Takeover performance according to the level of disengagement during automated driving

Evan Gallouin, Xuguang Wang, Philippe Beillas, and Thierry Bellet
Université Gustave Eiffel, France

Abstract

Taking over the manual control of a car after Automated Driving (AD) is a key issue for future road safety. However, performance to resume this manual control may be dependant of the driver's level of engagement in driving during AD. Indeed, according to the level of automation (from L2 to L3 of the SAE), drivers will be in charge of monitoring the driving situation, or will be allowed to perform non-driving related tasks (NDRT) and thus, to be fully disengaged of the driving task. In this context, the present study aims to investigate the influence of the driver's level of engagement/disengagement during AD on takeover performance using a driving simulator. Four levels of engagement/disengagement were studied: (C1) being engaged in driving situation monitoring without TakeOver Request (TOR) to resume the manual control, (C2) being engaged in driving situation monitoring with a TOR to resume the manual control, (C3) being disengaged of the driving monitoring by performing a cognitively demanding secondary task with a TOR to resume the manual control, and (C4) being disengaged of the driving monitoring in a relaxed position situation with eyes closed and with a TOR to resume the manual control. Forty participants were performed sixteen critical takeover scenarios involving different critical takeover situations. Drivers reaction times and collision risks were measured to assess their takeover performances and to investigate the safety of automation levels 2 and 3. Driving situation monitoring with a TOR (C2) induce shortest reaction times and a lower number of collisions. For the relaxed posture (C4), drivers took longer time to react than the other three conditions. Driving situation monitoring without TOR (C1), had the highest number of collisions. This suggests that the engagement in driving is not always effective and efficient without TOR. Moreover, being in a relaxed position during automated driving decreases takeover performance.

Keywords: Takeover Performance; Automated Driving; Driving Supervision; Reaction Time; Collision

Introduction

Until today, car drivers have to be fully engaged in driving. Driving seems simple and intuitive, but this task is in reality complex and cognitively demanding for the driver. In the future, thanks to technical advances in automation, drivers may become less and less engaged in driving. Depending on the degree of automation (SAE, 2021), drivers will have to monitor the driving situation (level 2, partial automation) or will have the possibility to be engaged (level 3, conditional automation) in Non-Driving Related Tasks (NDRT). Drivers may be less vigilant than in manual driving because they will no longer need to control the vehicle constantly. Meanwhile, they may be engaged in a more or less cognitively demanding NDRT. The meta-analysis by De Winter et al. (2014) indeed shows that drivers' situational awareness (SA) is deteriorated with a Highly Automated Driving (HAD) or with Adaptative Cruise Control (ACC). Furthermore, in the study by Dingus et al. (2016), observation of real-world driving revealed that crash risk increased significantly when drivers' eyes were off the road for only two seconds. For the Level 3 of automated driving, occupants will be able to take their eyes off the road not for a few seconds, but for several minutes before they have to resume manual control of the vehicle.

Takeover Performance

In addition to having to monitor the driving or to perform NDRTs, takeover activities are new. Due to unexpected situations, such as accidents or road constructions, the automation system can request to resume the manual control of the vehicle in unplanned emergency TakeOver Requests (TOR). For this purpose, takeover performance has been studied in recent years (Gold et al., 2018; Yang et al., 2018; Lin et al., 2020). Most frequently characterized by the time and quality of takeover, the analysis of takeover performance in critical situations is important and necessary for safety (Gold et al., 2013). Its performance varies depending on many factors, such as the time available to takeover, the type of alarm or the engagement in the NDRT (Zhang et al., 2019).

Takeover Request

At level 2 of automation, the system manages the lateral and longitudinal control of the vehicle while the driver has to be engaged in driving situation monitoring. The driver must supervise the AD and be able to resume manual control at any time without being asked to intervene, because the system is not always able to detect its malfunctions or its limits. At level 3 of automation, drivers will be able to perform NDRTs and thus will no longer be required to be engaged in driving supervision. This implies that the AD systems must be able to detect all relevant limits and reliably return control to the driver by using a warning.

