Beat Trustfully: The Correlation Between Heart Rate and a Multi-dimensional Trust Questionnaire

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Abstract. Background: Both industries and academia are paying deep attention to the concept of trust in automation since it is significant that creates people's desire to use and buy autonomous cars.

Objectives: Regarding the previously introduced trust questionnaire by our research team, this study was conducted to present more objective insights of this questionnaire to show its convergent validity based on the physiological data.

Methods: Using a dynamic driving simulator, the 8-step experiment was performed on 29 min with 21 participants. The steps provided building, improvement, destruction, and re-building of trust. The experiment contained both manual and autonomous driving. Subjects completed stress and trust scales regarding the experience they performed. Finally, they answered to the trust questionnaire; their heart rate was acquired throughout the experiment.

Results: The Mean ± SD of participants' trust score was 139 ± 5.76. Self-driving car's unsafe behaviors were accompanied by a rise in the individuals' heart rates (objective metrics of stress). Throughout the two phases of fastest and riskiest parts of the scenario, people felt the highest stress (6 out of 10) and the least trust (4.33 out of 10), that were obtained from the mentioned one question scale.

Conclusion: Regarding the results, the mean score of people's trust from our multi-dimensional questionnaire is far from the desired score, which is 235. Objective (heart rate) and other subjective data (stress and trust) confirmed that the participants' trust in an autonomous vehicle was low. So, it can be claimed that there is a consistency between subjective and objective data with the results of our comprehensive trust questionnaire.

Keywords: Autonomous vehicles · Trust · Heart Rate · Stress · Multi-dimensional questionnaire

1 Introduction

The number of autonomous cars on the road is predicted to rise quickly as more people adopt automated driving, particularly with the advent of partially automated systems like level-1 and level-2 [1]. People who are reluctant to give up control are more likely

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to have to rely on conventional vehicles to some extent even as they continue to share the road. People who are uncomfortable with autonomous systems may feel more pressured as a result of this separation, which could make utilizing self-driving cars more stressful [2]. Gaining trust in self-driving cars is essential to putting this automation technology into practice and maximizing its benefits, although the public trust in these sophisticated vehicles is still lacking [3, 4]. The literature, however, suggests that trust can improve and ease human-autonomous vehicle interaction [3, 5]. Due to the critical role that trust plays in individuals' acceptance and willingness to use these vehicles, it has garnered significant attention and discussion among scholars in recent years [6, 7]. On the other hand, various studies have highlighted a direct and positive correlation between trust and perceived comfort levels in self-driving vehicles [8]. Increasing trust in self-driving cars has been shown to improve people's comfort levels and make travel more pleasant [9, 10]. So far, various tools have been constructed to assess individuals' trust in autonomous vehicles from different perspectives, contributing to the exploration of this crucial topic [11–13]. Referring to the multidimensional questionnaire that was developed by the authors for trust in self-driving cars [14], in the present study the consistency between subjective and objective data was investigated to demonstrate the convergent validity of the questionnaire based on the physiological data. In order to accomplish this, some driving tests were conducted to assess the relationship between the trust questionnaire and people's heart rates.

2 Methods and Materials

Briefly, the steps are mentioned in the following table and contain building (1a, 1b, 1c), improvement (2), destruction (3), further destruction (4), and re-building (5a, 5b) of trust in an autonomous vehicle (Based on Shahrdar et al. [15]). In addition to the traffic condition and car aggressiveness (risk number), some other features like driving location (city/highway) and time (day/night) changed during the experiment. The first two phases consisted of manual driving in a city on a sunny day, with low and high traffic occurring in sequence to build trust. To reach the goal, the car drove safe and slowly to make trustworthy situation, and in some cases (phases 2, 3 and 4) it increased the speed and created some dangerous maneuvers with one light crash that had not any damages or stop for the car (4). All steps are shown in Table 1 in details.

