Effects of Non-driving Task Related Workload and Situational Awareness in Semi-autonomous Vehicles

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Abstract. Recent advances in autonomous and semi-autonomous vehicles have resulted in more efficient vehicle maneuvers, which causes drivers to be less involved in operational driving, thus leading to increased drivers' engagement in other non-driving related activities. High levels of automation arise concerns such as a decrease in situational awareness (SA) and driving performance as drivers are likely to undertake a non-driving related task during vehicle maneuvers. For cars with conditional or higher automation (SAE Level 3 or up), there is a need to study and monitor drivers' level of engagement/involvement with the vehicles. Considering the key factors for safety when drivers perform a non-driving related task (NDRT) during conditional automation, issues concerning drivers' SA and takeover performance in absence or failure of automation need to be addressed. In this study, we designed and conducted driving simulator experiments to investigate drivers' SA while they were performing a NDRT during the conditional automated driving. We also investigated drivers' takeover time and takeover quality in different NDRTs. We found that drivers' vigilance levels are different while performing different NDRTs during semi-automation. Our results show that the response time was typically between 5–8 s and the deviation of distance to the center of the lane ranged from −0.66 m to −0.3 m which might suggest the variability in takeover quality during different NDRTs.

Keywords: Autonomous vehicles · Situational awareness · Conditional automation · Takeover time · Takeover quality

1 Introduction

1.1 Background

Human errors caused 94% of all traffic crashes in the United States according to the data from the National Highway Traffic Safety Administration (NHTSA) [1]. With numerous new scientific advancements in the automotive industry in recently years, understanding

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human factors in autonomous or semi-autonomous vehicles is significant. The Society of Automotive Engineers (SAE) International has defined six levels of automated driving systems with Level 0 referring to no automation and Level 5 referring to full automation - commonly referred to as self-driving vehicles [2, 3]. Drivers are actively engaged in vehicle maneuvers in Level 1 and Level 2 vehicles whereas for Level 3 or higher ones, the vehicle can handle certain or all parts of trips on its own and is normally consider as autonomy or semi-autonomy. Level 2 automation combines two or more functions to relieve driving, such as adaptive cruise control and automatic emergency braking. However, drivers are still fully engaged with vehicle maneuvers. In Level 3 automation or up according to SAE definition, although drivers are still seated in the driver's seat, they are not actually driving when the automation features are being used. According to the NHTSA, Level 3 and higher are qualified as automated driving systems (ADS) [4]. They can essentially drive themselves, however, drivers can intervene and take control as needed. While automated vehicles have high potentials to save lives and reduce injuries for both drivers and passengers as well as bicyclists and pedestrians due to the advanced technologies, it is important to understand driver's role and interaction with vehicle systems [5, 6]. High levels of automation arise concerns such as a decrease in situational awareness (SA), driving performance with drivers most likely to undertake a non-driving related task [7]. In recent years, there have been several accidents involving Level 2 or 3 semi-autonomous vehicles, which were mainly caused by driver distraction on non-driving related tasks (NDRTs) during conditional automation when the advanced driver assistive features were being used [8].

Therefore, the goal of this study is to understand drivers' SA in performing NDRTs during driving semi-autonomous vehicles and study takeover time and takeover quality in conditional automation condition.

1.2 Literature Review

In order to design solid experiments for measuring SA, takeover time and quality for NDRTs, we first summarized the state-of-the-art measuring strategies and experimental designs. A review of existing driver control transitions to assess takeover time was conducted in 2017 [9] in which the authors also conducted their own study to determine automation to manual takeover times while the participants were reading newspapers or monitoring the system. They found that the total time to take over ranged between 1.97–25.75 s [9]. A study conducted in [10] highlighted age as a factor influencing takeover performance in automated vehicles. The study included younger drivers $<$ 28 years of age and older drivers $>$ 60 years of age that participated in the driving simulator study involving two conditions - with and without a secondary task (a cellphone conversation) in different traffic densities (low, medium and high). They measured the quality of takeover as a measure of maximum longitudinal or lateral accelerations and time to collisions. Gold et al. [11] conducted a study measuring takeover time in which they measured two different takeover times with a highly engaging secondary task (i.e., placement of tablet was different for two conditions, center console and handheld). They used two degrees steering wheel angle and 10% breaking pedal positions to measure reaction times after the automation alarmed the user to take over. They found that the reaction time was between 5–7 s. They used maximum acceleration after takeover as a measure of the quality of takeover between the experimental and baseline conditions. The results did not show any significant differences between the two experimental conditions, however, they twice as high as the baseline condition for participants with reaction time of 5 s and thrice as high for participants with 7 s of reaction time.