It could therefore be argued that supervising the road constantly, as opposed to being disengaged from driving monitoring, increases takeover performance because drivers have their eyes on the road and can detect failures more quickly.

Out-of-the-Loop

On the one hand, research suggests that drivers may neglect their monitoring task (Banks et al., 2018) and do not always respect safety requirements. Indeed, Boos et al. (2020) showed that drivers who were well aware of their responsibility to supervise the road tended to neglect their supervision task, in part because they were too confident in their system. On the other hand, when drivers performed NRDT while the system was in AD, they were considered as not being in the driving control loop. Endsley et al. (1995) then discussed the out-of-the-loop performance problem, leaving "*operators of automated systems handicapped in their ability to take over manual operations in the event of automation failure*", partly due to decreased Situation Awareness (SA). Unlike L2 of automation, drivers will be disengaged from driving situation monitoring for L3. When they have to take the control of the vehicle, they must collect information about the environment and the situational risks in order to make an adequate decision and response to avoid an accident, which requires time.

Non-Driving Related Tasks

Furthermore, many studies focused on NDRTs as a factor that influences takeover performance including time and quality (Bueno et al., 2016; Gold et al., 2016). In particular, engagement in NDRTs has a significant effect on the quality of takeover (Lee et al., 2021; Zeeb et al., 2016), especially if the driver is engaged in the NDRT when a TOR is issued. Yang et al. (2019) also showed that a relaxed posture could have a negative effect on takeover performance.

Objectives and Research Questions

Using a driving simulator, the purpose of this study is to examine the effects of the level of engagement in driving situation monitoring on takeover performances as well as the effects of engagement in NDRT. Two research questions were formulated: (1) When engaged in driving monitoring, does TOR improve takeover performances? And (2) when engaged in NDRT, does the state of vigilance affect takeover performances?

Methods

Participants and Experimental Setup

Forty volunteers (20 males and 20 females) between 20 and 43 years old (M=26.9, SD=5.1) participated to this study. Their body varied between 158 and 190 cm in height (M=174 cm, SD=8.1 cm) and between 47 and 108 kg in weight (M=70.85 kg, SD=14.5 kg). The local ethics committee approved the experimental protocol. Informed consent was obtained prior to experiment for all participants.

This study was conducted using a static driving simulator composed of a steering wheel, three pedals, a control panel and five screens in a semicircle and three mirrors are integrated. The vehicle automation was simulated by the V-HCD software environment (Bellet et al. 2019). All data from the driving simulator, including vehicle control commands and environmental information such as collisions, lane positions and vehicle speeds, were recorded under the RTMaps software environment.

Scenarios and Experimental Conditions

16 scenarios were designed, taking place on a two or three lane highway at a cruising speed of 90 km/h for a duration of 2 to 4.20 minutes and all end with a critical situation that must be controlled manually by the vehicle occupant. For each scenario, the participant could either brake or change lane to avoid the collision. The times available (Time Budget - TB) to takeover control and to avoid accident were short in order to simulate an emergency situation (mean TB=4.2 s). Pre-tests were carried out to ensure that the TB was short enough provide a challenging task in terms of manual control resuming, but not too short to allow the participants to avoid the crash in case of a prompt and efficient reaction.

In order to investigate the influence of the driver's level of engagement/disengagement during AD on takeover performance, four test conditions were studied (Figure 1):

- Condition 1 (C1): Being engaged in the driving situation monitoring to decide to resume the manual control without any TOR, implying a cognitively demanding task of supervision.
- Condition 2 (C2): Being engaged in driving situation monitoring but supported by a TOR when a takeover is required, implying a supervision that is less demanding from the cognitive aspect.
- Condition 3 (C3): Being disengaged from the task of monitoring by performing a cognitively demanding NDRT, implying a state of hyper-vigilance.
- Condition 4 (C4): Being disengaged from the task of supervision in a relaxed position with eyes closed, implying a state of hypo-vigilance.

