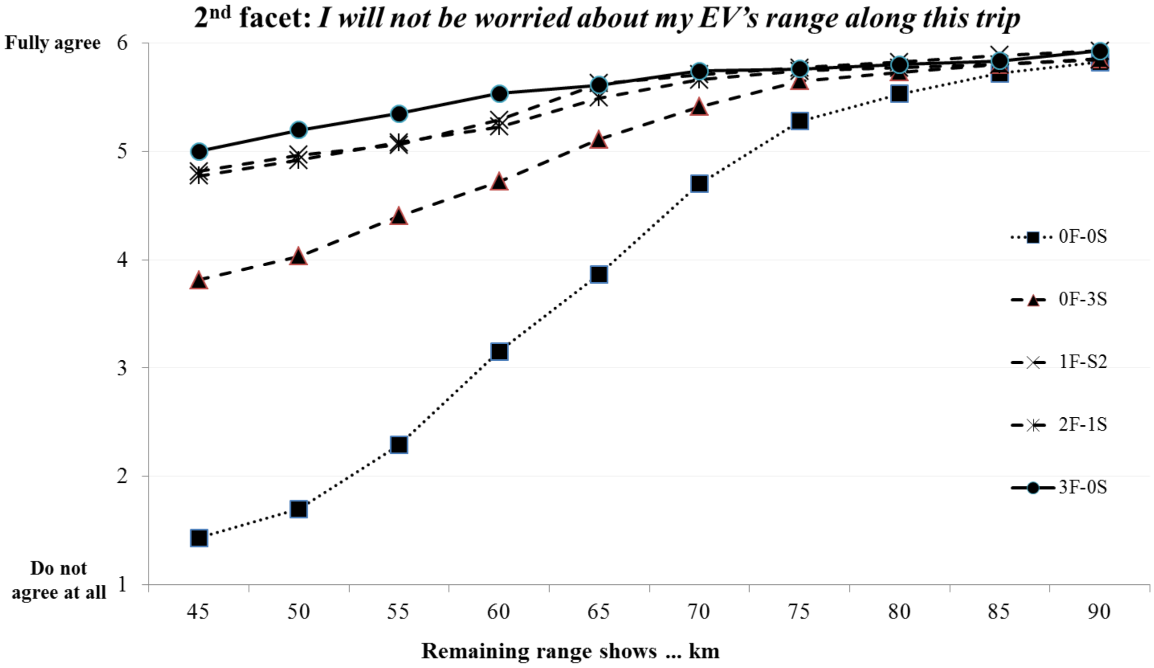

Figure 4. Results from the Safe-Range-Inventory (SRI) referring to the facet *worrying about the EV's range during the trip*.

3rd facet: *I am sure that I will reach my destination with my EV on time*

Again we used the same analysis procedure as in the previous facets[4].

An ANOVA for repeated measures revealed a main effect for condition, $F(4, 90) = 52.29$, $p < .001$, $\eta_p^2 = .62$, remaining range, $F(9, 88) = 37.46$, $p < .001$, $\eta_p^2 = .80$, and their interaction, $F(34, 63) = 7.80$, $p < .001$, $\eta_p^2 = .83$.

Pairwise comparisons (Bonferroni corrected) showed that if the remaining range status was lower (45 km) than the distance of the route to be taken (60 km), the addition of charging

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[4] Three participants did in addition not fill in this item and were therefore not included in our analysis.

stations, independently of their being fast or slow (0F-3S; 1F-2S; 2F-1S; 3F-0S), significantly increased participants' belief in reaching their destination on time compared to the no-charging-station condition (0F-0S), all *t*s > 6.81 and *p*s < .001.

Furthermore, in comparing the slow-charging condition (0F-3S) to the fast-charging conditions (1F-2S; 2F-1S; 3F-0S), analysis revealed that participants would also be more confident in reaching their destination on time using their EV, all *t*s > 5.99 and *p*s < .001. By analyzing the three fast-charging conditions, results showed no significant influence on participants' confidence in being on time with their EV under any condition, all *t*s < 1.29 and *p*s > .10.

We revealed the same pattern of results when the remaining range status was equal to the length of the planned route (60 km). Having any kind of charging station along the trip, increased participants' confidence to be on time, all *t*s > 5.74 and *p*s < .001. Additionally, the fast-charging conditions (1F-2S; 2F-1S; 3F-0S) decreased participants' worrying compared to the slow-charging station condition (0F-3S), all *t*s > 4.10 and *p*s < .001. Analysis between the three fast-charging conditions revealed, again, no significant influence on participants' confidence to be on time using their EV under any condition, all *t*s< 1.67 and *p*s > .10.