Another study by Louw et al. [6] employed a monitoring condition versus a secondary task using an iPad during automation to determine driver reaction in the form of takeover performance. They used maximum lateral and longitudinal acceleration, time to first steer and time to lane change as measures to study performance. Driver reactions to avoid collisions were measured using steering, and braking. They found that regaining vehicle control was challenging for participants who were distracted during automation deeming them “further out of the loop”. de Winter et al. [12] demonstrated that it is crucial for drivers to be mindful while using automation until automation is perfected. They used different levels of automation alongside a secondary task to determine driver workload and response time to an intervention. They used NASA-TLX scores on the divided attention task along with mean speed, maximum speed and standard deviation of lateral position to measure driving performance. Results varied depending on the level of automation. Zeeb et al. [13] used writing emails, reading a new text and watching a video clip as levels of engagement on a secondary task. Participants had to take over driving while engaging in secondary tasks. Besides having people perform tasks while taking over, the study also uses an absolute steering wheel angle velocity > 0.075 degrees per second, absolute steering wheel acceleration > 5 degrees per second as a measure of takeover performance. The brake pedal position was similar to other studies. They used deviation from the center of lane and lateral acceleration over the periods of 5 and 10 s.

2 Methods

2.1 Overview

Most drivers perform non-driving related tasks such as using their cellphones, using the in-vehicle display system, talking to passengers, etc. while driving. These secondary tasks induce workload, thereby, decreasing human performance. In the context of highly automated vehicles, drivers are more likely to be involved in non-driving related secondary tasks. Understanding driver involvement in non-driving related tasks and workload becomes critical in the situations involving drivers resuming control of vehicles - referred to as “takeover”. Thus, in this study, we are using a driving simulator to investigate driver SA, takeover time and quality while they are performing non-driving related tasks. Three scenarios were using in the experiments, baseline, checking Google Map, and playing cellphone games during semi-autonomous driving and transition, which are corresponding to low, moderate, and high workload. Additionally, we designed a survey to measure SA and proposed our methods for takeover measurement. The workload was measured by using a perceived workload self-rating scale.

2.2 Participants

Twenty-three subjects (eleven females and twelve males) from within the Michigan Tech community volunteered to participate in this study. They were in the age group of 18–30 years old (mean age = 23.43, SD = 2.35). All participants were experienced drivers with a valid driver's license and at least a year of driving experience. The study was approved by the Michigan Tech Institutional Review Board. All the subjects were screened for simulator sickness prior to the study.

2.3 Experiment

The objectives of this study were to determine SA while the drivers performed a NDRT in a semi-autonomous vehicle simulated environment and investigate their takeover time and takeover quality during transition. For measuring the SA, we designed a SA survey the participants need to answer questions pertaining to objects presented in the simulation to determine vigilance during the virtually simulated drive. Additionally, we used NASA-TLX [15], a task load self-rating scale to determine perceived workload. Our research questions are as follows:

- Are drivers vigilant enough to be aware of their environment while performing a non-driving related task in a vehicle involving conditional automation?
- How do different NDRT secondary tasks impact takeover quality and takeover performance during driver request takeover intervention from autopilot mode of conditional automation?

Table 1 Description of variables

Variables	Description
NASA-TLX	Measures workload in six subjective subscales: mental demand, physical demand, temporal demand, performance, and frustration recorded for game and navigation experimental conditions
SA	A newly designed survey with questions about road sign and stationary object recognition
Takeover time	Reaction time measured in seconds from the end of conditional automation to steering wheel angle $> 2°$
Takeover quality	Offset deviation from the center of the lane after takeover from conditional automation

The experiments consisted of a baseline condition and two non-driving related tasks - using Google Map and playing cellphone games - during semi-autonomous driving and transition, which were corresponding to low, moderate, and high workload conditions. Each participant performed the NDRTs during conditional automation. Both tasks were administered on an iPhone 6 s. Participants were made aware that they were expected to be vigilant of their surroundings while performing the NDRTs. The order of these tasks was counterbalanced. The dependent variables measured in this study were workload, SA, takeover reaction time and takeover quality. The detailed description is listed in Table 1.