2.1 Participants

Twenty-six people were recruited at the experiment, but only 21 of them completed the test (11 males, 9 females); their ages ranged from 19 to 27 years (M = 23.19, SD = 2.82), with an average of 3.9 years of driving experience. Other 5 persons did not complete the test due to simulator sickness, however, the indoor temperature was kept around 19–21 °C using the air conditioner to prevent motion sickness symptoms. In addition to different educational background, they were from various countries such as Spain, Italy, Poland, Colombia, Algeria, etc., while all of them had been living in Italy since at least 4 months before the experiment date. Only 2 out of 21 participants didn't have driver's licenses. The majority of them were students, although some worked in Italian industries. Just 14.28% of respondents had never heard of autonomous vehicles.

Table 1. Driving scenario features

Features	Phase Number							
	Phase 1a	Phase 1b	Phase 1c	Phase 2	Phase 3	Phase 4	Phase 5a	Phase 5b
Trust	+	+	+	+	−	−	+	+
Stress	−	−	−	+	+	+	−	−
Driving Type	Manual	Manual	Automatic	Automatic	Automatic	Automatic	Automatic	Automatic
Driving Time	Sunny Day	Sunny Day	Sunny Day	Sunny Day	Sunny Day	Night	Night	Sunny Day
Driving Location	City	City	City	City	City	Highway	Highway	Highway
The amount of traffic	Low	High	Low	High	High	High	High	Low
Risk Number	0.3	0.3	0.3	0.45	0.6	0.6	0.3	0.3
Driving Duration (min)	4	4	4	4	4	4	2.5	2.5

- Trust description: Positive mode states that the step was designed to build, increase, or rebuild participants' trust. Negative sign shows it has developed for destroying their trust.
- Stress description: Positive mode states that the step was designed to make a stressful condition. Negative sign shows it has developed to decrease stress.
- Risk number: The lowest value of "risk number" on the software is 0.3, the highest is 0.9.

2.2 Apparatus

The experiment was conducted in a dynamic driving simulator in a closed space that has been created inside the laboratory of Human Centered Design and Vehicle Design by Simulation at the University of Salerno in Italy (UNISA). The virtual predefined roads were projected on three displays (size 65 inches, Hisense brand) that created a 120° horizontal field of view; the simulator is equipped with an adjustable seat, a steering wheel, pedals for gas and brake, and surrounding sound equipment. For driving simulation, BeamNG software was utilized [16]. The whole scenario took 29 min including straight and curved roads with traffic, traffic signals and signs, and other cars, except pedestrians, under different situation (e.g., risk number, ego speed, the amount of traffic, mentioned in Table 1). In the software, southern Italian roads were selected to control their stress as a confounding factor. In this way, they were familiar with the driving route and expended less mental effort on analyzing the road.

2.3 Procedure

First, the research team explained the study goals and procedures to all volunteers, who were free to withdraw from the experiment at any point, even during its course. After signing on a consent form, participants filled out a demographic questionnaire, then they started 2–3 min warm-up driving to become more familiar with the system. Participants would announce their readiness to start the experiment. The scenario consisted of 8 steps, two first stages were manual, while the remaining 6 steps were full-autonomous driving without any human input. Between each step, participants responded to stress and trust 10-point Likert scales by a tablet, regarding the stage they passed. At the end of the experiment, in order to avoid the probable simulator sickness, the participants were invited to leave the simulator seat and answer the trust questionnaire [14] while seating on a comfortable seat in a relaxed posture. Furthermore, their heart rate was collected using the chest strap, Polar H10 [17], throughout the whole experiment, since it is a suitable objective indicator to investigate people's stress and anxiety [18, 19]. Worth mentioning that participants could percept all vibration feedback received from the road such as road bumps, as well as hearing the environmental sounds with 2 speakers. Participants were free to do each kind of non-driving related task during autonomous phases, but after following up the road and the car behaviors, using their cell phones was the most preferred activity they performed but for short times (Fig. 1).