As in the other facets before, all effects were diminished when the remaining range status was higher (here 90 km) than the length of the route (60 km) to be taken (for an overview see Figure 5)

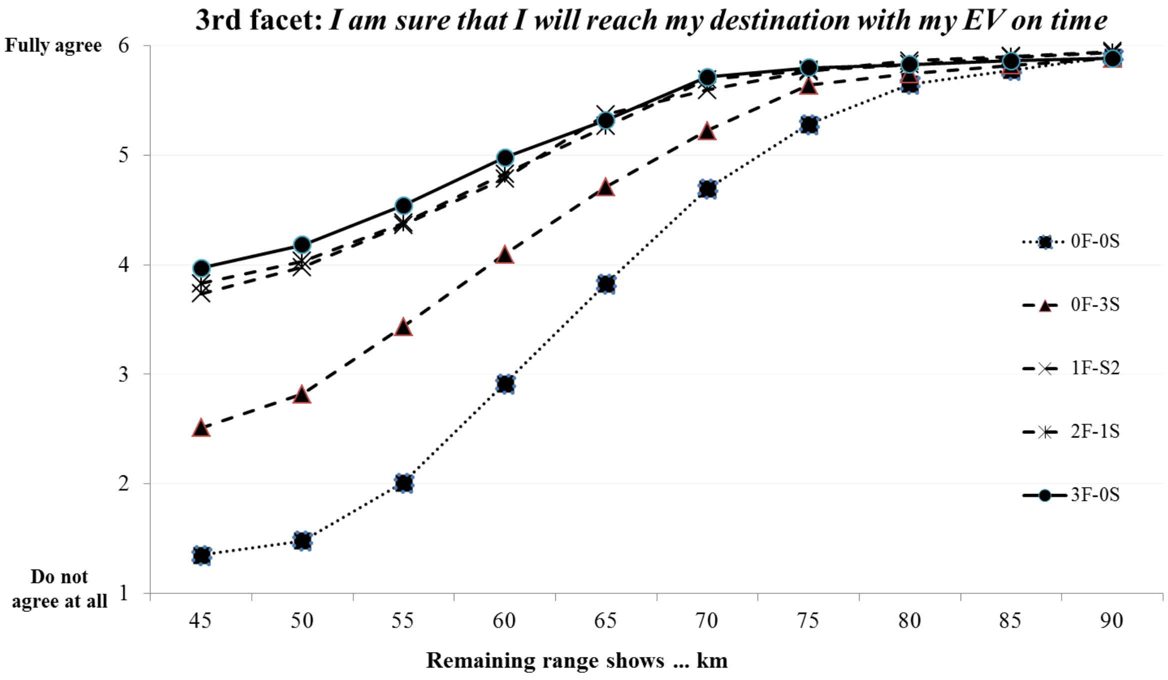

Figure 5. Results from the Safe-Range-Inventory (SRI) referring to the facet ***to reach the destination with an EV on time.***

4. Discussion on specific results

By using the three facets introduced in the Safe Range Inventory, we were able to estimate and predict certain cut-off point where different combinations of charging station (fast vs. slow) were particularly useful to reduce EV users range anxiety. Results showed that when the remaining range status was lower than the length of the planned route, participants’ range anxiety was reduced by any type and combination of charging station. Fast-charging stations, however, were particularly useful in decreasing EV drivers’ concerns when the remaining range was quite small—in other cases, the exchange of just one slow-charging station with one fast-charging station seemed to be sufficient to reduce the driver’s range anxiety. Slow-charging stations reduced range anxiety too, but only when the remaining range was above the distance to be traveled.[5]

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[5] Even with 55 km or less available for a 60 km trip and no charging opportunities (Figure 3), some of the EV drivers remain confident they will reach their destination. When we confronted participants with this seemingly contradictory information, they almost always responded that the display of remaining ranging within their experience with EV is never 100% correct. From their experience, even if the remaining range is virtually zero they still have 10-15 km left to drive—and mostly they use this rest consequently.

Table 1. Showing statistical analysis comparing each condition against the other within every facet and depending on the status of remaining range. M_{diff} = mean difference, *SE* = standard error of the mean, *d* = Cohen’s d effect size. *** $p < .001$, ** $p < .01$, * $p < .05$ (Bonferroni corrected).

Remaining Range

45

	Condition	0F-3S			1F-2S			2F-1S			3F-0S		
		M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*
Facet 1: "Concerns"	0F-0S	**2.52*** **	0.23	1.39	**3.40*** **	0.21	2.14	**3.44*** **	0.21	2.15	**3.91*** **	0.18	2.97
	0F-3S				**0.88*** **	0.20	0.43	**0.92*** **	0.20	0.45	**1.38*** **	0.22	0.77
	1F-2S							0.04	0.12	0.02	**0.51***	0.17	0.33
	2F-1S										0.46	0.17	0.31
Facet 2: "Not worried"	0F-0S	**-2.38*** **	0.22	1.36	**-3.38*** **	0.21	2.17	**-3.34*** **	0.22	2.04	**-3.57*** **	0.21	2.36
	0F-3S				**-1.00*** **	0.19	0.51	**-0.96*** **	0.19	0.47	**-1.19*** **	0.23	0.63
	1F-2S							0.04	0.11	0.03	-0.19	0.15	0.12
	2F-1S										-0.23	0.15	0.15
Facet 3: "On time"	0F-0S	**-1.16*** **	0.18	0.78	**-2.38*** **	0.22	1.45	**-2.48*** **	0.22	1.48	**-2.62*** **	0.21	1.58
	0F-3S				**-1.22*** **	0.19	0.57	**-1.32*** **	0.19	0.60	**-1.46*** **	0.22	0.65
	1F-2S							-0.10	0.08	0.03	-0.23	0.17	0.08
	2F-1S										-0.14	0.18	0.04