2.4 Materials

Driving Simulator and Scenarios. We used the NADS miniSim in our study. NADS miniSim is a PC-based Quarter Cab driving simulator which provides a horizontal FOV 138 to 180° and a vertical FOV 27 to 50° [14]. The ISAT and miniSim software were used to create the scenario design and run simulations respectively. We used the ISAT to create a basic rural setting involving curvatures and passing traffic as seen in Fig. 1. In the scenario, the semi-autonomous driving and transition triggers were embedded. For the three experiments of baseline, navigation, and gaming, we modified the exception of locations of road signs and other objects like runners, deer, and dogs along with the specifics of conditional automation to minimize learning effects.

Table 2 SA survey with multiple choices

Scenarios	Survey questions
Baseline	How many white cars did you see while driving? a) 1 b) 3 c) 5 d) 0 How many deer did you see while driving? a) 1 b) 3 c) 5 d) 0 Did you see a person running on the side of the road? a) yes b) no Have you seen this sign while driving? a) yes b) no
NDRTs (Navigation and gaming)	Have you seen this sign while driving? a) yes b) no How many deer did you see while driving? a) 1 b) 3 c) 5 d) 0 How many white cars did you see while driving? a) 1 b) 3 c) 5 d) 0 Did you see a person running on the side of the road? a) yes b) no

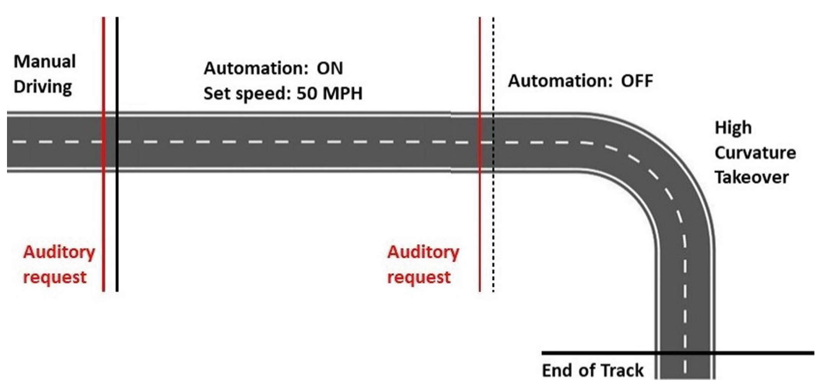

Fig. 1. Driving scenarios with conditional automation takeover model.

SA Surveys. We designed the SA surveys which included questions about road signs and stationary objects presented in the scenario while the participants were engaged in the non-driving related tasks. There were three surveys for the three conditions respectively. The questions on the game and navigation experimental conditions were the same but in a different order. The survey is shown in Table 2.

2.5 Procedure

After signing the informed consent form, participants were asked to fill out basic demographic information. Participants had to clear the simulator sickness test which involved manual driving in the simulator for five minutes in a basic city scenario. Following this, they were assigned to the baseline condition in which the conditional automation starts and stops. Participants began with manual driving until conditional automation took over. Participants were explicitly asked to sit back and be aware of the surroundings while the car was in autonomous mode. They were then asked to fill out the baseline condition SA survey. Then, depending on the order of assignment, participants either performed the game or the navigation tasks as discussed in the above sections. At this point they were engaged in NDRT in which they either played a game of 2048 or look up a list of places on Google Maps application until they heard an auditory stimulus intervention demanding them to takeover driving. Following each of these tasks, participants were asked to fill out the respective SA surveys. The entire experimental procedure lasted for about 30 min.