Fig. 1. Driving experiment using the dynamic simulator

2.4 The Questionnaires

As mentioned before, a demographic questionnaire, the trust questionnaire (Appendix A), which was developed by UNISA research team, and two 10-point Likert scales of trust and stress were responded. The trust questionnaire contains 3 dimensions (Personal, technical, and social), 21 sub-dimensions, and 47 questions with 5-answer options (1 = completely disagree, 5 = completely agree). 24 out of 47 questions were designed negatively, indeed the scores must be reversed (5 = completely disagree, 1 = completely agree). Thus, the minimum and maximum achievable scores are 47 and 235, respectively.

3 Results

Regarding autonomous driving sections, participants experienced highest stress (Mean = 6) during phase 4 that was full-autonomous driving with the most dangerous behaviors of the car, while the least stressful stage (Mean = 3.90) belongs to phase 5b which was planned to rebuild their trust in the AV. Figure 2 shows their stress graph during the experiment.

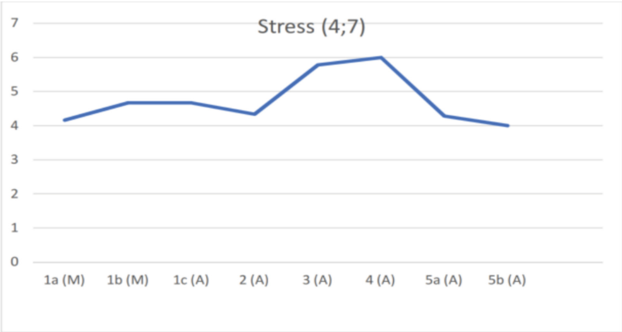

Fig. 2. Participants' stress means during 8 steps of the experiment.

The Mean ± SD of participants' trust score from the main questionnaire was obtained 139 ± 5.76 (maximum possible score = 235). Likert scales' results showed 4.33 out of 10 as the minimum amount of trust which belonged to phase 4 (the riskiest step). Moreover, phase 3 with 5.28 stands as the second unpleasant step from trust point of view. Step 1c was the most trustworthy part of the study with trust mean score of 6.76 out of 10. In this part the car started safe and smooth full autonomous driving with the lowest speed and risk number, in a low traffic city during a sunny day. Worth mentioning that the mean score of the trust scale in two last parts (5a and 5b) increased to 5.95 and 6.42 and reached values that were close to the highest obtained level.

The analysis yielded a sample mean of 139 with a standard deviation of 5.76, derived from a sample of 21 observations. The 95% confidence interval for the population mean was calculated to range from 136.38 to 141.62. This interval suggests that, with 95% confidence, the true mean of the population falls within this range, reflecting the reliability and precision of the sample data (Fig. 3 and Fig. 4).

The average of participants' heart rate for the whole experiment was 71.83 bpm (minimum 57 and maximum 80 bmp), but the highest heart rate was experienced in the phase 3 with 84.58 bmp (when dangerous maneuvers began). It is notable that the usual resting heart rate typically falls between 60 and 100 beats per minute [20] (Fig. 5).

Furthermore, 2 questions about participants' perceived comfort and motion sickness were asked using 10-point Likert scales. They reported low motion sickness (3.23 out of 10) and a moderately comfortable state (4.90 out of 10).

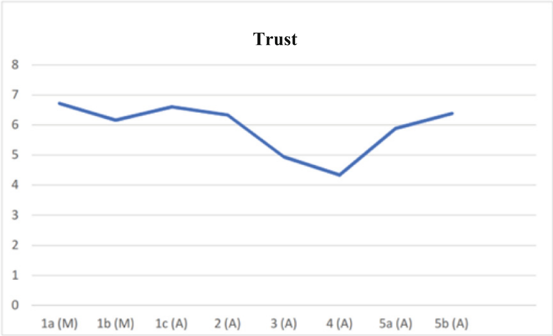

Fig. 3. Participants' trust means during 8 steps of the experiment.