Remaining Range

50

	Condition	0F-3S			1F-2S			2F-1S			3F-0S		
		M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*
Facet 1: "Concerns"	0F-0S	**2.54*** **	0.22	1.27	**3.30*** **	0.20	1.37	**3.39*** **	0.22	2.15	**3.79*** **	0.18	2.92
	0F-3S				**0.76** **	0.19	0.41	**0.86*** **	0.19	0.46	**1.25*** **	0.21	0.76
	1F-2S							0.09	0.12	0.05	**0.49***	0.16	0.35
	2F-1S										0.39	0.15	0.29
Facet 2: "Not worried"	0F-0S	**-2.33*** **	0.22	1.30	**-3.27*** **	0.20	2.09	**-3.22*** **	0.22	1.98	**-3.50*** **	0.20	2.34
	0F-3S				**-0.94*** **	0.19	0.50	**-0.89*** **	0.18	0.45	**-1.17*** **	0.21	0.63
	1F-2S							0.05	0.10	0.04	-0.23	0.16	0.14
	2F-1S										-0.28	0.15	0.18
Facet 3: "On time"	0F-0S	**-1.34*** **	0.19	0.84	**-2.50*** **	0.21	1.51	**-2.55*** **	0.21	1.51	**-2.70*** **	0.21	1.61
	0F-3S				**-1.16*** **	0.18	0.55	**-1.21*** **	0.17	0.56	**-1.36*** **	0.21	0.62
	1F-2S							-0.05	0.06	0.03	-0.20	0.17	0.07
	2F-1S										-0.15	0.17	0.05

Remaining Range

55

	Condition	0F-3S			1F-2S			2F-1S			3F-0S		
		M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*
Facet 1: "Concerns"	0F-0S	**2.38*** **	0.21	1.27	**2.89*** **	0.20	1.73	**2.95*** **	0.20	1.80	**3.40*** **	0.19	2.50
	0F-3S				**0.51***	0.17	0.29	**0.57** **	0.14	0.34	**1.02*** **	0.17	0.71
	1F-2S							0.06	0.10	0.04	**0.52** **	0.14	0.42
	2F-1S										**0.45** **	0.12	0.38
Facet 2: "Not worried"	0F-0S	**-2.11*** **	0.22	1.13	**-2.77*** **	0.21	1.64	**-2.79*** **	0.23	1.60	**-3.06*** **	0.21	1.88
	0F-3S				**-0.66*** **	0.16	0.35	**-0.68*** **	0.15	0.34	**-0.95*** **	0.19	0.53
	1F-2S							-0.02	0.08	<0.01	-0.29	0.15	0.18
	2F-1S										-0.27	0.15	0.18
Facet 3: "On time"	0F-0S	**-1.43*** **	0.19	0.74	**-2.35*** **	0.21	1.27	**-2.37*** **	0.21	1.27	**-2.53*** **	0.20	1.32
	0F-3S				**-0.93*** **	0.16	0.45	**-0.95*** **	0.15	0.44	**-1.11*** **	0.21	0.51
	1F-2S							-0.02	0.06	0.02	-0.18	0.16	0.06
	2F-1S										-0.16	0.16	0.05

Remaining Range

60

	Condition	0F-3S			1F-2S			2F-1S			3F-0S		
		M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*
Facet 1: "Concerns"	0F-0S	**1.80*** **	.19	0.95	**2.25*** **	.20	1.27	**2.31*** **	.20	1.33	**2.69*** **	.19	1.88
	0F-3S				0.45	.165	0.26	**0.52** **	0.14	0.30	**0.89*** **	0.17	0.70
	1F-2S							0.06	0.10	0.04	**0.43***	0.13	0.44
	2F-1S										**0.37***	0.12	0.41
Facet 2: "Not worried"	0F-0S	**-1.57*** **	0.22	0.81	**-2.13*** **	0.23	1.18	**-2.07*** **	0.24	1.13	**-2.38*** **	0.23	1.41
	0F-3S				**-0.57** **	0.16	0.32	**-0.51***	0.15	0.27	**-0.81*** **	0.16	0.50
	1F-2S							0.06	0.08	0.05	-0.25	0.14	0.17
	2F-1S										-0.31	0.14	0.23
Facet 3: "On time"	0F-0S	**-1.18*** **	0.20	0.57	**-1.87*** **	0.21	0.94	**-1.92*** **	0.22	0.95	**-2.06*** **	0.21	1.07
	0F-3S				**-0.69*** **	0.15	0.32	**-0.73*** **	0.16	0.32	**-0.88*** **	0.18	0.43
	1F-2S							-0.04	0.07	0.02	-0.19	0.12	0.10
	2F-1S										-0.15	0.12	0.09

Remaining Range

65

	Condition	0F-3S			1F-2S			2F-1S			3F-0S		
		M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*
Facet 1: "Concerns"	0F-0S	**1.30*** **	0.17	0.73	**1.68*** **	0.18	1.05	**1.74*** **	0.18	1.13	**1.96*** **	0.19	1.41
	0F-3S				**0.38**	0.15	0.29	**0.44** **	0.13	0.35	**0.66*** **	0.15	0.59
	1F-2S							0.06	0.09	0.06	0.28	0.11	0.30
	2F-1S										0.22	0.10	0.29
Facet 2: "Not worried"	0F-0S	**-1.25*** **	0.19	0.70	**-1.76*** **	0.19	1.11	**-1.63*** **	0.21	0.96	**-1.75*** **	0.21	1.08
	0F-3S				**-0.52** **	0.15	0.24	**-0.38***	0.13	0.24	**-0.50***	0.15	0.34
	1F-2S							0.13	0.11	0.11	0.02	0.12	0.01
	2F-1S										-0.12	0.14	0.10
Facet 3: "On time"	0F-0S	**-0.88*** **	0.17	0.46	**-1.54*** **	0.20	0.95	**-1.44*** **	0.20	0.78	**-1.50*** **	0.18	0.89
	0F-3S				**-0.66** **	0.17	0.42	**-0.55** **	0.16	0.29	**-0.61** **	0.17	0.38
	1F-2S							0.11	0.16	0.13	0.05	0.13	0.05
	2F-1S										-0.05	0.12	0.08

