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BSc. Psychology

Bachelor Thesis

A Driving Simulator Study: Range Anxiety and Trust in Battery Gauge

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Abstract

Range anxiety is related to the use of electric vehicles (EVs) and is enhanced by untrustworthy feedback applications. This study aimed to confirm the influence of battery level on range anxiety and explore the relation of battery level on drivers' trust in the range feedback gauge. Also, the correlation between trust in gauge and range anxiety was researched. Participants (N = 21) completed two conditions in a Virtual Reality driving simulator, with exposure to either high or low battery feedback. This created low range anxiety and high range anxiety scenarios, respectively. Students participated in five-minute drives followed by the Primary Appraisal Secondary Appraisal questionnaire (PASA: Gaab, 2009) and an adapted Trust in Automation questionnaire (TiA: Körber, 2018). The TiA showed acceptable scores of reliability (13 items; α = .87) and a four-factor solution. The results were significant for the influence of battery levels on range anxiety. No further results were of statistical significance. The findings confirmed that battery level influences range anxiety. Limitations included a range feedback gauge that was not based on actual energy consumption; hence, future research should implement an authentic mechanical representation of it. The study applied a valid and reliable scale to assess trust in a feedback tool in the domain of EVs but did not find any relationship between trust in a range feedback gauge and range anxiety.

Keywords: Electric Vehicles, Range Anxiety, Trust, Driving Simulator, Feedback Tool

Introduction

Electric Vehicles and Their Importance Nowadays

The car as one of the most useful innovations for modern transportation has undergone great development throughout the past decades. The transport sector is amongst the greatest contributors to climate change due to the use of resources and air pollution. Thus, the European Union aims to reduce its greenhouse gas emission drastically (Biresselioglu et al., 2018). Electric vehicles (EVs) are seen as a promising solution for a more climate-friendly, sustainable alternative to current transportation options. In contrast to traditional vehicles, EVs do not rely on limited resources such as fuel or cause high CO2-emissions (Neumann & Krems, 2016; Anable & Bristow, 2007). Introducing EVs more broadly would not only positively influence the climate but also benefit the general health regarding reduced pollution and an expansion of technology (Haddadian et al., 2015; European Commission, 2016, as cited in Biresselioglu et al., 2018). Multiple reasons support the need for a more wide-spread implementation of EVs.

A general interest in evolving car technology and EVs is largely due to the growing area of driving assistance systems. Notably, this is also because those systems benefit the risk-reduction of accidents (Beloufa et al., 2014). Nonetheless, it appears that most people still possess combustion-powered vehicles (CPVs) or have access to one (Rios et al., 2019). This is to have an alternative due to occurring inconveniences when solely relying on an electric car. Hence, a full transition from CPVs to EVs is still far off, although a general interest in EVs exists.

Electric Vehicle Adoption

To enhance the transition to EVs the advantages of the adoption must be clear to the user. A study on benefits and drawbacks experienced by users of EVs lists the following observations. The connotation of independence, greater access as well as prestige linked to possessing a car might influence the perception of EVs advantages (Ziefle et al., 2014). However, the dependence on charging stations and the lack of flexibility when no energy source is found, make users refrain from EVs (Haddadian et al., 2015, as cited in Biresselioglu et al., 2018). Moreover, the costs for maintenance would compare overall as lower in EVs (Haddadian et al, 2015), although the purchase of CPVs is less expensive which inhibits the adoption of EVs (Biresselioglu et al., 2018). Besides technical, economic, and environmental factors identified as barriers, insufficient knowledge about the environmental benefits of EVs created a lack of trust (Biresselioglu et al., 2018). Generally, it is less likely for users to adopt a new technology if it is not clear which benefits it brings (Ziefle et al., 2014), or when trust in the technology is little or missing due to technical limitations (Biresselioglu et al, 2018). However, trust in the unknown technology is a prerequisite to the adoption process. Current research on EVs concerns their benefit and adaption process for current CPV-users. Further research on trust in technology, particularly user-interface processes, can provide additional insights in the adoption process of EVs.

Ziefle and colleagues (2014) studied arguments regarding the general use of cars as well as use of EVs and discovered that trust did not influence the perceived disadvantages of either type of car technology. Nevertheless, the results show that non-electronic cars are perceived as more trustful and comfortable than EVs and challenges of availability of charging options create a barrier for potential users (Ziefle et al., 2014), which Biresselioglu et al. (2018) consider "practicability concerns" (p. 1). Concluding from the literature that compares CVPs and EVs, the former show more benefits to an individual user while unclear benefits and challenges in the adoption process of EVs inhibit a fast-pacing take-over of this novel mean of transportation.

Human-Machine Interface

Creating new technology requires great attention to the point of interaction between humans and technology – the human-machine interface alias user interface (UI). During the design process, particular attention to the UI can facilitate the adaption process of users (Neumann & Krems, 2016). The construction process needs to consider the relationship of technical and psychological factors that influence the design of a UI (Franke et al., 2019) such as the behavior of the end user. For EVs, this would ultimately enhance the energy efficiency. Past research focused on design choices for displays mostly based on visual representation. Nevertheless, this visual-oriented approach should shift to a more cognitive-based perspective in which a drivers' perceptual capacities and rational thinking are considered (Franke et al., 2019). Such a design can be based on Wickens and colleagues' guidelines (2004, as cited in Neumann & Krems, 2016) that consider cognitive processes related to perception, attention, and memory.

Findings of a study focused on the effects of continuous and on-demand feedback on driving behavior (Beloufa et al., 2014) suggest that users performed better when feedback on battery usage and remaining energy levels was provided. Autonomy was increased due to efficient driving behavior. This implies that more precise information on energy usage is likely to enhance trust in the electric car and reduce or eliminate range anxiety. A study by Neumann and Krems (2016) revealed that the energy consumption units displayed was difficult for users to interpret, so assistance in interpreting the data or drawing inference on range indication is useful. Assistance should aim for “rapid, accurate and non-distracting” (p. 332) perception of the information. Exemplary, an energy-by-distance presentation is simpler to process in comparison to a distance-by-energy which can give the illusion that the variables have a linear relation (Franke, 2019). Accordingly, a range feedback gauge should be concise and comprehensible, so its information is trustworthy and of use to the driver.

