Discomfort in Automated Driving – The Disco-Scale

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Abstract. Due to the increasing amount of automation in vehicles the role of the driver changes from having an active part in the driving of the vehicle to a reactive monitoring task. Since there is currently no method to measure subjective comfort or discomfort we developed a 14-item scale to measure the discomfort of a driver. Research suggests that it is easier for users to sense the lack of comfort and because of this we used experienced discomfort as an indicator for the absence of comfort. The questionnaire was applied in an experimental driving simulator study and proved to have a high internal consistency (r = .91). Results suggest that this questionnaire is a useful tool for assessing discomfort in automated HMI. This first version is focused on, but not limited to, automation and advanced driver assistance systems in vehicles.

Keywords: Automated Driving, Human-Machine Interaction, Discomfort, Questionnaire.

1 Why Measure Discomfort

Due to the increasing amount of computerization and automation in vehicles, driving is no longer a completely self-paced task. In highly automated vehicles, the driver's role in the human-machine interaction (HMI) changes from actively choosing the vehicle's speed and direction to a reactive monitoring task. Research in the field of vehicle automation and fully automated driving primarily focuses on the effects of the change of task on driving safety. Often, human factors issues, for example complacency [1] or situation awareness [2] and their relation to the monitoring quality are investigated. While the ability of a driver to monitor the automation is legitimately the first concern of research, it is also important to evaluate the comfort of the driver for three reasons:

The comfort of the driver determines the acceptance of the automation, and therefore how frequently it is used. Comfort should be high to achieve acceptance and usage of the automation and thus higher passenger safety [3].

Drivers in non-automated vehicles try to stay in a comfort zone [4] through the regulation of several crucial variables. In automated driving, drivers can only influence these variables by completely taking over control of the vehicle. It is therefore important to define and evaluate automation specific variables dependent on experienced comfort of the driver for different driving situations. This could prevent the

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driver from taking over control only for minor adjustments that are not critical to the safety of the vehicle.

The comfort of the driver during the automated drive is important to car-manufacturers for economic reasons. Customers are more likely to buy a car they feel comfortable in.

2 How to Measure Discomfort?

While these arguments indicate the importance of assessing the comfort of the driver during an automated drive, research is missing a specific tool to measure comfort in human-machine interaction, and especially in the car environment. Why is that? Comfort is defined [5] as "[…] a general mood, or emotion which is pleasant but not especially aroused, tense, or activated." Due to the weak nature of the mood or emotion comfort, it might be hard to observe subjectively. Hence, Seidl [5] proposes to measure discomfort - the deviation from the normal un-aroused state that is defined as comfort. But what leads to the deviation of the normal comfort state? In the context of driving, Summala [4] defines four variables that need to be above a certain threshold for the driver to feel comfortable in non-automated driving. The variables are vehicle-road-system, rule following, good progress of the trip, and safety margins. The variable vehicle-road-system is influenced by the road and vehicle condition. Thus, it is not changed by driving highly automated, since an autonomous car drives on the same streets as a non-automated car. The variable rule following shows no variance in automated driving because the automated vehicle is programmed to always follows the traffic rules. Similarly, the good progress of the trip does not rely on driving automated or non-automated, but on traffic conditions. The progress of the trip is therefore not influenced when driving automated. The main variable for Summala, and also for this research is the safety margins. They are defined as the time and space margins around the vehicle, i.e., the distance to other vehicles and objects on and around the road and the amount of time the driver has to react to these objects. These margins are an individual variable that can differ individually for different drivers [4]. In an automated drive these margins are fixed for every driver regardless of a driver's subjective safety margin.

Consequently, the goal of the present research was on the one hand to translate and empirically evaluate Summala's Safety Margin Model for automated driving, and on the other hand to develop a questionnaire that measures the discomfort in drivers of automated vehicles based on the safety margins of the automated vehicle. This could give researchers and manufacturers a tool to assess individual safety margins that an automated vehicle has to keep for the driver to feel comfortable. While up to know researchers use single items to assess comfort [6], the goal of this study was to focus the assessment of comfort on the comfort of the driver towards the safety margins kept by the autonomous car. Since developers are not only interested in situational comfort arising from the safety margins, items measuring the comfort of using the automated system in general are also integrated into the questionnaire.

3 Development and Experimental Validation

The items of the questionnaire were derived from Summala's theory of safety margins. Questions targeting the car's performance in the situation (situational component) and the general automation performance (system component) were also integrated. Questions were answered on a five-point Likert-scale with the poles strongly disagree vs. strongly agree. An example for an item measuring situational safety margins is "With more clearance distance my journey would be more comfortable". An example for an item measuring the system component is "I feel endangered by the system".