Remaining Range

70

	Condition	0F-3S			1F-2S			2F-1S			3F-0S		
		M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*
Facet 1: "Concerns"	0F-0S	**0.85*** **	0.14	0.59	**1.09*** **	0.15	0.81	**1.14*** **	0.16	0.86	**1.26*** **	0.16	1.03
	0F-3S				0.24	0.12	0.22	0.29	0.12	0.27	**0.41** **	0.10	0.44
	1F-2S							0.05	0.07	0.06	0.18	0.08	0.24
	2F-1S										0.12	0.07	0.17
Facet 2: "Not worried"	0F-0S	**-0.71*** **	0.17	0.48	**-1.01*** **	0.15	0.74	**-0.96*** **	0.17	0.67	**-1.04*** **	0.18	0.75
	0F-3S				-0.30	0.12	0.25	-0.25	0.12	0.19	-0.33	0.12	0.27
	1F-2S							0.05	0.08	0.06	-0.03	0.11	0.03
	2F-1S										-0.08	0.13	0.08
Facet 3: "On time"	0F-0S	**-0.53***	0.16	0.32	**-0.90*** **	0.16	0.65	**-1.00*** **	0.16	0.70	**-1.02*** **	0.16	0.77
	0F-3S				-0.37	0.15	0.29	**-0.47** **	0.13	0.35	**-0.49***	0.15	0.41
	1F-2S							-0.10	0.08	0.06	-0.18	0.12	0.12
	2F-1S										-0.02	0.09	0.06

Remaining Range

75

	Condition	0F-3S			1F-2S			2F-1S			3F-0S		
		M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*
Facet 1: "Concerns"	0F-0S	**0.45** **	0.12	0.40	**0.56*** **	0.12	0.50	**0.60*** **	0.13	0.55	**0.69*** **	0.13	0.69
	0F-3S				0.10	0.09	0.10	0.14	0.09	0.16	**0.24***	0.08	0.30
	1F-2S							0.04	0.07	0.05	0.13	0.07	0.19
	2F-1S										0.09	0.06	0.14
Facet 2: "Not worried"	0F-0S	-0.37	0.14	0.33	**-0.50*** **	0.12	0.44	**-0.46***	0.14	0.39	**-0.49***	0.15	0.41
	0F-3S				-0.12	0.09	0.08	-0.09	0.08	0.08	-0.11	0.11	0.11
	1F-2S							0.03	0.08	0.04	0.01	0.10	<0.01
	2F-1S										-0.02	0.11	0.03
Facet 3: "On time"	0F-0S	**-0.36***	0.12	0.29	**-0.48** **	0.13	0.48	**-0.50*** **	0.11	0.50	**-0.52** **	0.14	0.51
	0F-3S				-0.13	0.11	0.16	-0.14	0.09	0.13	-0.16	0.10	0.21
	1F-2S							-0.01	0.06	0.03	-0.03	0.10	0.06
	2F-1S										-0.02	0.08	0.05

Remaining Range

80

	Condition	0F-3S			1F-2S			2F-1S			3F-0S		
		M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*
Facet 1: "Concerns"	0F-0S	**0.31***	0.10	0.35	**0.29***	0.10	0.30	**0.29***	0.11	0.30	**0.38** **	0.10	0.45
	0F-3S				-0.02	0.06	0.01	-0.01	0.06	0.03	0.07	0.04	0.12
	1F-2S							0.01	0.07	0.01	0.09	0.06	0.14
	2F-1S										0.08	0.06	0.11
Facet 2: "Not worried"	0F-0S	-0.20	0.12	0.20	**-0.29***	0.10	0.31	-0.24	0.12	0.23	-0.27	0.13	0.27
	0F-3S				-0.09	0.07	0.10	-0.04	0.08	0.04	-0.07	0.10	0.07
	1F-2S							0.05	0.08	0.05	0.02	0.09	0.01
	2F-1S										-0.03	0.11	0.04
Facet 3: "On time"	0F-0S	-.010	0.08	0.10	-0.21	0.10	0.31	-0.18	0.08	0.20	-0.18	0.10	0.26
	0F-3S				-0.12	0.09	0.15	-0.09	0.06	0.09	-0.09	0.08	0.15
	1F-2S							0.03	0.06	0.05	0.03	0.09	0.03
	2F-1S										<.0.01	0.07	<.0.01