Range Anxiety

The use of battery power in EVs has brought along the necessity for feedback on the remaining range, which comes with possible stress for the driver. Per definition of Franke and colleagues (2016), range anxiety describes a drivers’ concern about the vehicles’ range as its occurrence is tied to critical range situations and insufficient resources. More specifically, it describes a drivers’ heightened stress levels due to low energy levels or a battery level that appears to be insufficient to reach the destination or a charging station before running out of power (Rios et al., 2019). Low range creates a challenge for the user that is contrary to their need for independence, autonomy, and comfort (Graham-Rowe et al., 2012). According to Sonnenschein (2010), how the driver handles given or restricted autonomy can generate range anxiety. Currently, the charging process takes long and possibilities for charging are not as densely available as needed, which makes feedback on range particularly necessary (Neumann & Krems, 2016). These issues make long-distance travel inconvenient and increase drivers concerns about reaching a destination which Rauh and colleagues categorized as a “domain-specific form of psychological stress” (2015, p.178). Like general forms of anxiety, stress occurring in relation to the use of EVs is likely expressed on cognitive, emotional, behavioral, and physiological level. Experienced anxiety by a driver is influenced by factors of personality, environmental structures, and technical features of the car and will establish itself if the driver does not see himself capable of handling the situation (Rauh et al., 2015). Several studies show that range anxiety decreases after the driver has become used to the electric car (Graham-Rowe et al., 2012; Taylor, 2009 as cited in Beloufa et al., 2014; Wellings et al., 2011 as cited in Beloufa et al., 2014). Range awareness infers that ultimately users did not trust the systems’ feedback on range, but also were not anxious because they rather relied on their own previous experience with battery levels and range limits Rios et al., 2019. Range anxiety is likely to develop due to distrust in the system and is reduced if the indicated feedback has great overlap with the actual driving experience. Due to the reduction of range anxiety through long-term use of EVs, the concept deserves great attention at the beginning of the adoption process for general implementation to be successful.

The Primary Appraisal Secondary Appraisal (PASA) questionnaire was developed to measure stress appraisal in the context of behavioral therapy (Gaab, 2009). It assesses primary stress appraisal through the subscales Threat and Challenge. Self-confidence in one's abilities and control expectancies measure secondary stress appraisal. However, the scale is suitable to measure stress-inducing situations beyond its intended domain as the items refer to stress in general (Franke et al., 2012). An empirical understanding of the phenomenon of range anxiety is still lacking (Rauh et al., 2015), so by applying it in the domain of EVs, we can utilize it to measure range anxiety.

Trust Towards Electric Vehicles

Particularly trust in technology has been researched thoroughly for the past years due to the increase in new technologies. Initial trust formation is a prerequisite for people to try new technology as perceived risks and possible uncertainties need to be eliminated first (Gefen et al., 2003). McKnight and colleagues (2002, as cited in Li et al., 2008; 1998, as cited in Li et al., 2008) state that initial trust refers to trust in an unfamiliar party, including new systems. To aid the adoption, an understanding of initial trust formation is necessary (Li et al., 2008). If inference from prior experience can be drawn, users must rely on second-hand sources, context, and intuition.

Trust is affected by multiple factors and varies per individual and situation. Automated driving systems show the importance for drivers to understand how the system functions to facilitate trust in it. This enables them to use the technology correctly (Wintersberger & Riener, 2016). Ergo, understanding in or familiarity with feedback displays of EVs would support trust towards them. Zak (2017) aimed to gain better insight into interpersonal trust within organizations and confirms that trust and trustworthiness were caused by the neurochemical oxytocin and is hence, measurable (Kosfeld, 2005). While looking at factors influencing trust, stress was found to be an inhibitor to oxytocin (Zak, 2017). Based on this finding a stressful situation has a decreasing effect on the oxytocin-trust relationship and will decrease the level of trust expressed. A simulation of self-driving car use proved increased stress levels when trust in the vehicle was low (Morris, 2017). Research by Potts et al. (2019) also support this negative stress-trust relationship. Although literature focused on trust between people, we infer from the oxytocin production process a general indication of trust. Therefore, we apply it to trust in technology.

To determine the degree of trust in a system and anticipate users' behavior, the Trust in Automation (TiA) questionnaire was developed (Körber, 2018). Trust in technology is a steadily growing field of research and multiple facets of this questionnaire, such as Reliability and Competence, or Familiarity, are also applicable to the domain of EVs and HMI. Specifically, the phenomenon of range anxiety is interesting to elaborate on when bringing it in relation to indicated trust in the vehicle.

For the study at hand trust in the range feedback gauge was measured. With the use of the TiA and the PASA questionnaires, the trust-stress relation regarding trust in a range feedback gauge and range anxiety can be researched. A high range anxiety situation will create high stress levels which result in oxytocin inhibition. Ergo, trust scores will be lower than in the low range anxiety situation. Range anxiety and trust can only be indicated subjectively by the user.

Current Study

To determine whether any relation existed between users' indicated trust in the range feedback gauge and their experienced range anxiety, the current study researched correlations between range anxiety and trust. It utilized a driving simulator and measures experienced range anxiety and trust in the range feedback gauge by means of questionnaires. Trust measured in this study solely documented the users' trust in the battery feedback tool. Based on the discussed literature, we expected to confirm that different battery levels induce different degrees of range anxiety. The condition with high battery levels should induce low range anxiety in the participants, thus low range anxiety condition. The second condition presented low battery levels to create a high range anxiety setting, therefore a high range anxiety condition. Secondly, we expected that trust scores will differ between both conditions due to the corresponding range anxiety levels. Range anxiety should decrease expressed trust. Thus, low battery levels should evoke a lower trust score in comparison to high battery levels. Lastly, a negative correlation between range anxiety and trust was expected. As range anxiety was calculated by subtracting the scores of the secondary stress appraisal from the primary stress appraisal, the scores of each subscale of the secondary stress appraisal should increase when the trust score increases and hence, decrease when the trust score is lower. Thus, a positive correlation between trust and the scores of the subscale self-confidence in one's abilities as well as the subscale control expectancies was expected.

Methods

Participants

All participants were students either recruited via the University of Twente or personally contacted by the researchers. Requirements to participate entailed possession of a drivers' license, a minimum age of 18, no visual impairments or the use of contact lenses, confirmation that the participant is not pregnant, and that they are not prone to motion sickness. Two of the 23 participants who completed the study were excluded because items of the TiA questionnaire were adapted following their participation. Of those 21, seven indicated to be male, 13 to be female and one identified as *non-binary & Other*. Four of the participants were *Dutch,* 15 *German* and two selected *Other*. The latter indicated either Luxembourgish or Romanian nationality. Participants had a mean age of 21.3 (SD = 2.51) and an age range from 18-29 years. The study was approved by the Ethical Committee of the University of Twente.