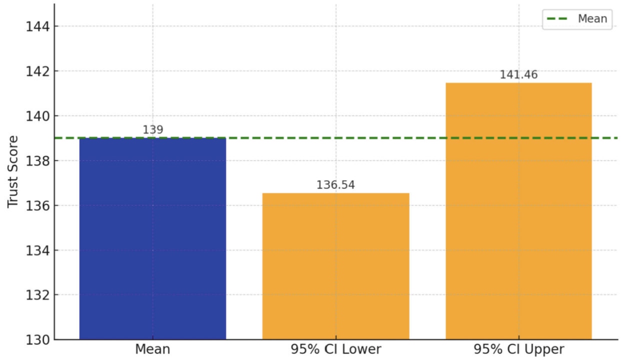

Fig. 4. Mean trust score with 95% confidence interval.

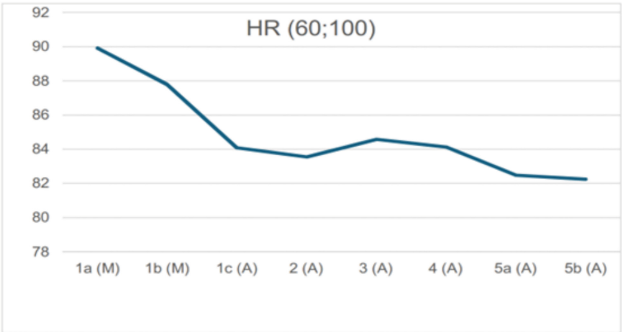

Fig. 5. Participants' heart rate means during 8 steps of the experiment.

4 Discussion

The current study was conducted to explore the consistency between subjective and objective data with the multi-dimensional trust questionnaire that was developed by this research team before. Using a dynamic driving simulator, the authors tried to create a driving environment to achieve more real output. Given the extensive use of the correlation between heart rate and trust in self-driving vehicles across various research studies [21–23] and acknowledging that heart rate consistently serves as a significant indicator reflecting individuals' stress levels [24, 25], we opted to utilize heart rate as a reliable metric to gauge individuals' levels of trust and stress towards the self-driving vehicle. Concerning the outcomes, it's pertinent to note that the average trust score obtained from our multi-dimensional questionnaire falls considerably below the target level of 235. Furthermore, the convergence of objective metrics, such as heart rate data, with subjective evaluations of stress and trust, underscores a consistent pattern indicating a lack of trust among participants toward autonomous vehicle technology. Consequently, a coherent alignment emerges between the subjective perceptions and the empirical data, affirming the conclusions drawn from our comprehensive trust assessment questionnaire.

5 Limitations

It is essential to affirm certain limitations inherent in the study, notably the relatively small number of participants involved. Additionally, the diverse range of nationalities represented among participants may introduce variability stemming from differences in technological landscapes across nations, potentially impacting the study's findings. In future investigations, addressing these limitations will necessitate not only expanding the participant pool but also ensuring a more balanced and homogeneous composition in terms of nationality and gender. Moreover, conducting experiments using driving simulators saves considerable costs and time, executing all these stages with a real self-driving vehicle may potentially provide superior and more realistic results. Lastly, heart rate was evaluated as a physiological indicator of either increased or decreased trust. Even though the literature has demonstrated that heart rate is a reliable indicator and the most effective physiological index for evaluating acute stress in driving simulator studies, further measurements can be included in future investigations. For instance, using measurements like electroencephalography (EEG) or galvanic skin response can offer a more thorough comprehension of the physiological dynamics at work.

6 Conclusions

In summary, our study findings provide compelling evidence supporting the robust correlation between heart rate data, serving as a reliable index for stress and fear, and the trust questionnaire regarding self-driving cars. These results not only validate the questionnaire's reliability in accurately gauging individuals' trust levels in autonomous vehicles but also emphasize its potential as a valuable tool for researchers in related fields. Thus, this study contributes to the growing body of knowledge and underscores the questionnaire's versatility for future research endeavours, affirming its utility in advancing our understanding of trust in autonomous vehicle technologies.

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Appendix A

(See Table 2).

Table 2. Trust in autonomous vehicles questionnaire developed by Mosaferchi et al.

