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I Drive My Car and My States Drive Me: Visualizing Driver’s Emotional and Physical States

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Abstract
Drivers’ emotional and physical states have a big impact on their driving performance. New technological sensing methods are currently investigated and will soon allow to automatically detect the driver’s state. Yet, how to communicate the detected state to the driver is less well understood. In an iterative design process, we developed two concepts to increase the driver’s awareness of this issue: (1) a *dashboard* which provides a continuous overview of four potentially safety-critical states, namely drowsiness, aggressiveness, high workload, and hypoglycaemia, and (2) *on-time warnings* which alert the driver to an immediate safety risk. We then let 70 drivers experience both concepts in a driving simulation and collected their qualitative feedback in post-study interviews. We found that participants preferred to receive only safety-critical notifications of the driver’s state but appreciated a progressive status indicator for easier interpretation. Based on our findings, we suggest first recommendations for visualizing driver’s states.

Author Keywords
Driver’s State; Qualitative Feedback; Visualization.

ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]

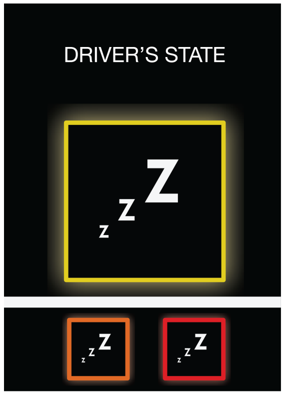

Figure 1: An *on-time warning* is displayed when a critical value is reached (here: drowsiness). A warning features a color-coded frame indicating the urgency.

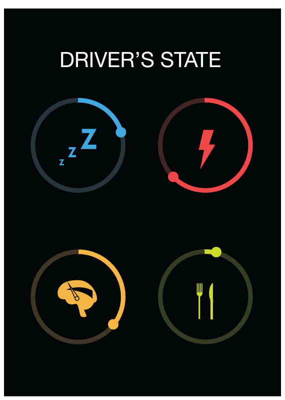

Figure 2: The *dashboard* continuously displays all four states to the driver. Each state is visualized by an icon and a circular progression indicator.

Introduction

Emotional and physical states can have a strong effect on the driver's performance and potentially result in fatal accidents [2, 10, 16]. For example, drowsy drivers may fall asleep whereas aggressive drivers could initiate risky overtaking maneuvers. Previous research suggests that drivers' performance and attentiveness can be improved when the system detects the situation and makes drivers aware of their state [1, 9, 15]. This automatic detection is technologically challenging but sensors and smart data analytics quickly facilitate a deeper understanding of the driver's states and the situational context. While cars can already detect the state of drowsiness [5, 13, 14], academia and the automotive industry strive to extend the car's abilities to also detect other, potentially safety-critical states such as aggressiveness [7, 11], overload [17, 18], and hypoglycaemia (i.e. low blood sugar level) [3].

Current approaches for responding to a critical driver's state focus on a combination of audible and visual warnings as well as basic recommendations for rest (e.g., a coffee cup [6, 15, 19]). Since having insights into the system's reasoning can improve its understanding, transparency, and trust [12], we think that providing more details about the driver's states may be more comprehensible to drivers than unexplained warnings like the coffee cup. Hence, the following two questions guided our multi-step research:

(1) How would drivers visualize their states?

(2) Is an on-time warning (Figure 1) or a continuous dashboard (Figure 2) the preferred approach?

Concept Development

To explore possibilities for communicating the driver's state, we conducted a design workshop with five user experience experts. We requested each participant to sketch emotional and unemotional graphical representations (e.g., icons, emoticons, and diagrams) of the four driver states drowsiness, aggressiveness, high workload, and hypoglycaemia since these states can have a high influence on driving performance. After discussing the results in the group, they together decided on two favorite representations (Figure 3). The first sketch combined an icon with a colored frame. The second sketch showed all states simultaneously in a status indicator diagram.