To evaluate the discomfort-questionnaire, we conducted a laboratory experiment. N = 32 participants (21 female) with a mean age of M = 22.97 years (SD = 2.90) were asked to drive a route in a state-of-the-art driving simulator running Stisim Drive (Version 2.08.06) by System Technology Inc. that simulated an extensively automated car.

Participants were told that the car automatically steered, regulated the speed, and kept enough distance to road obstacles. The task of the participants was to monitor the automated drive and to intervene if they felt that the automation was not safely steering or keeping the distance to obstacles. In a first training scenario, participants were asked to intervene on purpose by breaking to test if they were able to control the simulation, e.g., reach the pedals. In the second training, participants were told not to intervene so that they could get used to the automated drive. Thereafter, participants drove through six different driving situations. The situations were approximately three minutes long and the order was randomized for all participants. In all situations, the automated vehicle approached another vehicle that was driving ahead. The driving situations represent three types of roads: a country road, a country road with a construction site narrowing the driving lane, and a highway exit. The distance kept by the automation was varied twofold, either half of the speed in meters (uncritical condition), for example 50 meters (slightly over 160 feet) distance when driving 100 km/h (slightly over 60 mph), or a quarter or less of the speed in meters (critical condition). The uncritical condition corresponded to the legal regulation for German passenger cars with regards to distance between vehicles. The critical condition undercuts this regulation by about 50%.

Directly after each situation our 14-item questionnaire to assess discomfort was completed by participants. We were therefore able to derive the discomfort level during the automated drive in relation to the situation and the general discomfort for high and low distance over all situations combined.

4 Key Findings

The results show a difference in subjective discomfort measured by our questionnaire for different distances kept by the automation between vehicles on the road. This effect can be observed over all three different situations (Fig. 1).

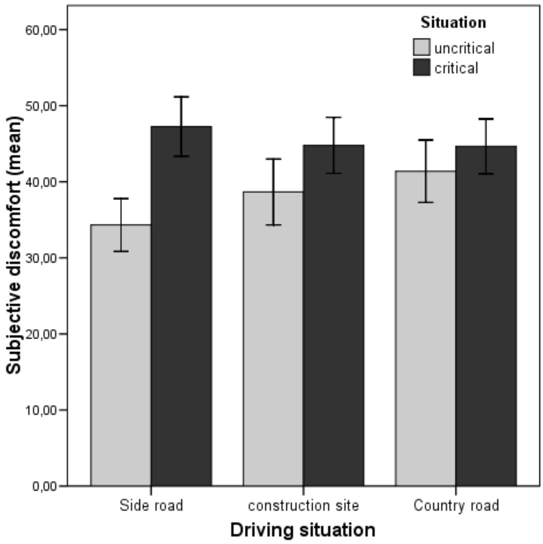

Fig. 1. Mean sum score of the subjective discomfort for all situations and conditions

Subjective discomfort is higher in situations in which the automated car maintains a small distance. This finding for automated driving is consistent with Summala's theory of safety margins [4] for non-automated driving. Independent of the distance kept by the automation, the different driving situations have a further influence on the discomfort, as can be seen in Fig. 1. The observed effect does not translate to a statistically significant difference between the situations and the subjective perceived discomfort. No main effect was found for the type of situation ($F_{(2,186)} = 0.70$; $p = .50$).

Independent of the situation, the distance kept by the automation in general seems to influence the subjective discomfort measured by the Disco-Scale. A main effect in condition "uncritical vs. critical" was found to be significant ($F_{(1,186)} = 23.23$; $p < .01$).

5 Future Work

Although the Disco-Scale already yielded a high internal consistency it is still a work in progress and is continuously improved. The questionnaire is going to build the basis of extensive studies on HMI in automated vehicles. An increase in the number of participants through further experiments is needed to validate the questionnaire, and items that may yield a lower corrected item-total-correlation will be exchanged.

Once the final set of questionnaire items has been determined and the questionnaire has been proven to have good psychometric properties, different variables of automated driving will be evaluated to determine their impact on subjective discomfort felt by the passenger. Relying on Summala's [4] theory of safety margins, further variables will include curve radii selected by the automation, side clearance, time to collision, time headway, as well as different road conditions that could influence the comfort/discomfort of the passenger during automated driving. The discomfort questionnaire could help to determine how automation parameters in the HMI must be adjusted for different conditions and situations. This would lead to the driver trusting the automation and feeling comfortable using it, and thus keeping the driver from taking over the control of the car. The questionnaire might also help researchers as well as practitioners to test non-invasive physiological measurements, for their validity to detect discomfort. This could allow for the real time adjustment of driving parameters of the automation according to the comfort state of the driver.

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