For C3 and C4, participants experienced automated driving with 2 NDRTs. These two NDRTs were selected to induce two opposite states of vigilance in the driver. First, the objective was to induce a state of hyper-vigilance (C3) thanks to a game on a touch pad. The touch pad was placed on the dashboard in the right of the steering wheel. Participants were asked to, as fast as possible, select the verbs (1 to 3) in the infinitive form among 5 words in French on the pad in a given time. The difficulty level increased with less and less time given for selecting right verbs as the game progressed. This task required a high level of engagement in gaming. Participants had no time to observe the road environment before TOR, thus were disengaged from the task of road supervision.

C4 corresponded to a state of hypo-vigilance (C4) where the participants were in a relaxed position with their eyes closed. The seat was tilted back 40° for all participants and they were instructed not to open their eyes until the TOR was present.

A same traffic scenario cannot be used to test more than two conditions. Sixteen traffic scenarios were all different in order for participants to avoid learning effect. They were grouped into 4 blocks of 4 scenarios. Combining 4 test conditions and 4 blocks of scenarios forms 16 combinations, allowing a group of 4 participants to test 4 conditions. Therefore, each block of 4 scenarios was played once for each test condition, while each participant performed 16 trials (4 conditions x 4 scenarios).

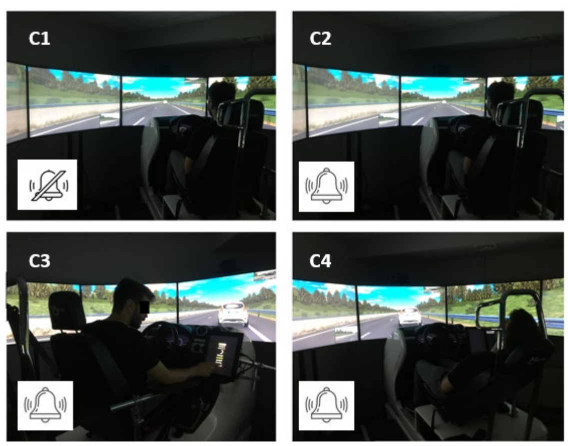

Figure 1. Overview of the 4 tests conditions

Procedure

Before starting the experiment, participants were informed about the study and filled in a demographic questionnaire. The driving simulator and its operation were then presented to them. A phase of training with the simulator was first performed in manual driving. Then, before each test condition, participants performed two additional short trainings in order to be prepared and to understand how each condition works. Finally, they performed 4 scenarios by condition. The experiment lasted about 3 hours (including 2 breaks) for each participant.

Takeover performance measures

In this study, TakeOver Time (TOT) was used to measure takeover performance. It was determined by the interval from the TOR to the first action performed by the participant on the steering wheel, the pedals (brake or accelerator) or one of the turn signals which will deactivate the AD mode. To measure takeover quality, the number of collisions was considered.

Results

A total of 640 takeover situations (40 participants x 16 takeovers) were performed. Among these 640 scenarios, 10 were not correctly registered due to technical issues. Data was analysed therefore presented from 630 observations. Regarding the first action to takeover control, 96.5% (608) of reaction concerned the brake pedal use, 1.3% (8) the activation of a turn signal, 1.1% (7) depressing accelerator pedal and 1.1% (7) the rotating of the steering wheel. Three different ways of takeovers were observed: 58.1% (366) of situations were controlled by staying on the same lane, 28.7% (181) of the situations were achieved by changing lanes to the left, and 13.2% (83) by changing lanes to the right.

