Semi-Autonomous Vehicles: Examining Driver Performance during the Take-Over

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Human factors elements are critical to the success of autonomous vehicle technology. These human factors elements can include understanding how drivers adopt and interact with this technology, identifying the challenges that a driver may face during the driver-vehicle interaction, and considering these challenges in the design of the driver-vehicle interface. Previous analyses suggested that take-over – when an individual regains control of the vehicle – is one driving period that could raise critical safety concerns. This on-going study aims to observe how drivers perform during the critical take-over period. In addition, this study also explores the effectiveness of two warning to take-over intervals (warning given 7.5 seconds or 4.5 seconds before take-over). Some trends in the preliminary results are emerging; particularly a possible improved performance over three sections of drives (4 take-overs in each section). Findings and future directions are discussed.

INTRODUCTION

According to the U.S. Department of Transportation (2013), in 2012, over 33 thousand people died in motor vehicle crashes, and 2.36 million people were injured. The industry has been tirelessly working towards creating a safer driving environment, and autonomous vehicle technology has been proposed as a potential solution. Companies like Volvo, Nissan and even NASA have issued statements with the desire to implement an autonomous vehicle by 2020 (Los Angeles Times, 2015; Nissan, 2015). Due to this accelerated interest, the National Highway Traffic Safety Administration (NHTSA) has made autonomous vehicle technology research a primary point of focus (NHTSA, 2013, 2014) and has described 5 total levels for vehicle automation (NHTSA, 2013). These five levels are: level 0 (no automation), level 1 (function specific), level 2 (combined function), level 3 (limited self-driving), and level 4 (fully self-driving).

It is estimated that autonomous vehicles could be introduced as early as 2020. However, this technology may not be fully adopted by the majority of the population until approximately 2060 due to vehicle cost and selective location availability (Littman, 2015). Given the fast pace of technology innovation, human factors research is needed to understand driver behavior when interacting with each level of autonomous driving.

The NHTSA has placed an importance in research on autonomous vehicle technology, specifically the human factors elements that are incorporated in take-overs such that "drivers can safely transition between automated and non-automated vehicle operation" (NHTSA, 2013). According to NHTSA (2013), a warning should be provided to the driver in an autonomous vehicle prior to any transition or take-over. A sufficient warning to take-over interval is essential to allow the driver to fully assess the situation and re-engage in the driving task. It is important to design the driver-vehicle interface to support seamless transition. A few assistive systems are being developed, including vehicle route planning and path mapping, placement of sensors, vehicle display units, collision avoidance (Bergholz, Timm, & Weisser, 2000), long range radars and GPS tracking (Los Angeles Times, 2015), vehicle to vehicle communication (NHTSA, 2014), and gesture control (BMW Group, 2015). A systematic understanding of driver behavior during take-over period is highly necessary. Research in other domains (e.g., aviation) can broaden our understanding about automation and can provide insights to the potential and hindrances of the technology. For example, previous research identified important considerations on system error (Sarter & Woods, 1997), over-reliability (Parasuraman & Riley, 1997), under-reliability (Endsley & Kiris, 1995; Kaber, Onal, & Endsley, 1995), and communication errors (Hollands & Wickens, 1999).

A few pioneering projects have started looking at driver engagement and disengagement using eye tracking (Merat, Jamson, Lai, Daly, & Carsten, 2014) as well as path mapping via eLane measuring standard deviation of lane position, mean and minimum longitudinal velocity, steering wheel angle input, time headway and time to contact (Merat, Jamson, Lai, & Carsten, 2014). In addition, there has been considerations on using augmented reality to assist in the take-over process, and encourage driver reengagement (Lorenz, Kerschbaum, & Schumann, 2014).

As a first step to understand driver behavior during take-over in semi-autonomous driving, this research focuses on answering two questions: 1) how do drivers react after they have been disengaged from the task of driving in a semi-autonomous vehicle (e.g., level 3); 2) how do drivers adapt and learn with accumulating experience in transition. This study aims to observe driver behavior during the take-over (the brief period of time when driver regains control from the vehicle) between manual driving and an artificially designed semi-autonomous driving. In addition, this study also aims to determine how driver's performance at the take-over is affected by increasing experience and the amount of time between the warning and the take-over (the warning to take-over interval).