Prototype for Communicating Driver's State

Based on a literature review and the workshop results, we developed two concepts for communicating the four aforementioned states. We iteratively improved these concepts by discussing paper prototypes with drivers. Afterwards, we developed digital prototypes for the following two concepts:

On-time Warnings: Each driver's state is visualized by a single icon inside a frame (Figure 1). The color of the frame indicates the urgency of the state: yellow for low, orange for medium, and red for high urgency. An on-time warning only appears in case a state exceeds a dangerous threshold. This visualization allows drivers to quickly interpret whether their state could have an impact on driving performance and requires an immediate action. But, the driver does not obtain detailed insights into the course of the states.

Continuous Dashboard: The dashboard provides an overview of the four states as well as their course and is displayed continuously to the driver (Figure 2). Each state is represented by a circular status indicator. We used the same icons as for the on-time warnings but selected different colors in order to enhance the discrimination between state visualizations. This visualization allows drivers to monitor the course of their states, which could improve the driver's comprehension of the system's detection and interpretation. Yet, due to the larger amount of information, this visualization could be more distracting.

Figure 3: The expert design workshop resulted in two visualization concepts for driver’s states.

Table 1: Participant’s qualitative feedback from semi-structured interviews, analyzed using the Grounded Theory Method.

On-time Warnings
prefer that states are only displayed when relevant
clear and intuitive visualization
color-coding if helpful
Dashboard
continuous information about uncritical states unnecessary
information too detailed
easier interpretation of icons
facilitates meaning of visualization due to status indicator
Relevance of Driver’s State
visualizations are useful
expect increase in driving safety
visualizations raise awareness of driver’s state

Formative Simulator Study

As a next step in our iterative design process, we conducted a formative simulator study to obtain insights into drivers’ evaluation of both concepts.

Study Design and Procedure

In order to collect high-quality feedback, we let participants experience both concepts in a high-fidelity driving simulator setup. Initially, participants completed a test drive on the highway to get familiar with the driving simulator. Afterwards, we presented the two systems in a counterbalanced order and for 5 min each. We requested participants to drive naturally but to adhere to the German traffic regulations on a three-lane highway with medium traffic. We emphasized the priority of the driving task. We asked participants to imagine being on a long trip with a car that can automatically detect their current states. As secondary task, participants had to verbally report changes in the state visualization. We thereby ensured that they actually use the display and can later evaluate it.

Since the implementation of a sensor setup was not within the scope of this research project, we chose to simulate a working sensor setup. For the on-time warnings concept, each state was shown for 20 s with a yellow frame and then changed from orange to red for another 20 s each. For the dashboard concept, a state indicator increases for 10 s, remains at the maximum for 20 s, and then decreases again. After a 25 s break, the procedure was repeated for the next state in both concepts. In reality, states do not change that fast but we decided to present all visualized states to drivers in order to obtain holistic feedback. After each concept, participants completed a short questionnaire. In the end, participants were asked to fill out a final demographic and feedback questionnaire. We collected qualitative feedback by means of semi-structured interviews. The overall study took one hour.

Study Setup

We used a high-fidelity driving simulator with a car mock-up based on a platform at Audi in Ingolstadt, Germany. The driving simulation was displayed on a 250° circular screen in front of and a 6x3m screen behind the car. Both visualizations were displayed on a 10.6 in Microsoft Surface tablet, which replaced the central information display (CID).

Participants

We recruited N=70 (28 female) participants with an average age of 35.5 years (SD=9.9). Our participants were experienced drivers, who possessed a driving license for M=17.0 years (SD=9.3). 91% of the participants owned a car.

Results

We recorded the interviews and analyzed the data using the Grounded Theory method [8]. Two researchers coded the qualitative data independently and categorized the codes iteratively. Participants’ quotes are supported by an anonymized participant’s ID (e.g., P21). An overview of the results can be found in Table 1.

Participants’ Feedback: 37 participants preferred the on-time warnings, which are only displayed when a state becomes *‘actually relevant’ (P21)*. 18 of our 70 participants found the *‘continuous information of non-critical states unnecessary’ (P8)*. 19 of them thought that the information was confusing because it was *‘too small, too detailed, too much’ (P174)*. These statements are generally in line with the questionnaire results (see Figure 4), which show that participants considered the continuously displayed dashboard significantly more distracting than the on-time concept, as supported by a t-test ($t(69)=-6.6$, $p<.001$, $d=0.8$). However, participants appreciated the clear and intuitive visualization of the on-time warnings (n=22). They emphasized that the color-coding of the on-time warnings helped them to quickly make sense of the criticality due to its similarity to a traffic light’s warning system (n=35).