TakeOver Time

Due to the short TB available in this experiment, the mean TOTs obtained were also very short (from 1.01 s for C2 to 1.41 s for C4). A repeated measures Analyse of Variance (ANOVA) was conducted on TOTs for the four test conditions (C1 to C4), showed in Figure 2. A post-hoc Bonferroni test showed that participants took significantly shorter time in C2 to takeover control than the three others conditions (p<0.001).

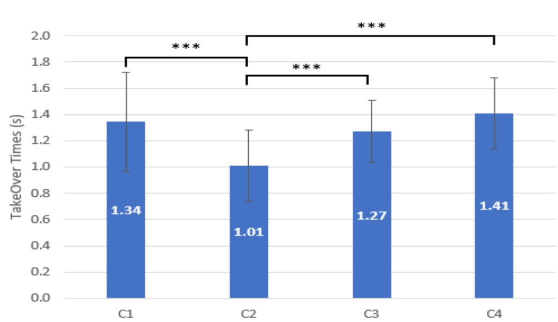

Figure 2. Mean TOTS in all situations

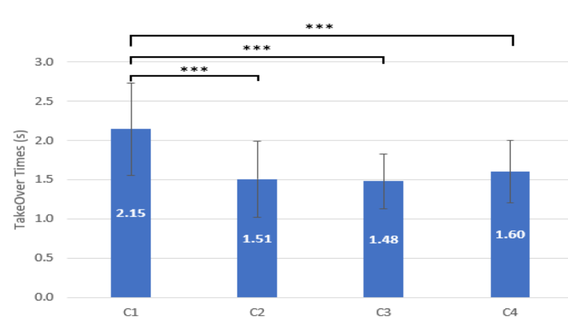

Figure 3. Mean TOTs when collisions

Accidents Analysis

Among the 630 situations, 139 accidents occurred. The mean TOTs when a collision occurred were different from the mean TOTS in all situation. A repeated measures Analyse of Variance (ANOVA) was conducted on TOTs, showed in Figure 3. A post-hoc Bonferroni test showed that participant took significantly longer time in C1 to takeover control when a collision occurred than the three others conditions ($p<0.001$). In addition, the highest number of accidents was observed in C1 (48 collisions) and C4 (40 collisions), followed by C3 with 27 collisions and C2 with the smallest number of collisions (24).

Discussion and Conclusions

The main objective of this study was to investigate the influence of the driver's level of engagement/disengagement during AD (partial and conditional automation) on takeover performance using a driving simulator. We were interested in takeover time and in the collisions as a quality of the takeover performance. Our results suggest that the TakeOver Request is very important in partial automation. Without TOR, drivers take longer to react and have more accidents, which could indeed confirm that drivers neglect their supervisory task (Boos et al., 2020) and perform worse in reacting to critical situations. It appears here that the TOR positively affects takeover performance.

When participants were engaged in NDRT, we found no significant differences in TOT between hyper and hypo-vigilant state. In contrast, the number of accidents was higher in case of takeover from a hypo-vigilant state (40) compared to a hyper-vigilant state (27). This could be explained by the postural difference, since according to Fitts's law (Fitts, 1954), the longer the distance between the hands and the steering wheel, the longer the takeover task from a reclined posture. On the other hand, the fact that drivers have to be cognitively engaged in the NDRT prevents them from being in a hypo-vigilant state and thus from being in a state that is more favourable to taking control of the driving. It could therefore be accepted that the state of vigilance has an impact on the quality of accident takeover.

Finally, when drivers are required to supervise driving without being alerted to a possible system failure, the results show that they took about the same amount of time to regain control of the system as when they were engaged in cognitively engaging NDRTs. In contrast, they had more accidents in the first case (48 vs 27). Results thus show the limits of human drivers' abilities to monitor L2 systems that might fail. A large amount of additional data has been collected and remain to be analysed in the near future, as the time of the eyes on the road, takeover quality, visual strategies, motor behaviours of drivers, etc.

