# Examining the impacts of drivers' emotions on takeover readiness and performance in highly automated driving

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With SAE Level 3 of automation, if the AV reaches its system limit, the driver will be required to resume control of the vehicle within a short period of time (SAE, 2018). Previous studies showed that drivers had difficulty taking over control since they were decoupled from the operational level of control and did not have adequate situational awareness to deal with such an urgent event (Peterson et al., 2019). To tackle this problem, researchers have investigated the impacts of different factors on drivers' takeover performance, including the optimal takeover request (TOR) lead time (Eriksson & Stanton, 2017), workload (Reimer & Mehler, 2011), traffic density (Padlmayr et al., 2014), scenario complexity (Gold et al., 2016), and driver's age (Clark & Feng, 2016). Nevertheless, few studies paid sufficient attention to the influence of emotion.

Prior research in surface transportation human factors emphasized the influence of negative emotions, especially anger, anxiety, and nervousness, on manual driving. Anger led to risky and aggressive driving anger (Deffenbacher et al., 2003; Schoefer & Diamantopoulos, 2008), while anxiety and nervousness can narrow drivers' attention to fixate on some specific driving tasks and ignore other critical ones (Jeon et al., 2014). Furthermore, researchers went beyond certain emotions and systematically explored the effects of valence and arousal of emotions on manual driving performance (Cai & Lin, 2011; Chan & Singhal, 2013; Steinhauser et al., 2018). For example, Cai & Lin (2011) investigated drivers' emotional states across the valence-arousal dimensional space (both normalized between -1 and 1) and found that optimal driving performance was obtained when the drivers were in the specific emotional state, i.e., arousal between -0.3 and 0.4 and valence between 0.1 and 0.4. This indicated that positive emotions with a medium level of arousal engendered better driver performance.

However, in highly automated driving (i.e., SAE Level 3), especially during the takeover transition period, the influence of emotions on driving performance is largely ignored. Our study, therefore, aimed to examine the effects of drivers' emotional states on takeover readiness and performance.

A human subject experiment was conducted with 24 participants in a desktop driving simulator. The experiment adopted a within-subject design with four types of emotions examined: angry, sad, happy and calm. There was an emotion-induction phase when participants were asked to watch two 4-minute movie clips. Close to the end of the movie clips, a takeover request was issued, and participants were required to take over control of the vehicle immediately. Once participants negotiated the driving situation for the AV, they could hand back the control to the AV. After each takeover event, participants were required to recall the scenes in the movies and then complete the Self-Assessment Manikin (SAM) survey (Bradley & Lang, 1994). The sequence of four conditions was counterbalanced using a Latin square design. Takeover driving behavior and subjective ratings of takeover readiness and performance were recorded for each takeover event.

The elicitation of the four emotions was successful. Results showed that emotions significantly affected drivers' takeover readiness and performance in highly automated driving. Specifically, calm led to the highest takeover readiness and the best takeover performance as demonstrated by the smallest maximum longitudinal acceleration, the smallest maximum longitudinal jerk and the largest minimum time to collision. Drivers drove smoothly and negotiated the events appropriately in the calm condition. In contrast, anger led to the lowest takeover readiness and the most aggressive driving style.

Overall, our results are critical to understanding the vital role emotions play in order to optimize takeover performance in highly automated driving. It has important implications for the design of in-vehicle alert systems. For example, based on the specific emotional states the driver is in, the system should be able to provide adaptive lead time for the takeover request. These results will contribute to models of human-AV interaction via taking effects of drivers' emotional states into consideration and will enhance the interaction between drivers and highly automated vehicles.

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