Tailoring Takeover Requests in Autonomous Driving to Mental Workload

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Synopsis

In recent times, autonomous driving has emerged as a technology to take over driving tasks for humans. While the future of automated vehicles is to drive fully autonomously without accidents or human intervention (i.e., SAE Level 5), current research in autonomous vehicles still requires human intervention during complex scenarios (i.e., SAE Level 3). There are multiple aspects to consider when the vehicle transfers the control to the driver, such as Takeover Request (TOR) time, modality, and warning location. In this work, we investigate the correlation between TOR time and the mental workload of the driver, measured by EEG, before and after taking control of the vehicle to best tailor these events to the current workload of the driver in the future. We found that the mental workload rises significantly often after the TOR and that the transfer time had no significant effect on the mental workload in our setup.

Background

There are multiple technical aspects to consider regarding the transfer of control between driver and car to avoid accidents and further risks for the passengers. One important aspect is the Takeover Request (TOR) time and the driver's preparedness to take control of the vehicle. We propose achieving this by monitoring the driver's mental state through EEG and adapting the TOR time based on the driver's best mental state. Specifically, we are examining the mental workload of the driver, which is defined as human attention allocated to a cognitively complex task (Paas, 1994). Higher mental workload while driving has also been found to correlate with worse driving (Paxion, 2014). There are multiple works investigating takeover times as presented in the systematic survey by Salubre et al. (Salubre, 2021). However, to the best of our knowledge, we are the first to investigate this correlation with EEG for the takeover scenario.

To investigate the correlation between mental workload and TOR time we propose to answer the following two Research Questions:

R1. Can we detect a rise in mental workload measured by the EEG after a takeover?
R2. Does the mental workload significantly change with varying takeover time?

Methods

We conducted a study with 43 participants, 3 were excluded due to recording errors. In the study participants were seated in a driving simulator performed 12 tasks in which they were asked to let the car autonomously drive up to a certain point where a transfer of control was requested. Depending on the TOR condition, the time a subject had to resume control of the car was either 4s, 8s or 12s. While the car was driving, subjects had to complete non-driving related tasks, chosen to cause little mental workload, but keep them immersed in the simulator. The EEG was simultaneously recorded with a 24 channel Dry electrode ANT-Neuro EEG device with a 500Hz sampling frequency. Dry electrodes were chosen as they are considered to be more convenient in driving scenarios in comparison to gel-based electrodes. The data was preprocessed with a

1Hz to 40Hz bandpass filter. Mental workload was then computed as proposed by Kartali et al. (Kartali, 2019). The data of 5s before TOR and after takeover were considered and cut into 3s windows with a 2.9s overlap. Relative bandpower of the theta-band in the Fz electrode and the alpha-band in the Pz electrode was computed for each window. The mental workload was calculated as the ratio between the two. For noise reduction we used a bad channel detection technique proposed by Komosar et al. (Komosar, 2022) to remove windows deemed too noisy. The mental workload was found to be unstable between subjects and epochs, most likely due to the dry electrode signal quality. In order to alleviate this problem, we compared mental workload in each individual takeover. The ratio of epochs where mental workload was higher before takeover than after was then computed. To answer **R1,** we performed a one-sample t-test to check if the ratio of epochs with higher mental workload significantly exceeded 50%. To answer **R2,** we performed a two-sample t-test to check if the ratios of the three TOR conditions (4s, 8s, 12s) were significantly different to each other. A Shapiro-Wilk test was used to ensure normal distribution for all three conditions.

Results

The results were all found to be normally distributed. The mean ratio between all subjects for each condition and the p-values on whether the mental workload is significantly higher after the takeover are presented in table 1. The mean ratio is significantly above the chance level in each condition as well as overall, meaning that the mental workload was higher during manual driving than in the non-driving task in most cases, as intended by the task design.