Materials

Hardware

The virtual reality equipment included a Varjo VR-2 headset and the Logitech G920 Driving Force consisting of a steering wheel and pedals. Because an automatic transmission is common in EVs the simulation represented an automatic Sedan. Thus, only the brake and gas pedals were used. The brake pedal also functioned as reverse gear when pushed for at least two seconds. A PlayStation chair on a frame from Next Level Racing completed the car set-up (Appendix A).

Software

The driving simulation was programmed in Unity (version 2019.2.21f1). To create the simulation, the Varjo VR-2 utilized its respective software Varjo (Soft), and the steering wheel and pedals were connected via the Logitech Gaming SDK. Unity, Varjo (Soft), Logitech Gaming SDK and SteamVR ran on an Alienware Computer. The calibration and tracking of the headset were executed with SteamVR. Although not of relevance for the study at hand, the screen visible to the participants while driving was recorded via Varjo including the participants' gaze.

The car resembled a four-seater Sedan vehicle. Vehicle Physics v1 by NWH was used to enable a customizable vehicle simulation. The rear-view mirror as well as the outside mirrors of the car were not functional in the simulation. The car interior provided a dashboard behind the steering wheel which included real-time feedback. The far left showed a circular efficiency display color-coded in a green-yellow-red gradient. It indicated the extent to which the driving during the simulation could be regarded as eco-friendly. The calculation was based on constant speed and compared current speed values to prior ones. Therefore, greater efficiency was achieved when the driver kept the speed as constant as possible, showing the needle of the gauge within the green area. Accelerations or slowing down of speed increased the differences in speed values and, consequently, were represented as lower efficiency within the red third of the feedback gauge. Eventually, this tool provided constant feedback on the eco-friendliness of the participant's driving behavior. It was only enabled during the first two run-throughs out of the four experimental conditions. The speedometer was displayed on the right side ranging from 0 to 260, for which accuracy was given in kilometers per hour. Between efficiency and speedometer, an animation of a battery symbol represented the remaining range capacity of the car. Although it provided no concrete range indications nor battery percentages, the feedback worked with a red-green color scheme to demonstrate the need to charge the car. For the two conditions at hand, low and high range anxiety, feedback via a battery, efficiency and speedometer gauge was included. The low range anxiety condition presented a car with a green battery at 80% capacity to the participant at the beginning of the scenario (see Figure 1). In contrast, the high range anxiety condition entailed a red battery gauge at 10% capacity (see Figure 1). While driving a decrease in the battery could be observed, which was calculated on time that had passed during the simulation. Additionally, no change in color was to be expected during the simulations as that feature was pre-set for each condition.

Figure 1

Dashboards of the Low Range Anxiety Condition and the High Range Anxiety Condition

The driving environment was created with the Fantastic City Generator and intelligent Traffic System (iTS). The virtual city consisted of four-lane roads, high-rise buildings, trees, and traffic lights and seems to be based on an American city looking at the directional traffic signs presented. The street structure included tunnels, bridges, and other road users, such as other cars or busses (Appendix B). The amount of traffic throughout the driving time remained constant, yet difficulties could arise when a simulated traffic user on the left lane made a right turn against usual traffic rules. In this regard, the driving environment deviated from reality.

Routes and Tasks

Four pre-set routes with shared starting points were randomized amongst the conditions to ensure variation (Appendix C). Instructions on the course of the journey were given verbally given by the researchers. If the participant did not follow the route as planned, they were led back on track as quickly as possible. Instructions were given ahead of time to ensure the driver could react promptly and they were formulated as precisely as possible, such as “Take a right at the next possibility”. To finish the drive, the researcher usually instructed to park the car, for example, “Please stop the car on the side of the road after passing the traffic light”.

In general, participants were asked to behave in accordance with the traffic rules and drive as they usually would under given circumstances. For each condition, participants had to follow one of the predetermined routes by instructions for a duration of five minutes at a time. For the high range anxiety condition, before starting participants were briefed that their car’s battery was considerably low with only 2 kilometers range left. They were told to drive as they usually would under these circumstances but advised to adjust their driving behavior accordingly. It was stated that participants before them had encountered the issues of running out of battery. This aimed to evoke range anxiety during this condition. All other details in the procedure remained the same. After each driving task participants were asked to fill out the online questionnaire.

Questionnaires

Qualtrics Research Suits was used to collect data for the questionnaires in between the driving experiences. The order of the questionnaires was first the Primary Appraisal Secondary Appraisal Questionnaire (PASA), followed by the NASA Task Load Index, the Safety Buffer Questions, and the adapted Trust in Automation (TiA) Questionnaire for each condition. The Safety Buffer Questions were also asked before the first condition and the TiA items were excluded after the first two conditions. For the current study, the PASA and the TiA questionnaire are of interest.

To be able to measure trust in the range feedback gauge the Trust in Automation questionnaire was modified. Four of the initial six subscales were used for the study, respectively the Reliability/Competence, the Understanding/Predictability, the Familiarity, and the Trust in Automation subscale, creating a total of 14 items (Körber, 2018). The statements were adjusted to ask for trust in the range feedback tool, e.g. "I trust the system" became "I trust the battery tool" (Appendix D). Answers were provided on a 5-point Likert scale ranging from *Strongly disagree* (1) to *Strongly agree* (5). Mean scores of all items provided the overall trust score.

The PASA questionnaire measures stress using four subscales. The first two, Threat and Challenge, make up the score for primary stress appraisal. Secondary stress appraisal is measured by the two subscales Self-confidence in One's Ability and Control Expectancies. All items make use of statements that participants must confirm or disagree with using a 6-point Likert scale (*Strongly disagree* (1); *Strongly agree* (6)). The items were translated from German to English by use of forward-backwards translation (Appendix E; World Health Organization, 2010). Stress scores were based on mean scores of the whole questionnaire or subscales.