METHOD

We simulated partial-autonomous driving in a driving simulator. Take-over scenarios were activated when the vehicle approached a construction zone (therefore the driving environment became much more complex and human operation was needed). This study aims to explore how participants handle a take-over during partially automated driving. Moreover, the study was also designed to examine whether warnings of two different warning to take-over intervals (i.e., how much in advance was the warning provided) differ in terms of their effectiveness, as well as how drivers' take-over performance would change over time.

Participants

Results reported in this paper are based on a preliminary analysis of driving performance from 10 undergraduate students (6 male and 4 female, M_{age} = 19.2). These participants were gathered from the University's Experimetrix portal.

Materials

Simulated driving. Driving simulation was run on a console version of STISIM Drive 3 (Figure 1). The simulation was displayed on three adjacent 42-inch television screens. The graphics were presented at a resolution of 1920 x 1080 pixels. The simulator is consisted of three displays, a steering wheel, driving pedals, and a driver's seat. Participants were allowed to adjust the seat according to their personal preferences. The simulator collected various driving performance measures and at a rate of 60Hz. Two auditory notifications were used to indicate the upcoming transition from automation to manual driving (i.e., driver taking over) and from manual driving to automation (i.e., manual driving will end and automation will be activated). The warning for an upcoming take-over was a beep of 400 Hz followed by a beep of 350 Hz. The notification of the upcoming activation of autonomous control was two beeps of first 350Hz and then 400 Hz.

Figure 1: STISIM Drive 3 Simulator

Questionnaire measuring opinions concerning autonomous driving. A questionnaire adapted from Schoettle and Sivak's (2014) was used for measuring opinions of drivers concerning autonomous vehicles to assess our participants' familiarity to autonomous driving and opinions of the driving scenarios that we developed. Participants completed this self-report questionnaire before and after completing simulated driving. By collecting opinions from every participant before and after his/her simulated driving experience, we may be able to identify the potential changes in their opinions regarding partially autonomous driving with accumulating experience. Due to the small sample size, no results from this survey are reported.

Procedure

Participants first completed an online version of the questionnaire. They then participated in the experiment session in the lab. Participants were provided a consent form as well as a brief demographic survey.

Once they had completed all of the surveys, the participants were provided instructions about the simulated driving task. The notification sounds (warning for driver takeover, warning for automation about to start) were played to the participants and explanations were provided for both. Participants then practiced simulated driving during a practice drive which was based off of the experimental drives. During this drive, participants experienced a simple driving route with stop signs, and also two transitions from computer controlled drive (partially autonomous) to manual and vice-versa. Sound notifications of the state changes were provided in advance before a transition took place. Participants were allowed to repeat the practice if they desired additional time. Prior to the practice, participants were encouraged to direct any questions to the experimenter. Participants then completed the experiment session.

The experiment session consisted of three drives. The vehicle was centered in a rural highway environment with construction zones placed at specific intervals. Each drive was a total of 12.52 km, and the set speed limit during the autonomous portion was 67.5 km/h, and that same speed limit remained the advised speed throughout the manual drives. Each drive contained four manual zones (designed as construction zones) which expanded a constant distance of 0.94 km, and four autonomous driving sections were presented in each drive. Each autonomous driving sections was of either 1.81 km or 2.41 km. These distances were selected based on time, with each autonomous drive lasting 1.5 minutes (1.81 km) or 2 minutes (2.41 km). Two distances of autonomous driving were used instead of one, in order to encourage drivers to disengage

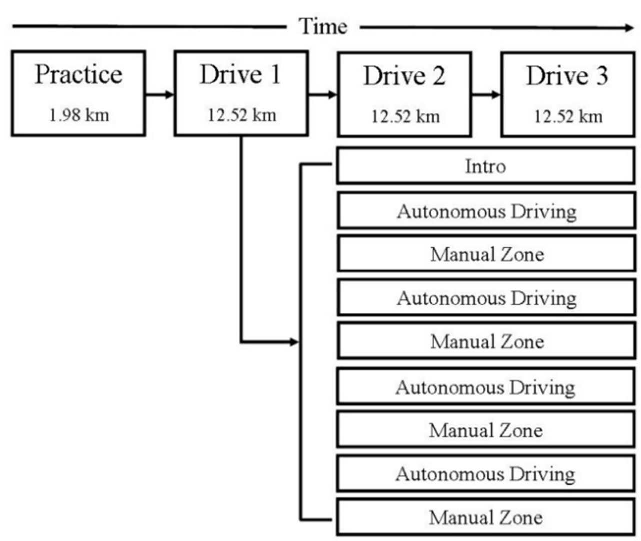

Figure 2: An Overview of the Research Procedure

from the driving task during autonomous driving portion and also to reduce the repetitiveness and temporal predictability of the take-over. An overview of the procedure is illustrated in Figure 2. Given greater familiarity to imperial units than to the metric units of our participants, we presented imperial units in our scenarios. We converted these measures into metric units for the presentation of this paper.