Remaining Range

85

	Condition	0F-3S			1F-2S			2F-1S			3F-0S		
		M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*
Facet 1: "Concerns"	0F-0S	0.12	0.09	0.15	0.12	0.09	0.15	0.12	0.10	0.15	0.21	0.09	0.31
	0F-3S				<0.01	0.06	<0.01	<.0.01	0.06	<0.01	0.09	0.05	0.19
	1F-2S							<0.01	0.08	<0.01	0.09	0.05	0.19
	2F-1S										0.09	0.06	0.19
Facet 2: "Not worried"	0F-0S	-0.08	0.10	0.08	-0.17	0.09	0.19	-0.08	0.11	0.09	-0.11	0.11	0.11
	0F-3S				-0.08	0.06	0.11	<0.01	0.06	<0.01	-0.03	0.10	0.03
	1F-2S							0.08	0.08	0.10	0.05	0.08	0.06
	2F-1S										-0.03	0.11	0.03
Facet 3: "On time"	0F-0S	-0.04	0.07	0.05	-0.13	0.09	0.25	-0.12	0.07	0.17	-0.09	0.09	0.17
	0F-3S				-0.09	0.07	0.20	-0.07	0.05	0.11	-0.04	0.06	0.11
	1F-2S							0.01	0.05	0.01	0.04	0.08	0.07
	2F-1S										0.03	0.06	0.02

Remaining Range

90

	Condition	0F-3S			1F-2S			2F-1S			3F-0S		
		M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*	M_{diff}	*SE*	*d*
Facet 1: "Concerns"	0F-0S	0.07	0.08	0.09	-0.01	0.11	0.01	0.05	0.09	0.06	0.10	0.08	0.15
	0F-3S				-0.07	0.08	0.11	-0.02	0.06	0.03	0.03	0.03	0.06
	1F-2S							0.05	0.09	0.07	0.10	0.08	0.16
	2F-1S										0.05	0.05	0.09
Facet 2: "Not worried"	0F-0S	-0.03	0.10	0.04	-0.10	0.08	0.14	-0.02	0.11	0.04	-0.10	0.09	0.15
	0F-3S				-0.07	0.05	0.10	0.01	0.06	0.01	-0.07	0.09	0.11
	1F-2S							0.08	0.08	0.11	<0.01	0.06	<0.01
	2F-1S										-0.08	0.09	0.12
Facet 3: "On time"	0F-0S	0.02	0.07	0.01	-0.05	0.06	0.18	-0.04	0.06	0.10	0.02	0.08	0.04
	0F-3S				-0.06	0.06	0.17	-0.05	0.04	0.13	<0.01	0.06	<0.01
	1F-2S							0.01	0.04	0.04	0.06	0.06	0.10
	2F-1S										0.05	0.06	0.05

5. General Discussion and Conclusion

In the present study, we aimed to investigate a wide range of driving range safety and anxiety issues with specific scenarios of varying qualities of e-mobility infrastructures available in order to test for optimized equipment with different types of charging system; fast-and-expensive as well as slow-and-cheap stations. Such considerations had to be coordinated with the fine-graded selection of preferred and optimized locations of charging stations (Asamer, Reinthaler, Ruthmair, Straub, & Puchinger, 2016), especially for city centers (Ghamami, Nie, & Zockaie, 2016).

To test our research questions in a multi-faceted way, we developed the so-called Safe-Range-Inventory (SRI), a scenario-based multidimensional assessment tool based on previous considerations on bi-axial grid measurements in general and, in particular, on the *Response Grid* introduced by Franke et al. (2015). Although the SRI shows some overhead for instruction at the beginning of testing, it then supports in the following a very efficient and reliable method of collecting complex datasets for different scenarios.

Utilizing the SRI we revealed the following most intriguing findings: 1) The ability of fast-charging can decrease range anxiety by giving EV users the possibility of faster recharge cycles that fit their psychological needs 2) There are certain cut-off points which we have to bear in mind in which anxiety drastically increases within a very narrow band of remaining driving ranges, 3) There are certain configurations of charging stations which offer a very good balance between cost and range safety.

Regarding the cut-off points, we revealed dramatic increases from low to high safety concerns (here defined as a delta of 2 points on the y-axis) just within a narrow band of about 15 km of remaining driving range. These cut-off-points, in which the psychological effects of anxiety arise, must be addressed in a couple of fields related to e-mobility, e.g. reserve energy indicators, but also when we think of the general density of charging stations. Certainly, the specific technology of EVs requires more complex considerations than those typical for fuel-based vehicles, as weather and light conditions do affect mobility aspects much more in EVs and because charging stations are much less flexible in their use than ordinary fuel stations where far more alternatives are available and faster fueling times can be achieved.

Regarding the specific configurations of charging stations, we found out that the addition of just one fast-charging station to the portfolio of 3 stations substantially increases safety feelings. However, the addition of further fast-charging stations does not increase such safety feelings in a significant way. As the installation and maintenance of fast-charging stations – at least up to now – have meant a fundamental increase in cost, a well-balanced mixture of fast and slow charging stations is mandatory in at least two aspects: 1) to be able to establish an accessible, reliable and also global infrastructure of stations very soon, and 2) to ensure the cost-efficient operation of such an infrastructure. Both aspects are essential for high acceptance and, consequently, for a high adoption rate of e-mobility activities.