Design

The study implements a within-subject design with two conditions. It belongs to a greater study where a 2x2 within-subject design was applied; namely, low vs high range anxiety condition x efficiency feedback presented vs no efficiency feedback presented. The independent variable Battery Level refers to the differing battery levels of the two conditions and the independent variable Range Anxiety indicates the differing levels of stress appraisal during each condition measured by the PASA. The dependent variables included Range Anxiety and Trust, while Range Anxiety was also exchanged for scores of the Self-confidence in One's Abilities or Control Expectancies subscale for the correlational analyses.

Procedure

The following steps were taken in order to adhere to the Covid-19 regulations. Participants as well as the researchers who were present filled out the Viral Infection Risk Checklist by the BMS lab before starting the experiment. Next to hand-sanitizing, all equipment was disinfected before each participant. Participants were required to wear a hairnet and an eye cover underneath the VR glasses and windows were opened for additional ventilation.

Preparation of each experimental trial included calibration of the VR glasses with the base station if the latter were moved or had been unused for several days. Participants scanned the QR code to gain access to the Qualtrics questionnaire and started with the first part. The online questionnaire asked participants to give informed consent and enter demographical information, such as gender, nationality, and age. After the general set-up, the procedure of the experiment, and the car functions were explained, the participant was adjusted to the chair before putting on the VR glasses. This was done with the support of one of the researchers to ensure that the VR headset was secure yet comfortable. Before starting the first scene, participants were made aware of the possibility of motion sickness and reminded that pausing or ending the experiment was possible at any moment.

Within Unity the first scene was started and after the driver was positioned in the virtual car five minutes were used for a test ride. Once the participant was familiar with the car and the driving they were asked if any motion sickness occurred and if they felt comfortable to continue. For transparency, the next step included starting the eye calibration and screen-recording the scene via Varjo while including the Gaze function as recording this data was relevant to other research linked to this experiment. Each participant first completed the low range anxiety condition in which a green battery gauge with high battery levels was presented. For the second, the high range anxiety condition, the battery levels were visibly low and colored red. For completeness, the experiment continued with two more conditions, both excluding the efficiency gauge. The latter two were not of relevance for the study at hand. Each participant followed the same order of conditions. Between rides, participants were able to take a break if necessary.

Each condition consisted of a five-minute drive. Afterwards, the participant completed the respective part of the questionnaire which started with an indication of motion sickness, followed by the items of the questionnaires listed above. With the start of each condition the procedure of eye calibration and positioning the driver had to be repeated. After the final condition and the completion of the last part of the questionnaire the researchers usually engaged in a short conversation with the participant to gain some insights into their experience and note down any remarks or limitations participant had encountered.

Data Analysis

Data Preparation

The final dataset featured 21 participants after unfit responses were excluded. All data of condition three and four as well as all other items not of interest within the first two conditions besides the TiA questionnaire and the PASA were deleted. Due to the greater research framework of this study, all questionnaires that did not belong to the study at hand were excluded as well. To only have relevant data remain, sensitive information like IP and location was removed. Additional exclusion criteria were any lacking item answers of the trust or PASA questionnaire, whether the progress of the questionnaire was below 99%, or a missing SONA ID because no ID implied an exemplary run-through by the researchers. The final step to the data was to delete the first two respondents as the items of the trust questionnaire were modified once more after their data collection.

Continuing, variables were renamed and indicated items of the TiA and PASA scale were reversed. In preparation for the Pearson's correlation calculation, the data had to be put into a long format to create the independent variable Trust from the trust scores of each condition. The same was done for the overall PASA score to create the dependent variable Range Anxiety. Besides, the same preparatory procedures were done for the secondary stress appraisal subscales. As the data had to be put into a long format each time, the cleaned data set was duplicated beforehand to conduct multiple correlation analyses.

PASA and Trust in Automation Questionnaire

To test the hypotheses, the overall PASA score, the primary and secondary appraisal score, and the PASA scores for each subscale were calculated for each condition. The scores for primary and secondary are computed by the use of means of their respective subscales and the overall PASA score, referred to as stress index, is thus calculated by subtracting the secondary appraisal score from the primary one (Gaab, 2019). As the PASA measures stress appraisal, the use of the PASA score in the framework of this study will imply the severity of range anxiety.

All trust items included in this study come from the subscales Reliability/Competence, Understanding/Predictability, Familiarity and Trust in Automation subscales of the TiA questionnaire. The greater TiA scale was originally designed for the field of trust in automation processes. The study at hand reverts to four of the six subscales of the original questionnaire and the items' wording has been modified to fit the application to the range feedback gauge. The Factor Analysis of the new scale was therefore exploratory. To establish the adapted TiA questionnaire as reliable and valid, Cronbach's Alpha was calculated for all included subscales and the overall scale. Once the raw data was cleaned, it became apparent that one item of the Reliability/ Confidence subscale had not been included in the modified questionnaire following both conditions. Thus, it was specifically checked if the exclusion of this item changed the Cronbach's Alpha score of the subscale in comparison to using the intended subscale with all items included.

Hypotheses Testing

First, a paired t-test was run for the independent variable Battery Levels and the dependent variable Range Anxiety by using the PASA scores to determine whether there were significant differences in range anxiety between the low and high range anxiety conditions.

Secondly, a trust in the range feedback gauge score was calculated for each condition. This included adding up all scores of the four subscales to receive an overall trust score. A paired t-test was conducted on the independent variable Battery Levels, referring to the contrasting conditions of low and high range anxiety, and the dependent variable Trust, to research if participants scored lower trust score during the high range anxiety condition compared to the low range anxiety condition.

Lastly, to determine if there is a possible correlation between trust in the battery gauge and range anxiety, a Pearson's correlation was conducted. This concluded the dependent variable Range Anxiety for the whole PASA score or the dependent variables Self-confidence in One's Abilities and Control Expectancies when using only the scores of the subscales. The independent variable throughout all Pearson's correlations was Trust.

Results

Adapted Trust in Automation Questionnaire

Cronbach's Alpha

To check the reliability of the four individual subscales that construct the applied TiA questionnaire a reliability analysis, more specifically Cronbach's Alpha, was conducted. According to Nunnally (1978, as cited in Lance et al., 2006) a score of .7 is considerable in the context of exploratory research, which agrees with the categorization of an acceptable score made by George and Mallery (2003). The results indicated that all four subscales score between good and excellent scores ranging from .81 for the Understanding/Predictability subscale with four items up to .93 for the Familiarity and the Trust in Automation subscales, each consisting of two items. The Reliability/Competence subscale consisted of five items ($\alpha = .88$), which makes the scale still reliable after excluding one item post data collection. The adapted TiA questionnaire, made up of 13 items ($\alpha = .87$), can be considered a reliable measurement as the Cronbach's Alpha is good in terms of George and Mallery's (2003) categorization.