3 Results

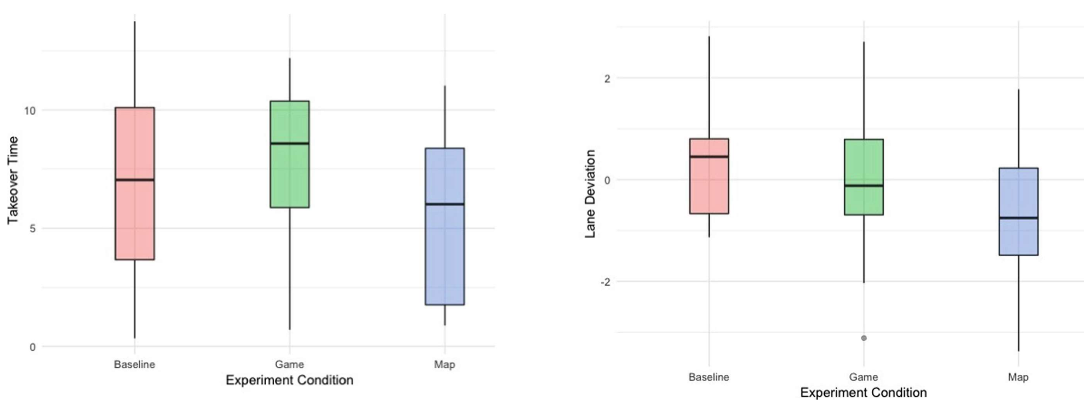

Fig. 2. Takeover time calculated from the moment automation stops to an increase in steering wheel angle $> 2°$ and takeover quality measured as lane deviation analyzed for 20 s after automation shuts off

Data were analyzed using the R studio software. While visually analyzing the lane deviations obtained from the driving simulator, we found that two participants were driving on the left side of the road and others had missing data points. Only 16 participants were considered for this analysis due to missing data. Data was submitted to a repeated-measures analysis of variance (ANOVA) (Fig. 2).

We found that people took over faster in the map navigation condition compared to the gaming and baseline conditions as seen in Table 3. The gaming condition was more engaging in comparison to the other two conditions. A repeated-measures ANOVA revealed no significant effect of the type of task on workload. This may suggest that either game or navigation conditions failed to capture the change in workload.

Table 3. Results of takeover time

Experimental condition	Mean (s)	Standard Deviation (s)
Baseline	6.80	4.38
Game	7.41	4.08
Navigation	5.47	3.89

We also measured overall workload using the NASA-TLX at the end of the drive. We did not find any significant differences for workload across either the gaming or the navigation condition with $F = 0.956$ and $p = 0.336$. Our assumption was that the gaming condition would be more engaging, thus, making the task of takeover challenging. We did find slower response times for takeovers in gaming condition in comparison to the navigation condition which suggests that the participants were immersed in the task. However, the workload results do not reflect this assumption. We measured the SA following the drive and we did not find any significant differences across the baseline, gaming or the navigation condition $F = 3.106$, $p = 0.0547$. The participants were likely not very aware of their surroundings while they were engaged in the NDRTs despite being asked to be aware of the driving environment before the start of their respective session.

4 Discussion and Conclusion

Considering takeover time, our results were similar to previous findings reported in the literature review section of this paper. Our study reported the mean takeover time of an average 5 s for the navigation condition and 7 s for the gaming condition. The gaming condition was designed to be more engaging and hence, reflects in slower takeover times in comparison to the navigation condition. The faster response times in the navigation condition may be due to the fact that most current drivers regularly use one or the other form of navigation during day-to-day driving tasks and hence, the participants may have had experience with managing take-over from current technology equipped in most vehicles such as the cruise control.

Considering workload and the SA assessment, we do not see major differences between the game and maps tasks. This may have happened due to the fact that there was no element of driving involved while performing the game and map tasks. Participants were entirely focused on the secondary task, which was either gaming and navigation. One of the reasons we did not see major differences between the groups maybe due to the fact that our study was under powered.

In conclusion, we found the SA changed as the engagement level of the non- driving related task changed. Future work will involve analyzing correlations, and driving simulator data using multidimensional scaling techniques and hierarchical clustering to analyze driver takeover performance at different time intervals after the takeover from the autonomous mode. It will also be worthwhile to compare driving simulator data with the surveys to establish relevance.

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