6. Outlook

In the present paper, we have demonstrated the usability and meaningfulness of multi-faceted assessment tools for examining the range safety and anxiety aspects involved in optimizing the use of fast-charging stations. To plan and optimize tangible and more global charging infrastructures, the Safe-Range-Inventory (SRI) has to be used with concrete scenarios addressing specific concerns, for instance neuralgic locations and constellations in metropolitan areas, specific concerns for fast and effective long-distance traveling on major highway systems or specific problems with less densely populated areas of the countryside. In order to be helpful for local authorities, the authors will provide all materials and information upon request to any institution. Future research has to address further modification of the study design by varying details of the scenarios (e.g., different route length), including non-EV users. To test for gender- or age-specific effects we should also use matched samples; another promising factor to be included in future studies might be the level of experience and expertise and certain personality factors which might adapt the attitude and behavior of participants. In doing so, the SRI can be applied to a broader range of prospective EV users, modified to greater ranges and transformed into a charger network design recommendation. Although we acknowledge that that the perceived range anxiety might also depend on an interaction of other factors like charging costs (Flores et al., 2016) as well as battery erosion, we hope that the SRI will help to support the major goal of e-mobility:

To ensure less pollution, more intelligent and flexible mobility, simpler and thus more easily maintained infrastructures, and – last but not least – cost-efficiency for the users.

Authors' note

We would like to thank the project coordinator Gilbert Lenski of the research project "DC-Ladestation am Olympiapark", which was funded by the German Federal Ministry of Economy, Transportation, Research and Environment. We would also like to thank Roman Vilimek and Andreas Keinath for valuable references provided for the study. Additionally we want to thank Simone Deibel from Forschungsgruppe EPÆG – Ergonomics, Psychological Æsthetics, Gestalt who coordinated the project on the student level.

References

Asamer, J., Reinthaler, M., Ruthmair, M., Straub, M., & Puchinger, J. (2016). Optimizing charging station locations for urban taxi providers. *Transportation Research Part a-Policy and Practice, 85*, 233-246. doi:10.1016/j.tra.2016.01.014

Bohringer, C. (2003). The Kyoto Protocol: A review and perspectives. *Oxford Review of Economic Policy, 19*(3), 451-466. doi:10.1093/oxrep/19.3.451

Bunzeck, I., Feenstra, C. F. J., & Paukovic, M. (2011). *Preferences of potential users of electric cars related to charging: A survey in eight EU countries.*

Carbon, C. C., & Leder, H. (2005). The Repeated Evaluation Technique (RET): A method to capture dynamic effects of innovativeness and attractiveness. *Applied Cognitive Psychology, 19*(5), 587-601. doi:10.1002/acp.1098

Carbon, C. C., & Leder, H. (2007). Design evaluation: From typical problems to state-of-the-art solutions. *Marketing Review St. Gallen (Thexis), 2007*(2), 33-37.

Dimitropoulos, A., Rietveld, P., & van Ommeren, J. N. (2011). Consumer valuation of driving range: A meta-analysis. *Tinbergen Institute Discussion Paper*, *133*(3), 1-35.

Dong, J., Liu, C. Z., & Lin, Z. H. (2014). Charging infrastructure planning for promoting battery electric vehicles: An activity-based approach using multiday travel data. *Transportation Research Part C-Emerging Technologies, 38*, 44-55. doi:10.1016/j.trc.2013.11.001

Ellingsen, L. A. W., Singh, B., & Stromman, A. H. (2016). The size and range effect: lifecycle greenhouse gas emissions of electric vehicles. *Environmental Research Letters, 11*(5). doi:10.1088/1748-9326/11/5/054010

Flores, R. J., Shaffer, B. P., & Brouwer, J. (2016). Electricity costs for an electric vehicle fueling station with Level 3 charging. *Applied Energy, 169*, 813-830. doi:10.1016/j.apenergy.2016.02.071

Fontes, T., Fernandes, P., Rodrigues, H., Bandeira, J. M., Pereira, S. R., Khattak, A. J., & Coelho, M. C. (2014). Are HOV/eco-lanes a sustainable option to reducing emissions in a medium-sized European city? *Transportation Research Part a-Policy and Practice, 63,* 93-106. doi:10.1016/j.tra.2014.03.002

Franke, T., Günther, M., Trantow, M., Rauh, N., & Krems, J. F. (2015). Range comfort zone of electric vehicle users – concept and assessment. *IET Intelligent Transport Systems, 9*(7), 740. doi:10.1049/iet-its.2014.0169

Franke, T., & Krems, J. F. (2013). What drives range preferences in electric vehicle users? *Transport Policy, 30,* 56-62. doi:10.1016/j.tranpol.2013.07.005

Franke, T., Neumann, I., Buhler, F., Cocron, P., & Krems, J. F. (2012). Experiencing Range in an Electric Vehicle: Understanding Psychological Barriers. *Applied Psychology-an International Review-Psychologie Appliquee-Revue Internationale, 61*(3), 368-391. doi:10.1111/j.1464-0597.2011.00474.x

Fransella, F., Bell, R., & Bannister, D. (2004). *A manual for repertory grid technique*. Chichester, UK: Wiley.

Gattol, V., Saaksjarvi, M., & Carbon, C. C. (2011). Extending the Implicit Association Test (IAT): Assessing consumer attitudes based on multi-dimensional implicit associations. *PLoS ONE, 6*(1), e15849. doi:10.1371/journal.pone.0015849

Gebauer, F., Vilimek, R., Keinath, A., & Carbon, C. C. (2016). Changing attitudes towards e-mobility by actively elaborating fast-charging technology. *Technological Forecasting and Social Change, 106,* 31-36.