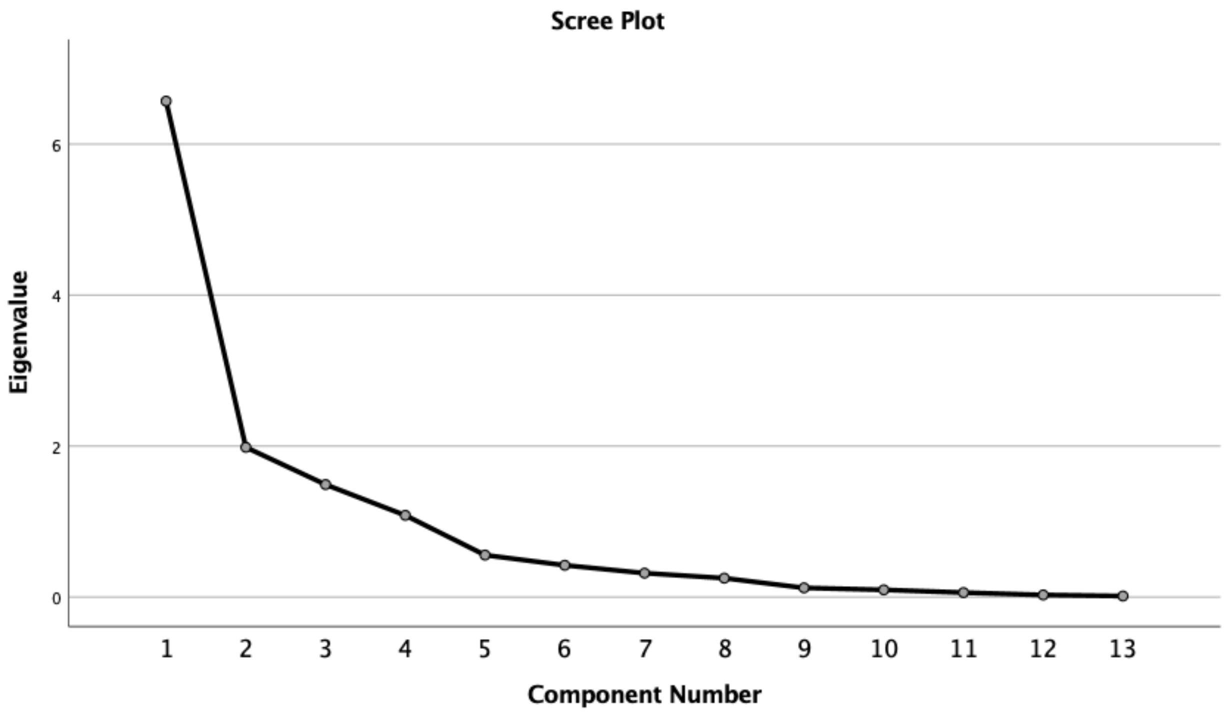
Exploratory Factor Analysis

To conduct an analysis of validity, an exploratory factor analysis (EFA) of the four subscales of the TiA was conducted. This was done to determine if these items measured the same four factors as the initial subscales that were used to develop it after those were modified in wording. Prior to the data analysis, the item "The feedback tools are capable of taking over complicated tasks" of the Reliability/Competence subscale was excluded due to an error during the data collection.

The Eigenvalues of each item were computed and displayed in a scree plot, which illustrates the number of independent components. When using a scree plot an elbow criterion was is used to determine the number of factors underlying the measured concept. Hence, the point where the slope of the curve changes to a more horizontal leveling is used as a cut-off. The scree plot suggested a four-factor solution (Figure 3). This confirmed that the modified TiA questionnaire measures four underlying factors as expected based on the original questionnaire.

Figure 3

Scree Plot Displaying the Eigenvalues of All Trust in Automation Items



Consequently, the EFA was run with four factors and an orthogonal rotation. No items needed to be excluded based on their factor loading scores. Three of the items were detected to be loading somewhat equally on two factors. For the item "I am confident about the battery tool's capabilities.", and the recoded item "It is difficult to identify what the battery tool will do next" an allocation to one of the two factors that the items loaded on was plausible due to a difference of at least 0.1 in factor-loadings between the factors in question. However, for the recoded item "The battery tool reacts unpredictably" the two factor-loadings were almost identical. The items loaded highly on multiple factors, so the respective underlying concepts were possibly correlated (Table 1).

Table 1

Rotated Factor Matrix

Item	Factor 1	Factor 2	Factor 3	Factor 4
I can rely on the battery tool.	.91			
I trust the battery tool.	.90			
The battery tool works reliably.	.86	.3		
The battery tool is capable of interpreting situations correctly.	.83		.31	
I am confident about the battery tool's capabilities.	.64	.51		
recoded: The battery tool might make sporadic errors.		.89		
recoded: A feedback malfunction of the battery tool is likely.	.39	.87		
recoded: It's difficult to identify what the battery tool will do next.		.68	.54	
The state of the battery tool was always clear to me.			.9	
I was able to understand why things happened.	.52		.61	
recoded: The battery tool reacts unpredictably.		.6	.6	
I have already used similar systems.				.96
I can rely on the battery tool.				.95

Out of all factors, Factor 1 explained half of the total variance, whereas Factor 4 only accounts for around eight percent of it (Table 2). Overall, a total of 85.6% of the variance can be explained by the four determined factors.

