Driver Stress Response to Self-driving Vehicles and Takeover Request – An Expert Assessment

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Abstract. A self-driving car that operates on the SAE automation level 3 or 4 can navigate through different traffic conditions without human input. If such a system is on its operating limits, it will emit a takeover request before shutting down. This request will likely generate a physical response of the driver. Our goal is to shed light on the stress perception of drivers in various scenarios. To this end, we have carried out a feasibility study for preparation. Two subjects drove an autonomous vehicle and during the ride ECG signals were recorded, and afterwards evaluated. Unfortunately, the stress reaction to takeover requests could not be investigated, due to the poor function of the autonomous driving mode from the vehicle, however the reaction to autopilot misconduct without warning to the driver could be investigated instead.

Keywords: Automotive · Autonomous driving · Stress · Take over requests
Bio signal measurements · ECG

1 Introduction

Autonomous driving vehicles will enable us to safely use our travel time for other activities, improve traffic flow, minimize the risks and severity of accidents, and enable everyone to travel, regardless of abilities and condition and without the need for widespread public transport systems [1]. This will lead to an increase in vehicle safety and reduction of mental workload of the driver is to be expected [2]. The recommended practice SAE J3016 defines a taxonomy for on-road motor vehicles to classify driving assistants systems and automation systems on the dynamic driving task (DDT). This taxonomy is divided into six levels, from level zero (No Automation) to level five (Full Automation). With each step, the autonomous vehicle is more involved in the DDT and the human driver is in the role of an observer and failsafe [3]. The partial autonomous vehicle of near future will operate on the automation level 2 or 3, with some high-end models even on level 4. On these levels, the vehicle controls the primary and secondary driving tasks during long periods on its own and no human input is required. This technology will be available around the year 2025 [4]. Current and future vehicles on the SAE scale require that the driver is at all times able to take back the control over the vehicle, in case of malfunction or imminent system boundaries. In these cases, the vehicle emits a takeover request (TOR) to notify the driver. Research mainly focused on security variables as takeover time [5] (time until the driver is back in full control of

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the vehicle), but what is neglected so far is emotional and physical wellbeing (like stress reactions) of the driver during these TORs. This response will most likely take the form of short-term stress and increase the mental workload. The definition of stress varies widely depending on the field of research. In the context of this work, we follow Lazarus and Folkman defining stress as a noxious short time effect on body and mind that creates measurable physical responses [6]. This physical responses could be increased heartrate variance, dilated pupils or the rise of electrodermal activity [7]. A measurement of vital signs can help to further improve the road safety and well-being of the driver. We suspect that there are scenarios, which involve autonomous driving and takeover requests that could benefit from various bio signal measurements. First we assume, that a sudden TOR will increase the driver's stress and mental workload above the normal level, which correlates with the given traffic situation. Over time, the stress level reverts to a situational normal level. The second scenario utilizes information about the current position and route to destination of the vehicle to predict where a takeover request is likely to occur when the operating range of the autonomous system is reached, for example a motorway exit. With the inclusion of the driver over a longer period, we suspect a better stress response. Lastly, the continually taken measurement of driver vital signs helps to monitor the function and quality of the autonomous driving itself. In a situation, where the system assumes an error-free function and yet the driver's stress indicators rise, we could suspect a malfunction or a non-intuitive behaviour of the autonomous vehicle. With the detection of bio signals, we have the opportunity to create solutions that minimise the potential negative effect of autonomous driving. In future work we want to explore these scenarios, but the purpose of this study is to investigate, if there are physical reactions of the body to TORs, as well as the general stress response to autonomous driving.

2 Method

The first step is to test our thesis, that a takeover request generates a measurable biofeedback in the driver. In this study, two male drivers (subject 1: age 26 and subject 2: age 49), with several years of driving experience, will each undertake a ride in a Tesla Model S. Due to a workshop appointment two different Vehicles will be used. The first subject uses a model S 90D with software version 2018-6.1 and the second a model S 60D with software version 2018-10.04. Both vehicles are capable of driving autonomously over the course of several minutes and in different traffic scenarios. The subjects wear a Movisens mobile ECG device that continuously monitors the electrical activity of the heartbeat and is motion robust to avoid measurement artifacts. The stress parameter of heart rate variability can be calculated from electrical activity. Additionally, the sensors record the acceleration in X, Y and Z directions. The study is filmed with a dashboard camera. In addition, the conversations during the study are recorded as well. Both drivers are familiar with the route and accustomed with the autonomous driving mode of the vehicles. Over the course of the trip, the subjects are encouraged to comment on the driving manoeuvres and try to predict misbehaviour. As shown in Fig. 1, we have identified a suitable route from approximately 27 km length. This course consists of motorway (shown in orange) and city streets (shown in blue) in the area of Bottrop, Germany. It takes roughly 30 min to drive the 27 km long route. During this time, the vehicles are driven in autonomous mode as often as possible.