Gerssen-Gondelach, S. J., & Faaij, A. P. C. (2012). Performance of batteries for electric vehicles on short and longer term. *Journal of Power Sources, 212,* 111-129. doi:10.1016/j.jpowsour.2012.03.085

Ghamami, M., Nie, Y., & Zockaie, A. (2016). Planning charging infrastructure for plug-in electric vehicles in city centers. *International Journal of Sustainable Transportation, 10*(4), 343-353. doi:10.1080/15568318.2014.937840

Grunewald, N., & Martinez-Zarzoso, I. (2016). Did the Kyoto Protocol fail? An evaluation of the effect of the Kyoto Protocol on CO2 emissions. *Environment and Development Economics, 21*(1), 1-22. doi:10.1017/S1355770x15000091

Jensen, H. C. B., Schaltz, E., Koustrup, P. S., Andreasen, S. J., & Kaer, S. K. (2013). Evaluation of fuel-cell range extender impact on hybrid electrical vehicle performance. *Ieee Transactions on Vehicular Technology, 62*(1), 50-60. doi:10.1109/Tvt.2012.2218840

Junquera, B., Moreno, B., & Alvarez, R. (2016). Analyzing consumer attitudes towards electric vehicle purchasing intentions in Spain: Technological limitations and vehicle confidence. *Technological Forecasting and Social Change, 109*, 6-14. doi:10.1016/j.techfore.2016.05.006

Kontou, E., Yin, Y. F., & Lin, Z. H. (2015). Socially optimal electric driving range of plug-in hybrid electric vehicles. *Transportation Research Part D-Transport and Environment, 39*, 114-125. doi:10.1016/j.trd.2015.07.002

Kraftfahrt-Bundesamt (KBA). (2015). *Der Fahrzeugbestand am 1. Januar 2015 [Stock of vehicles on 1 January 2015]*. Retrieved from Flensburg, Germany:

Kurani, K. S., Turrentine, T., & Sperling, D. (1994). Demand for electric vehicles in hybrid households: Án exploratory analysis. *Transport Policy, 1*(4), 244-256.

Lemke, F., Clark, M., & Wilson, H. (2011). Customer experience quality: an exploration in business and consumer contexts using repertory grid technique. *Journal of the Academy of Marketing Science, 39*(6), 846-869. doi:10.1007/s11747-010-0219-0

Li, Z., & Ouyang, M. G. (2011). The pricing of charging for electric vehicles in China-Dilemma and solution. *Energy, 36*(9), 5765-5778. doi:10.1016/j.energy.2011.05.046

Lin, Z. H. (2014). Optimizing and Diversifying Electric Vehicle Driving Range for US Drivers. *Transportation Science, 48*(4), 635-650. doi:10.1287/trsc.2013.0516

Lindly, J. K., & Haskew, T. A. (2002). Impact of electric vehicles on electric power generation and global environmental change. *Advances in Environmental Research, 6*(3), 291-302. doi:10.1016/S1093-0191(01)00060-0

Maia, S. C., Teicher, H., & Meyboom, A. (2015). Infrastructure as social catalyst: Electric vehicle station planning and deployment. *Technological Forecasting and Social Change, 100*, 53-65. doi:10.1016/j.techfore.2015.09.020

Pearre, N. S., Kempton, W., Guensler, R. L., & Elango, V. V. (2011). Electric vehicles: How much range is required for a day's driving? *Transportation Research Part C-Emerging Technologies, 19*(6), 1171-1184. doi:10.1016/j.trc.2010.12.010

Philipsen, R., Schmidt, T., van Heek, J., & Ziefle, M. (2016). Fast-charging station here, please! User criteria for electric vehicle fast-charging locations. *Transportation Research Part F-Traffic Psychology and Behaviour, 40*, 119-129. doi:10.1016/j.trf.2016.04.013

Rauh, N., Franke, T., & Krems, J. F. (2015). Understanding the Impact of Electric Vehicle Driving Experience on Range Anxiety. *Human Factors, 57*(1), 177-187. doi:10.1177/0018720814546372

Schroeder, A., & Traber, T. (2012). The economics of fast charging infrastructure for electric vehicles. *Energy Policy, 43*, 136-144. doi:10.1016/j.enpol.2011.12.041

Stevens, D. D., & Levi, A. J. (2013). *Introduction to rubrics: An assessment tool to save grading time, convey effective feedback, and promote student learning*. Sterling, VA: Stylus Publishing.

Tamor, M. A., Moraal, P. E., Reprogle, B., & Milacic, M. (2015). Rapid estimation of electric vehicle acceptance using a general description of driving patterns. *Transportation Research Part C-Emerging Technologies, 51*, 136-148. doi:10.1016/j.trc.2014.10.010

van Vliet, O., Brouwer, A. S., Kuramochi, T., van den Broek, M., & Faaij, A. (2011). Energy use, cost and CO2 emissions of electric cars. *Journal of Power Sources, 196*(4), 2298-2310. doi:10.1016/j.jpowsour.2010.09.119

Yao, E. J., Wang, M. Y., Song, Y. Y., & Zhang, Y. S. (2014). Estimating energy consumption on the basis of microscopic driving parameters for electric vehicles. *Transportation Research Record*(2454), 84-91. doi:10.3141/2454-11