Table 2

Total Variance Explained by a Four-Factor Solution

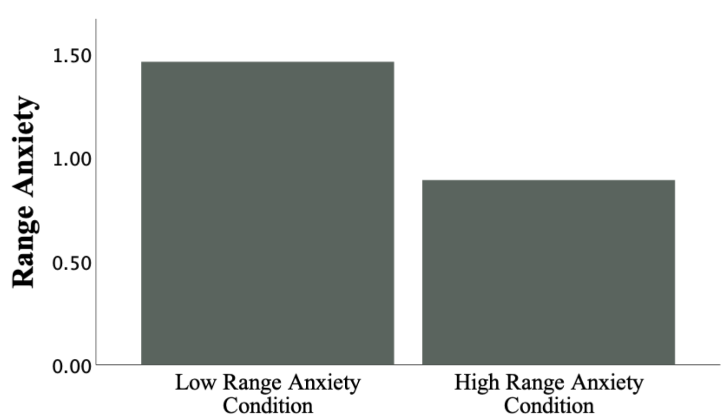
Factors	Extraction Sum Of Squared Loadings	
	% Of Variance	*Cumulative*
1	50.55	50.55
2	15.27	65.82
3	11.47	77.29
4	8.33	85.62

Range Anxiety

A paired t-test revealed that participants driving with low battery (*M* = -1.46, *SD* = 1.19) and ones driving with high battery levels (*M* = -.89, *SD* = 1.18) did differ significantly in regard to their stress levels ($t(20) = -2.21$, $p = .04$). Sum scores of range anxiety ranged between -32 and 32. These findings indicate that the first condition with high battery levels induced low range anxiety and therefore, the second condition with low battery levels caused higher range anxiety (Figure 4).

Figure 4

Mean Range Anxiety Scores in the Low and High Range Anxiety Condition



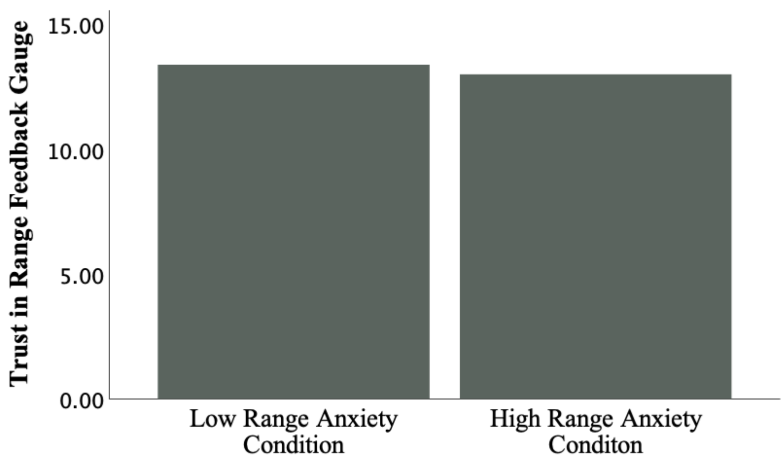
**Note.* The mean scores are shown in absolute values to facilitate visuality.

Trust in Range Feedback Gauge

A paired t-test comparing trust in the range feedback gauge was conducted. No significant difference in trust ($t(16) = .64$; $p = .53$) could be found between the participants in the low range anxiety condition ($M = 13.38$, $SD = 2.94$) and participants in the high range anxiety condition ($M = 12.99$, $SD = 3.3$). Trust in the range feedback gauge ranged from 13 to 65. Based on these results, the assumption that the level of range anxiety a driver experiences affect his trust in the battery gauge did not prove to be correct.

Figure 5

Mean Trust Scores in the Low and High Range Anxiety Condition



Trust and Range Anxiety

A one-tailed Pearson's correlation was conducted between trust in the range feedback gauge and range anxiety. The bivariate analysis did not support a significant correlation between the variables ($r = -.26$, $N = 37$; $p = .06$). This implied that the perceived trust of the driver in the range feedback gauge does not correlate with range anxiety.

Additionally, no positive correlations of statistical significance between trust and self-confidence in one's abilities ($r = .25$, $N = 37$; $p = .07$) nor trust and control expectancies ($r = .25$, $N = 37$; $p = .07$) could be reported when applying Pearson's correlation tests. Hence, trust in the range feedback and range anxiety did not correlate with each other.

Discussion

Three hypotheses were tested in this study. The first hoped to confirm the literature-based assumption that battery levels influence the degree to which range anxiety is experienced. The second hypothesis looked at the influence of the battery levels on trust in the range feedback gauge. For both significant differences were expected but only range anxiety significantly differed between the two conditions. Further, a negative correlation between range anxiety and trust in the range feedback gauge was expected but the findings suggest no significant correlations between trust and the overall PASA score nor the subscales of the secondary stress appraisal.

The modified TiA can be considered reliable and the EFA of the 13 items revealed a stable four-factor solution. These four underlying factors can be assumed to be the same common factors from the four subscales of the initial TiA that was adapted. Consequently, the factors can be determined to be Reliability/Competence, Understanding/Predictability, Trust in Automation and Familiarity (Körber, 2018).

Range Anxiety

The results of the present study confirm the assumption that battery levels as means of range indication have an influence on the experienced range anxiety of the driver. The differences in range anxiety found within the sample is indeed due to the varying battery levels that were presented to the user. This pattern of results is consistent with the previous literature as most acknowledge low, therefore insufficient, battery levels to be the root of range anxiety (Rauh et al., 2015; Khan et al., 2012). Most likely the restrictedness in autonomy and the insecurity of finding a charging station in time supports the creation of anxiety when becoming aware of low range (Sonnenschein, 2010). Overall, the confirmatory nature of this hypothesis is in line with the large body of literature concerning range anxiety and its causes.

Trust in Range Feedback Gauge

The results provide evidence that differences in trust in the range feedback gauge between the low and high range anxiety condition were statistically non-significant. This means that trust in the range feedback gauge is the same for both conditions, independent of the stress level. The finding of a causal relationship between oxytocin and trust has been widely supported by research in the field of interpersonal trust (Kosfeld, 2005; Zak, 2017). Kosfeld and colleagues (2005) specify the importance of the neuropeptide oxytocin in social interactions. Oxytocin elevates trust among humans and affects a persons' behavior in interpersonal interactions (Kosfeld, 2005). This also applies to contact with non-human mammals, but the limitation to humans and a very specific group of animals gives reason to believe that the oxytocin-trust relation does not apply to trust in technological devices. Further, a study on oxytocin and trust in automation revealed that the neurotransmitter indeed increased trust in the technology similarly to interpersonal trust but only if the design of the automation mimicked basic human characteristics (De Visser, 2017). Therefore, one possible explanation to why no difference in trust was found between the low and high range anxiety condition is that oxytocin production was not representative of trust formation in these scenarios. A literature review on the oxytocin-trust relation criticizes the lack of replicated studies confirming the association of trust and the neuropeptide (Nave et al., 2015). A recent article by Eskander and colleagues (2020) agrees with this critique. The researchers argue that the belief of a causal oxytocin-trust relationship has been replaced by seeing oxytocin as an influence on the brains' processes to modify beliefs rather than a cause to trust. While there is clear evidence that acute stress is related to a decrease in trust (Potts et al., 2019), and stress was indeed present during the high range anxiety condition, we can assume that the oxytocin-trust relation during this study was non-existent. Thus, trust in the range feedback gauge did not differ between the conditions.