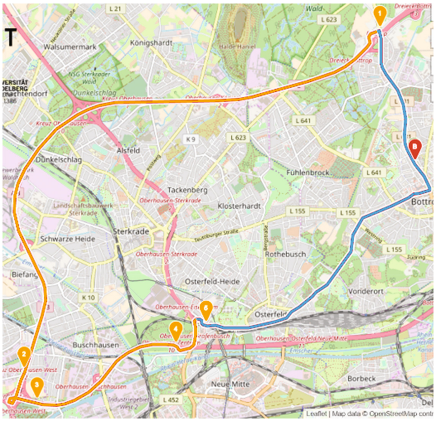

Fig. 1. Test course for first study, blue: city street, orange: motorway. red marker: Ruhrwest University Bottrop. Made with OpenStreetMap

During the motorway journey, the driving manoeuvres of driving onto the motorway and lane changes in autonomous mode are observed in particular. On the route through the city, special traffic situations are encountered which have led to repeatable autopilot malfunctions during the test drives. These include the merging of two lanes through a barrier area (Fig. 2 left side) and a curve with a much-used parking lane on the right-hand side of the lane (Fig. 2 right side). When the lanes merge, the Tesla crosses the marked barrier area instead of changing lanes to avoid it. In the curve with the parking lane, the Tesla consistently recognizes the parked vehicles as stationary traffic and stops behind the vehicles without any steering.

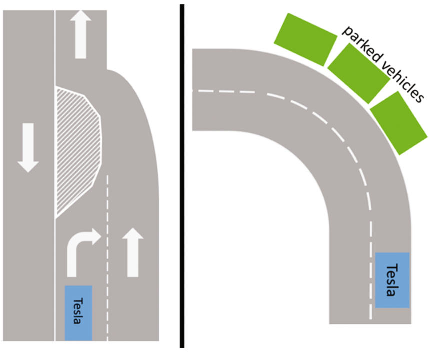

Fig. 2. Traffic situations; left: merging of two lanes; right: curve with parked vehicle

3 Results

During both trips, there was little traffic. During the trip of subject 1 there was light rain during the section on the motorway, but this did not result in any impairment of the function of autonomous driving. Unfortunately, the stress reaction during take-over requests could not be investigated during the experiment, due to the behaviour of the Tesla autopilot. In the traffic scenarios studied, the test vehicles did not submit a takeover request, but continued to drive independently. The stress generated is caused by the intervention of the driver to prevent accidents or to ensure a continuation of traffic. The further investigation deals with the physiological stress reaction to a ride in an autonomous vehicle in situations that require intervention by the driver to prevent incorrect behaviour. First, the general stress load during the entire journey is determined. A Poincaré plot (Fig. 3) is created for each subject. A larger point cloud indicates increased parasympathetic activity and thus less stress. A large difference in parasympathetic activity can be observed in the subjects. The ECG data suggests that subject 1 is more relaxed, which the video confirms. This can be explained by the greater familiarity with the behaviour of the autopilot on the driven route. In addition, subject 2 is exposed to more stress due to his professional position, which could not be completely eliminated during the experiment.

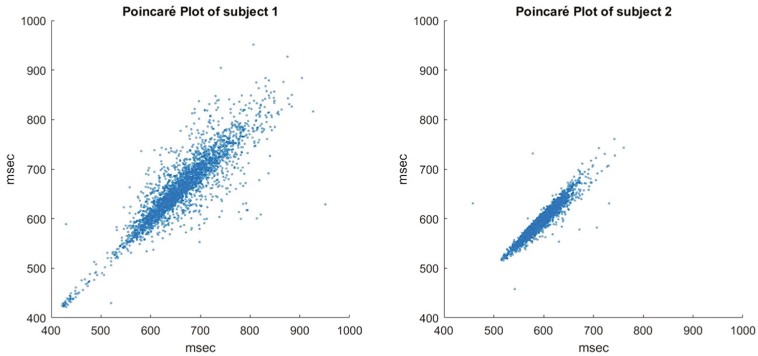

Fig. 3. Poincaré plots of both subjects

The individual scenarios are examined in more detail below. The ECG data are evaluated and the time between two heartbeats is measured by the means of R-peaks (RR- or NN-time). For each of the scenarios, motorway access, driving on parked vehicles and merging lanes, 120 NN intervals in consecutive order were taken into account and for the shorter lane changes 45 intervals each. The intervals of the NN times are visualized in tachograms (Figs. 4 and 5), with the areas marked in blue representing the heartbeats during the manoeuvres. The difference in parasympathetic activity between the two subjects can also be seen in the individual scenarios. While subject 1 shows an expected stress reaction in some manoeuvres, subject 2 only shows a permanent tension. In the following, only those scenarios are discussed which provided meaningful data. The scenario of driving onto the motorway was not able to generate a discernible stress reaction. However, this scenario should be considered in future research, as the autopilot of the Tesla has repeatedly shown malfunctions. From the multiple successful lane changes on the motorway, three comparable situations can be selected (Fig. 4). The first situation shows no discernible stress reaction, but in the other two situations with subject 1 a constant NN time is discernible before the start of the lane change up to the middle of the execution. The premature increase may be accompanied by mental preparation. The decline of NN time probably depends on the perceived certainty of success.