APPENDIX A

Condition		Remaining Range																										
		45-50			50-55			55-60			60-65			65-70			70-75			75-80			80-85			85-90		
		M diff	*SE*	*d*	*M* diff	*SE*	*d*	*M* diff	*SE*	*d*	*M* diff	*SE*	*d*	*M* diff	*SE*	*d*	*M* diff	*SE*	*d*	*M* diff	*SE*	*d*	*M* diff	*SE*	*d*	*M* diff	*SE*	*d*
Facet 1: "Concerns"	0F-0S	**0.30****	0.07	0.23	**0.56*****	0.08	0.36	**0.85*****	0.10	0.47	**0.78*****	0.10	0.42	**0.73*****	0.09	0.42	**0.57*****	0.08	0.39	**0.31*****	0.07	0.26	**0.20****	0.05	0.2	0.09	0.04	0.11
	0F-3S	**0.32***	0.09	0.15	**0.40****	0.10	0.20	**0.27****	0.07	0.15	**0.28***	0.08	0.17	**0.28****	0.07	0.20	0.18	0.06	0.16	0.17	0.06	0.02	0.10	0.02	0.03	0.04	0.03	0.07
	1F-2S	0.21	0.07	0.11	0.14	0.05	0.09	0.22	0.08	0.14	0.21	0.08	0.15	0.13	0.06	0.13	0.04	0.02	0.05	0.04	0.03	0.05	0.03	0.02	0.04	-0.03	0.02	0.04
	2F-1S	0.26	0.08	0.15	0.11	0.06	0.07	0.22	0.08	0.15	0.21	0.09	0.18	0.12	0.06	0.12	0.03	0.02	0.04	0.01	0.01	0.01	0.02	0.02	0.03	0.02	0.02	0.02
	3F-0S	0.19	0.07	0.14	0.18	0.07	0.16	0.13	0.07	0.16	0.05	0.03	0.09	0.03	0.02	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	0.03	0.06	-0.02	0.02	0.05
Facet 2: "Not worried"	0F-0S	**-0.27****	0.07	0.20	**-0.59*****	0.09	0.36	**-0.87*****	0.12	0.47	**-0.71*****	0.09	0.37	**-0.84*****	0.11	0.47	**-0.58*****	0.09	0.39	**-0.25*****	0.05	0.21	**-0.19****	0.05	0.19	-0.10	0.04	0.12
	0F-3S	**-0.22***	0.06	0.10	**-0.37****	0.09	0.17	**-0.32****	0.08	0.16	**-0.39****	0.09	0.22	**-0.30****	-0.07	0.21	-0.24	0.07	0.20	-0.08	0.03	0.08	-0.07	0.03	0.09	-0.05	0.03	0.07
	1F-2S	-0.16	0.05	0.09	-0.09	0.04	0.05	**-0.23****	0.06	0.14	-0.34	0.11	0.24	-0.08	0.03	0.08	-0.06	0.03	0.07	-0.05	0.23	0.07	-0.06	0.03	0.10	-0.04	0.02	0.10
	2F-1S	-0.14	0.05	0.08	-0.17	0.07	0.09	-0.14	0.04	0.09	-0.27	0.09	0.18	-0.17	0.07	0.13	-0.08	0.04	0.09	-0.03	0.02	0.03	-0.03	0.02	0.04	-0.04	0.2	0.04
	3F-0S	-0.20	0.09	0.11	-0.16	0.06	0.10	-0.19	0.07	0.13	-0.08	0.03	0.06	-0.13	0.05	0.12	-0.02	0.02	0.02	-0.04	0.03	0.04	-0.03	0.02	0.03	-0.09	0.06	0.13
Facet 3: "On time"	0F-0S	-0.13	0.05	0.10	**-0.53*****	0.10	0.37	**-0.90*****	0.13	0.50	**-0.92*****	0.11	0.48	**-0.86*****	0.11	0.49	**-0.59*****	0.10	0.41	**-0.37*****	0.08	0.34	-0.13	0.04	0.14	-0.12	0.05	0.19
	0F-3S	**-0.31*****	0.07	0.15	**-0.62*****	0.11	0.31	**-0.66*****	0.11	0.32	**-0.62*****	0.11	0.32	**-0.51*****	0.09	0.31	**-0.42****	0.11	0.37	-0.11	0.04	0.11	-0.07	0.03	0.10	-0.06	0.03	0.08
	1F-2S	**-0.25*****	0.05	0.13	**-0.38*****	0.08	0.19	**-0.43*****	0.08	0.22	**-0.59*****	0.14	0.37	-0.22	0.10	0.19	-0.17	0.06	0.18	-0.10	0.03	0.14	-0.04	0.02	0.09	-0.04	0.02	0.14
	2F-1S	**-0.20****	0.05	0.09	**-0.35*****	0.08	0.18	**-0.45*****	0.10	0.23	**-0.44****	0.11	0.27	**-0.43****	0.11	0.33	-0.09	0.04	0.09	-0.05	0.02	0.08	-0.06	0.03	0.11	-0.04	0.02	0.07
	3F-0S	**-0.21*****	0.05	0.11	**-0.36****	0.08	0.19	**-0.44*****	0.09	0.24	**-0.34****	0.08	0.22	**-0.39****	0.10	0.34	-0.09	0.03	0.09	-0.03	0.02	0.05	-0.03	0.02	0.04	-0.02	0.02	0.03

*** $p < .001$, ** $p < .01$, * $p < .05$ (Bonferroni corrected).