Additionally, it is of interest to look at the display of the range feedback that was chosen for this experiment and its underlying calculation. As discussed, the presentation of the energy-distance relation plays into the trustworthiness of the feedback tool (Franke et al., 2019). During the simulator study, the participants were presented a range feedback gauge with a percentage indication of battery status, however, an exact range indication was lacking. Instead, a gauge displaying energy-by-distance would have been simple to interpret and beneficial to discard any mistrust (Franke et al., 2019; Neumann & Krems, 2016). The trustworthiness of a feedback application also depends on the reliability of the tool. Participants of the study were driving for a maximum of five minutes during which the changes in battery were visible. As mentioned, the decrease in battery levels was programmed to be based on the time that had passed during the simulation instead of the actual driving behavior of the participant. It might have been that the driving duration was set too short for the user to become familiar with the consequences of their driving behavior on the displayed information. Without a clear understanding of the gauge, trust is not as likely to be expressed in general (Wintersberger & Riener, 2016). Longer periods of driving could have provided a chance to become accustomed to the interplay between efficient driving and battery levels and hence, increased the perceived reliability and trustworthiness of the tool (Khan et al., 2012). Notably, in this case, longer driving time would have exposed that the range feedback was not in fact based on the driver's behavior. Authenticity would only be increased if the range feedback gauge would be based on a theoretical model of an electric vehicle consumption process.

Trust and Range Anxiety

The purpose of this study was to gain a better understanding of the relationship between trust in the range feedback gauge and range anxiety. All correlations were non-significant, therefore, no correlation between trust and range anxiety exists. Also, between trust and one's self-confidence in one's abilities nor one's control expectancies no correlations were found.

One interpretation of these findings is that causality between trust and range anxiety or vice versa exist, nonetheless. Range anxiety is influenced by several factors amongst the level of battery (Rauh et al., 2015). As research suggests an influence of stress on trust (Morris, 2017; Zak, 2017), drivers' trust in the range feedback gauge could still be indirectly influenced by range anxiety.

One reason for the findings of this study could also be the use of the adapted TiA questionnaire, which might have been a not specific enough measurement of trust. If the TiA did not measure trust in range anxiety as intended, then no correlation between trust and range anxiety was to be found. A more specific trust scale could improve the assessment of trust, for example, a trust in information questionnaire.

Practical Implications

Although confirmatory, the finding that battery levels presented to the driver greatly influence the phenomenon of range anxiety supports existing literature. Furthermore, the use of the TiA scale was new to the domain of EVs. By showing its reliability and validity, this study has provided a new measurement to determine the perceived trust of drivers in a range feedback gauge.

Regarding the collaboration with the BMS lab, the current study supported the theoretical framework for the efficiency and battery gauge of the driving simulator. This enhancement aids the simulation in terms of the authenticity of the cars' mechanics and allows future research groups to work with a more complete representation of an electric vehicle.

Limitations and Further Research

The present study made use of a larger electric vehicle simulator project which was still in its developmental stages. Due to technical difficulties and required flexibility in the procedure as well as resulting time limitations findings of this study may have been influenced by this.

Limitations of Software and Simulator

At the time of the study, the simulator had still been in the process of development and continues to do so. To conduct the study at hand and in the context of advancing the simulator a battery and efficiency gauge needed to be implemented. Following this step, the experiment was eventually run with a range feedback indicator that was based on time passed during the simulation rather than the actual consumption of energy. Reasons for this implementation were time pressure as well as the lack of knowledge as to how energy consumption in EVs functions. Similarly, the efficiency gauge was eventually based on the theoretical framework of a combustion engine car instead of an electric vehicle. The driving experience was also lessened by the sensitivity of the gas and brake pedal, which were not possible to solve due to technical restraints. Furthermore, the steering wheel was subject to sensitivity while being hard to steer at the same time. Within the driving environment, the most drastic limitation within the traffic was the unexpected right turns of simulated cars that were positioned on the left-turn lane. These influences may have affected or hindered participants in driving efficiency conscious and impacted their overall stress levels.

Procedural Limitations

Within the procedure of the experiment, it should be noted that driving behavior of participants was possibly influenced by the timing of the instructions which were given by the researchers. This can only be solved by practice on part of the instructing person. About the questionnaires administered through Qualtrics, the forced response function should have been applied to all items in order to avoid missing responses and thereby, exclusion of participants.

In terms of the implementation of a new trust measurement in the research field of EVs, the necessary amounts of samples for a factor analysis should have been greater as it is intended for large sample sizes (de Winter et al., 2009). Additionally, the adapted scale was implemented with one item less than intended as it was forgotten to be included in the online questionnaire. Nevertheless, the scores of the Cronbach's Alpha confirmed the acceptable use of the trust measurement without the initial item.

Further Research

With the intention to assess the trustworthiness of the range feedback gauge it would need to be programmed to mirror the actual driving behavior of the participant and should be based on the framework of an electric vehicles' consumption. Otherwise, the simulator could be substituted with an actual electrical vehicle. Both options would ensure that the trust measurement is exclusively on the range feedback gauge of EVs instead of measuring perceived trust in a simulator tool. In an effort to measure trust in the range feedback gauge more accurately, participants should become familiar with the interplay of driving and consumption for which the driving period appears to be insufficient. Considering the simulation and virtual environment, traffic signs with speed limits would be of help in order to restrict the driving behavior if necessary and overall, replicate a more realistic scene.

When applying the modified TiA in the domain of EVs, an exploratory factor analysis can be repeated with a greater sample size. Because no correlation between trust and stress was found in this study, a framework with an indirect influence of trust could be explored, for example as a mediator variable on the battery level-range anxiety causation.