A visualization of the ratios of all three conditions as well as the p-values for significant differences between the three conditions are presented as boxplots in figure 1.Figure 1 A boxplot of the results. For all three conditions, the mean is significantly above the chance level (p-value < 0.001). All three combinations were not found to be significantly different to each other (p-value > 0.05). The p-values were 4s-8s: 0.705, 4s-12s: 0.245 and 8s-12s: 0.442. Hence, no combination was found to be significantly different to each other (p-values > 0.05).

Discussion

Since the mean ratio in all three conditions was significantly above 50% we can answer **R1** positively, and we detected a rise in mental workload after a takeover. However, for around 35% of participants this was not the case, which could be due to poor signal quality in dry electrodes but might also be caused by individual differences in driving experience or the non-driving related tasks inducing too much workload in some participants.

Although the boxplots in figure 1 and the p-values in table 1 show a tendency of smaller time windows to evoke more workload, the mean results were not found to be significantly different between any pair of the three conditions, and **R2** has to be answered negatively. However, it is unclear whether the results stem from poor signal quality due to dry electrodes or if there is generally no significantly observable effect of different TOR time length on mental workload.

In conclusion, in this work we attempted to examine the effect of the takeover time in autonomous driving scenarios on mental workload measured by EEG. Our results show that we were able to detect changes in mental workload with an expected rise after the takeover, however, the effect of different TOR timing remains unclear and needs further investigation.

TOR time	4s	8s	12s	All
Mean ratio	68.3%	65.8%	60.8%	65.0%
p-value	0.0003***	0.002**	0.02*	0.00000009***

Table 1 Mean ratio between all subjects for each condition and the p-values indicating mental workload being significantly higher after the takeover.

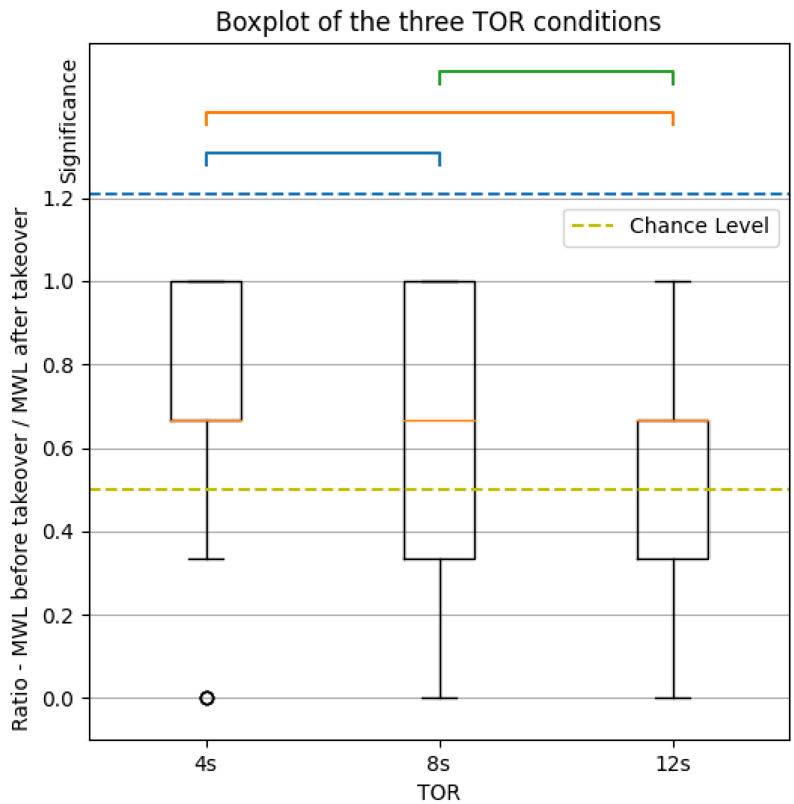

Figure 1 A boxplot of the results. For all three conditions, the mean is significantly above the chance level (p-value < 0.001). All three combinations were not found to be significantly different to each other (p-value > 0.05).

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