References

Banks, V. A., Eriksson, A., O'Donoghue, J., & Stanton, N. A. (2018). Is partially automated driving a bad idea? Observations from an on-road study. Applied ergonomics, 68, 138-145.

Boos, A., Feldhütter, A., Schwiebacher, J., & Bengler, K. (2020, September). Mode Errors and Intentional Violations in Visual Monitoring of Level 2 Driving Automation. In *2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC)* (pp. 1-7). IEEE.

Bellet, T., Deniel, J., Bornard, J. C., & Richard, B. (2019). Driver modeling and simulation to support the virtual human centered design of future driving aids. In Proceeding of the INCOSE International Conference on Human-Systems Integration (HSI2019), Biarritz, France (pp. 11-13).

Bueno, M., Dogan, E., Selem, F. H., Monacelli, E., Boverie, S., & Guillaume, A. (2016, November). How different mental workload levels affect the take-over control after automated driving. In 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC) (pp. 2040-2045). IEEE.

De Winter, J. C., Happee, R., Martens, M. H., & Stanton, N. A. (2014). Effects of adaptive cruise control and highly automated driving on workload and situation awareness: A review of the empirical evidence. Transportation research part F: traffic psychology and behaviour, 27, 196-217.

Dingus, T. A., Guo, F., Lee, S., Antin, J. F., Perez, M., Buchanan-King, M., & Hankey, J. (2016). Driver crash risk factors and prevalence evaluation using naturalistic driving data. Proceedings of the National Academy of Sciences, 113(10), 2636-2641.

Dogan, E., Honnêt, V., Masfrand, S., & Guillaume, A. (2019). Effects of non-driving-related tasks on takeover performance in different takeover situations in conditionally automated driving. Transportation research part F: traffic psychology and behaviour, 62, 494-504.

Endsley, M. R., Kiris, E. O. (1995). The out-of-the-loop performance problem and level of control in automation. Human Factors: The Journal of the Human Factors and Ergonomics Society, 37, 381–394.doi:10.1518/001872095779064555

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. Journal of experimental psychology, 47(6), 381.

Gold, C., Happee, R., & Bengler, K. (2018). Modeling take-over performance in level 3 conditionally automated vehicles. Accident Analysis & Prevention, 116, 3-13.

Gold, C., Körber, M., Lechner, D., & Bengler, K. (2016). Taking over control from highly automated vehicles in complex traffic situations: the role of traffic density. Human factors, 58(4), 642-652.

Gold, C., Damböck, D., Lorenz, L., & Bengler, K. (2013, September). “Take over!” How long does it take to get the driver back into the loop?. In Proceedings of the human factors and ergonomics society annual meeting (Vol. 57, No. 1, pp. 1938-1942). Sage CA: Los Angeles, CA: Sage Publications.

Lee, S. C., Yoon, S. H., & Ji, Y. G. (2021). Effects of non-driving-related task attributes on takeover quality in automated vehicles. International Journal of Human–Computer Interaction, 37(3), 211-219.

Lin, Q., Li, S., Ma, X., & Lu, G. (2020). Understanding take-over performance of high crash risk drivers during conditionally automated driving. Accident Analysis & Prevention, 143, 105543.

SAE (2021). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles - SAE International. (s. d.).

Yang, Y., Gerlicher, M., & Bengler, K. (2018, September). How does relaxing posture influence take-over performance in an automated vehicle?. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 62, No. 1, pp. 696-700). Sage CA: Los Angeles, CA: SAGE Publications.

Zeeb, K., Buchner, A., & Schrauf, M. (2016). Is take-over time all that matters? The impact of visual-cognitive load on driver take-over quality after conditionally automated driving. Accident analysis & prevention, 92, 230-239.

Zhang, B., de Winter, J., Varotto, S., Happee, R., & Martens, M. (2019). Determinants of take-over time from automated driving: A meta-analysis of 129 studies. Transportation research part F: traffic psychology and behaviour, 64, 285-307.