Conclusion

This research provides additional support to the relationships between battery levels of EVs and range anxiety. It can be said that the degree of reported range anxiety is dependent on the level of the displayed battery. The study aimed to answer the questions of a possible relation between battery levels and trust in the range feedback gauge but did not find any evidence in favor. No significant differences could be found for trust in the range feedback gauge when comparing high or low battery levels. Presuming, the oxytocin-trust relationship was non-existent and hence, stress levels did not have an effect on expressed trust in the range feedback gauge as anticipated. Additionally, the findings of the study include that no correlation between trust in the range feedback tool and overall range anxiety nor one’s self-confidence in one’s abilities or one’s control expectancies was found. With the use of the adapted TiA questionnaire, a reliable and valid measurement for trust in a feedback tool was applied. Limitations included the underlying model of the range feedback gauge that was not true to reality as well as a small sample size in regard to an exploratory factor analysis. Future research should adapt the range feedback gauge to match a realistic energy consumption process. This would make it more authentic and reliable.

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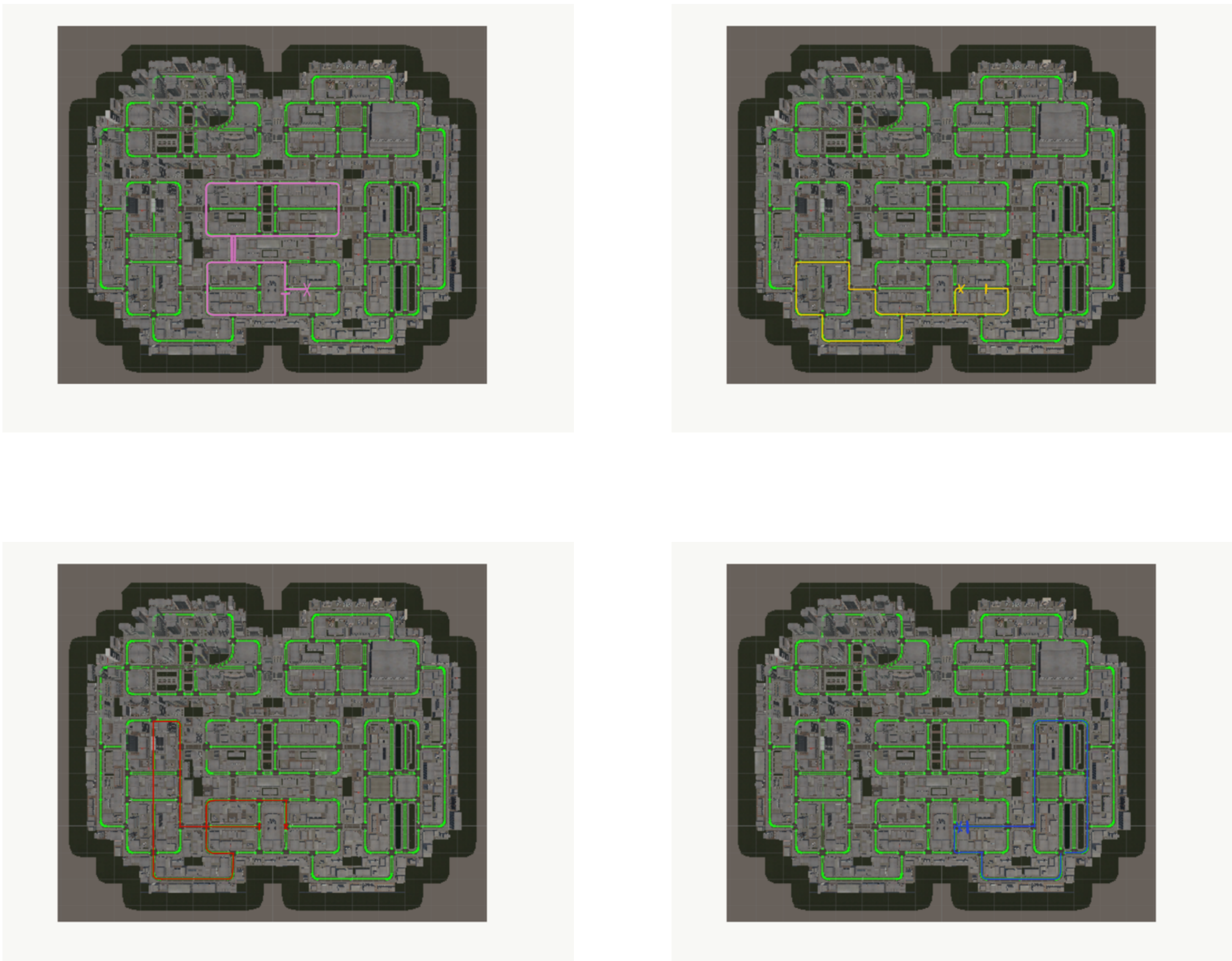
Appendices

Appendix A: Driving Simulator Set-Up

Appendix B: Virtual Reality Driving Environment

Appendix C: Four Route Templates



Appendix D: Adapted Trust in Automation Questionnaire

Adapted Trust in Automation Questionnaire

Reliability/ Competence

- The feedback tools are capable of interpreting situations correctly.
- The feedback tools work reliably.
- A feedback malfunction is likely.*
- The feedback tools are capable of taking over complicated tasks.
- The feedback tools might make sporadic errors.*
- I am confident about the feedback tool's capabilities.

Understanding/ Predictability

- The states of the feedback tools were always clear to me.
- The feedback tools react unpredictably.*
- I was able to understand why things happened.
- It's difficult to identify what the feedback tools will do next.*

Trust in Automation

- I trust the feedback tools.
- I can rely on the feedback tools.

Familiarity

- I already know similar systems.
- I have already used similar systems.

5-point Likert-Scale:
1 Strongly disagree
2 Rather disagree
3 Neither disagree nor agree
4 Rather agree
5 Strongly agree
O No response

Appendix E: PASA Questionnaire – English Translation

PASA Questionnaire - German to English Translation

6-point Likert Scale:

- Totally disagree
- Mostly disagree
- Somewhat disagree
- Somewhat agree
- Mostly agree
- Totally agree

1. I do not feel threatened by the situation.
2. The situation is of relevance for me.
3. In this situation, I know what I can do.
4. It is mostly dependent on my whether I can manage the situation.
5. This situation is uncomfortable for me.
6. The situation leaves me unbothered.
7. I do not know at all what I should do now.
8. Through my behavior I can protect myself the best against failure.
9. I do not feel uneasy because the situation is not a threat to me.
10. The situation is not a challenge to me.
11. In this situation I can think of many alternatives how to act.
12. I can determine much of what happens in this situation myself.
13. This situation scares me.
14. This situation challenges me.
15. For this situation I can think of many solutions.
16. When I manage the situation, it is because of my effort and my personal involvement.