Personal/Human-Related Dimension							
Num	Sub-Dimensions	Questions	Completely disgree	Disagree	No difference	Agree	Completely Agree
1	Knowledge	I'm able enough to take over the driving control from an AV in emergency/dangerous situations					
2		I need to learn about an AV continuously to use it efficiently *					
3	Personality	An AV is attractive for me to use					
4		I'm curious about functions/features of an AV					
5		I'm not afraid of using an AV					
6		I can control my stress when I expose with a dangerous situation in an AV					
7	Duration of the trip	I prefer to use an AV just for short trips (less than 20 min), not long trips *					
8	Companionship	I feel less stress in an AV when I'm not alone *					
9		I'm not worried if my children use an AV alone					
10	Situation Awareness	During the trip with an AV, I don't need to pay a lot of attention					
11		I can analyse surrounding information that I receive in an AV					

(*continued*)

Table 2. (*continued*)

Personal/Human-Related Dimension							
12	Expectations	If an AV doesn't behave based on my expectations, I'll use it again without any problem					
13	Deskillization	I believe that my driving skills won't decline because of using an AV					
14	Meaningfulness Attitude	The pleasure of driving will increase by using an AV					
15		I would enjoy the AV more if I could drive it myself sometimes					
Social Dimension							
Num	Sub-Dimensions	Questions	Completely disagree	Disagree	No difference	Agree	Completely Agree
16	Governmental considerations/support	I use an AV if some specific lanes are reserved for AVs in cities and highways *					
17		I'll buy an AV if the government gives us good financial support *					
18		I prefer AVs to use as public services like buses, more than personal cars *					
19	Brand	If I want to buy an AV, I prefer famous brands more than others *					
20	Development level of countries	I believe that people who live in advanced countries like Japan, can trust in an AV more *					
Technical Dimension							
Num	Sub-Dimensions	Questions	Completely Disagree	Disagree	No difference	Agree	Completely Agree
21	Personalized design	I prefer to connect my smartphone with the AV to experience a personalized trip					
22	Car Appearance	I prefer to ride with a big AV, rather than a small AV*					

(*continued*)

Table 2. (*continued*)

Personal/Human-Related Dimension							
23	Safety	I prefer to use an AV with more sensors than an AV with less sensors *					
24		I prefer to ride in low speeds with an AV than high speeds *					
25		I would like to have an emergency button inside the AV *					
26		I would like to receive information about pedestrians, bicyclists, and other vehicles from the AV					
27		I trust an AV with some technical confirmations of valid organizations like Euro NCAP (The European New Car Assessment Program) *					
28		I prefer to use an AV just during the day, rather than night *					
29		I prefer to use an AV just in cities, not highways *					
30	Internal Interfaces	I prefer to use a mechanical system to manage the AV *					
31		I prefer to use touch screens in the AV to set some features					
32		I prefer to receive information from the AV vocally (by playing sound effects)					
33		I prefer to receive information from the AV visually (by reading a text on the monitor or on my smartphone/smartwatch)					
34	Transparency	I prefer to be informed about technical problems in real-time *					
35		I prefer to be informed about traffic condition by the AV *					

(*continued*)

Table 2. (*continued*)

Personal/Human-Related Dimension							
36		I prefer to be informed about the next behavior of the AV before happening *					
37	Security	I believe that AVs can't be attacked like all technical systems (Cyber-attack) and my data will be kept safely					
38		I believe that AVs need an anti-virus like all computers *					
39	Technical support	I believe that technical support is an important part of after sales services *					
40		I believe that a real time customer service is necessary for an AV *					
41	Possibility of Interventions	I prefer not to drive myself in dangerous situations instead of the AV, because an AV can manage dangers better than me					
42		I prefer to drive myself in some cases instead of the AV, just for fun *					
43	Complexity	I can communicate with an AV with a simple appearance and features better, rather than a complex one *					
44	Usability	I'm sure that an AV will drive very well					
45		I believe that an AV can save our time, energy, and costs					
46		I believe an AV is easy to use					
47		I believe that an AV will send me useful feedback on all situations					

-Questions marked with an asterisk (*) should be reversed for scoring. (5=completely disagree, 4=disagree, 3=No difference, 2=agree, 1=completely agree).

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