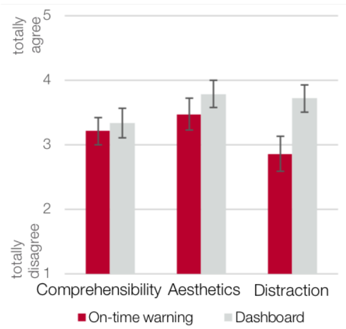

Figure 4: Participants evaluated the dashboard visualization as visually more appealing but also as significantly more distractive.

Recommendations for visualizing driver's states

(1) Only show the driver's state when it is critical and action is needed.

(2) Use color-coding to illustrate the urgency of the driver's state.

(3) Show the driver's state in the instrument cluster to improve visibility.

(4) Provide additional information in the CID by showing a circular status indicator to help the driver assess the current value.

46 of our 70 participants expressed the need to move the display closer to the driver's central visual field. While 28 participants preferred the location of the instrument cluster, 18 drivers suggested to shift it to the head-up display.

Comprehensibility: In the intermediate questionnaires, participants' satisfaction with both concepts' comprehensibility was mediocre (no significant differences). A reason could be that the icons for drowsiness and hypoglycaemia were easy to understand while the interpretation of aggressiveness and particularly workload was difficult according to participants. The interviews revealed that 31 of our 70 participants could interpret the icons more easily when an overview of all states was given. Additionally, they rated the dashboard better at facilitating the meaning of the visualization since it depicted progressive status indicators (n=31). Moreover, a t-test revealed that the continuous dashboard concept was evaluated significantly more positively with respect to its aesthetic appeal ($t(69)=-2.3$, $p<.022$, $d=0.3$).

Relevance of Driver's State: Overall, participants regarded a depiction of the driver's state as *'definitely useful' (P127)* and expected an increase in driving safety (n=35) for both concepts. They appreciated that the state display *'makes drivers extremely aware of their states' (P256)* (n=19). Yet, not all driver states were considered equally important: Participants considered drowsiness most critical (n=60), high workload (n=36) and aggressiveness (n=32) important, and hypoglycemia (n=26) less important because they *'won't die in the car due to hunger.' (P174).*

Desired Information: When asked about extensions for the current display in the final questionnaire, participants expressed a desire to receive feedback whether they are still able to drive (M=3.90, SD=1.08, Likert scale from *1=not useful at all* to *5=very useful*). Moreover, they thought suggestions by the system on how to improve their state (M=3.50, SD=1.05) as well as their state's effect on driving performance (M=3.26, SD=1.19) might be useful. Information on a chronological trend of the state's development (M=2.93, SD=1.09) and the used data for the state's assessment (M=2.64, SD=1.31) were considered rather irrelevant. Furthermore, participants mentioned concerns about privacy and possible misinterpretations made by the car (n=13).

Conclusions and Future Work

In an iterative design process, we developed two concepts for visualizing the driver's state. We let N=70 participants experience the two designs in a driving simulator and collected qualitative feedback. Overall, drivers appreciated to gain insight into their current state beyond a simple warning, expecting improved driving safety. Since participants pointed out advantages of both systems we suggest to combine on-time warnings and continuous status indicators. We summarize our findings in the sidebar.

Participants pointed out that the visualizations raised awareness for their driving state. However, the displayed states did not match participants' actual state, which might have influenced their perception. For example, a system which informs aggressive drivers of their state might even intensify the emotion and lead to rejecting the recommendation [4]. Future work has to address this limitation by re-evaluating drivers' preferences while assessing drivers' actual state. To avoid paternalism, careful suggestions for drivers to improve their state need to be explored.

Finally, the effect on driving performance needs to be examined. Since only half of the participants considered the states aggressiveness and workload important, an in-depth analysis of driver profiles and their need for visualized states could provide further insights.

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