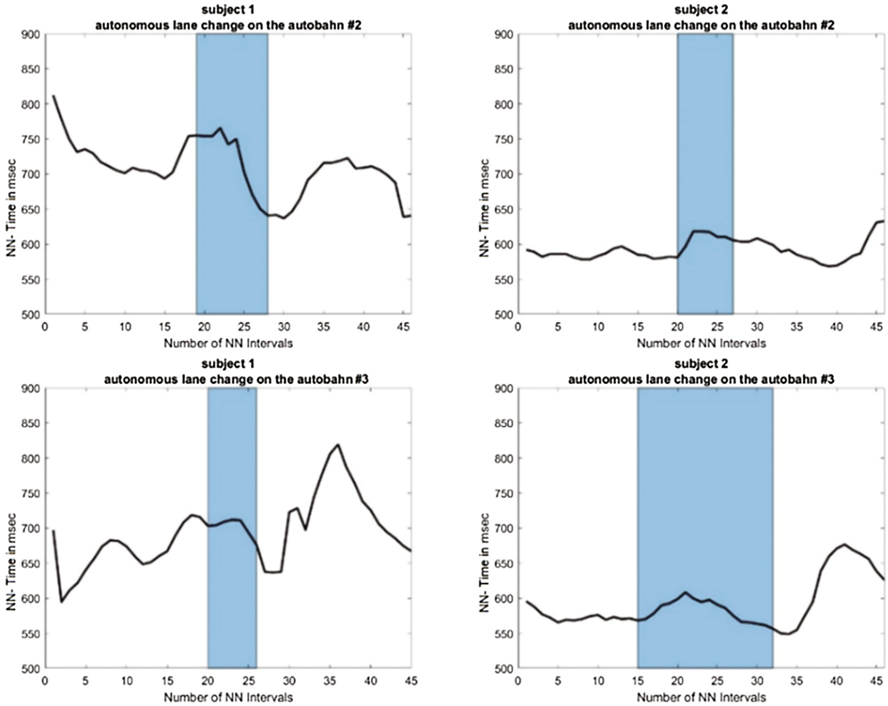

Fig. 4. Autonomous lane change on the motorway; left side: subject 1; right side subject 2; Situation 2 and 3

As with the motorway access, the drive onto parked vehicles did not cause any discernible reactions from the test persons. It can be assumed that due to the familiarity of both drivers with the relatively harmless situation no measurable stress was generated. Of the scenarios studied, the merging of the two lanes provided the most discernible stress reactions of the subjects (Fig. 5 left side). Before the autonomous maneuver began, the NN time was reduced, which remains constantly low for the entire duration of the maneuver, only to increase and vary again afterwards. The premature reduction of the NN time can be explained by the subjects' familiarity with the situation and the expectations thus generated.

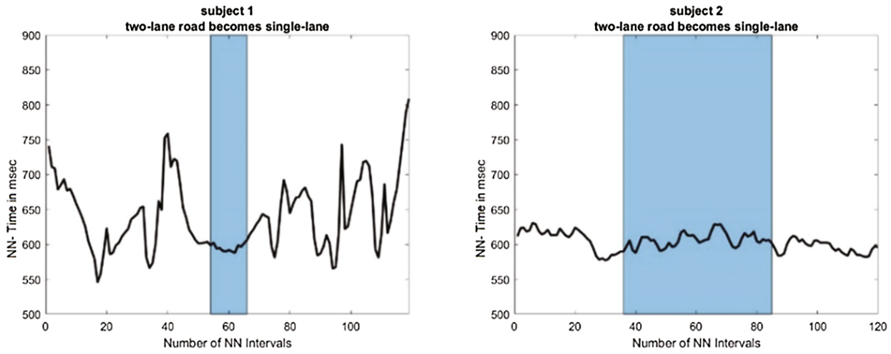

Fig. 5. Merging of two lanes; left side: subject 1; right side subject 2

4 Conclusion and Future Work

We could not investigate our assumption that take-over requests cause a physical stress reaction due to the function of the Tesla autopilot. However, it could be shown by a small sample that even situations in which a malfunction of the autopilot are correctly predicted, a stress response occurs. The measurement of the ECG by Movisens' chest strap sensor has proven to be feasible and can be used for subsequent studies. The results of the study will be used in future to carry out a larger experiment with a higher number of test persons. Currently, for legal reasons, only trained persons can use the autonomous mode in traffic. However, in order to obtain test subjects without experience with autonomous vehicles, the second study will be conducted on private property. In order to be able to bring about reproducible takeover requests, two combinable possibilities are available: On the one hand, non-permanent road markings from road construction can be used, and on the other hand, the acoustic warning signals of a TORs can be simulated by other hardware. The study leader can easily trigger this tone via a smartphone and the sound system of the Tesla. In addition to the results of the presented study, technologies that were not considered here will have an impact on future work. The image processing algorithms for contactless measurement of photoplethysmography (remote photoplethysmography or rPPG) should be mentioned. These allow cost-effective determination of heart rate, without additional worn sensors. The second technology that will have an impact on the progress of the work is deep learning. Neural networks can achieve very good results especially in the detection and classification of signals, such as stress in our case.

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