Design

The drives were designed to resemble a 4-lane rural highway, with various trees placed outside of the roadway. The autonomous portion contained oncoming vehicles. During this portion, the system was designed to control both the speed and lane position. Although the scenario attempted to mimic a level 3 autonomous vehicle (limited self-driving capabilities) within the capability of our simulator, we are aware of the limitations of our scenario to study semi-autonomous driving. The computerized controls were in fact level 2 (two advanced functions, including a cruise control and a lane position control, operating simultaneously). To be successful in our mimicry, we did not include any sudden objects on the road during these intervals, thus the vehicle appeared to drive itself during the autonomous drive and no input was required from participants. In addition, participants were instructed that the vehicle would drive it self during some period, but transition between autonomous drive and manual drive would take place after warning sounds were presented and the vehicle would initiate these transitions. By these designs, the participants were in a driving situation that involved more than level 2 autonomous driving, more similar to level 3.

The manual driving portions were designed as construction zones (Figure 3). During manual driving, participants controlled all aspects of the vehicle, including lateral control and longitudinal velocity control. There were six different construction zones that were designed and each was presented twice and in a randomized order across the three drives.

Figure 3: Entrance to one manual zone.

Before take-over, participants were notified using an auditory warning. This warning was presented at two warning to take-over intervals: one being .15 km (7.5 seconds) before the take-over took place, and the other being .09 km (4.5 seconds) before the take-over took place. After each take-over, participants had .12 km to re-engage in driving (i.e., resume full control of the vehicle) before a construction zone started.

RESULTS

In order to answer the question of how drivers react during take-over, various measures were collected and analyzed during take-over. The measures collected for analysis include drivers speed (average speed, and the minimum speed), standard deviation of lane position, brake input and throttle input. These measures were collected for the entire manual driving portion, however to single out the take-over, we specifically analyzed the .12 km zone that occurred immediately following the take-over, this distance will be called the take-over zone. There were 6 repetitions of each warning to take-over interval condition within participants during which these measures were collected. In addition to analyzing the two warning intervals, we were interested in examining the difference among the three drives to answer our question of whether people improve their performance with experience. A 3 x 2 repeated measures ANOVA (drive x warning interval) for each of the measures listed above was conducted to determine how drivers performed.

Longitudinal Velocity

There is a general trend of a decrease in speed during take over. In the analysis, we examined both average speed and minimum speed during the take-over period. To analyze this decrease in speed, a t-test was conducted for each drive and condition (comparing the minimum speed to the preset 67.5 km/h). The t-test revealed a significant difference between the start speed of 67.5 km/h and the average minimum speed for each drive and both conditions (Table 1).

Table 1

Results from T-Test for Minimum Speeds in Take-Over Zone

		t	*df*	*p*
7.5 seconds				
	Drive 1	-4.06	9	.003
	Drive 2	-3.59	9	.006
	Drive 3	-3.89	9	.004
4.5 seconds				
	Drive 1	-4.21	9	.002
	Drive 2	-3.99	9	.003
	Drive 2	-2.93	9	.017

The overall means on average speed during take-over showed some difference between the three drives, with a general trend of increasing average speed across the three drives (M_{drive1} = 45.95, M_{drive2} = 53.78, M_{drive3} = 58.49) during the take-over zone for the drives. A repeated measures ANOVA showed that there was a significant difference in average speed at the take-over between the drives, $F(2,18) = 10.16$, p = .001. A repeated measures ANOVA also showed that there was a significant difference between the minimum speed collected during take-over across the three drives, $F(2,18)$ = 11.04, p = .001. Further analysis showed that for both average speed and minimum speed at take-over, drive 1 was significantly different than drives 2 and 3. Drive 1 was a significantly lower speed than the next two drives, confirming that participants improved their performance with experience.

There was no notable difference between the warning to take-over intervals for either average speed or minimum speed at take-over. The change of means across these intervals are illustrated in Figure 4 (minimum speed), Figure 5 (average speed).

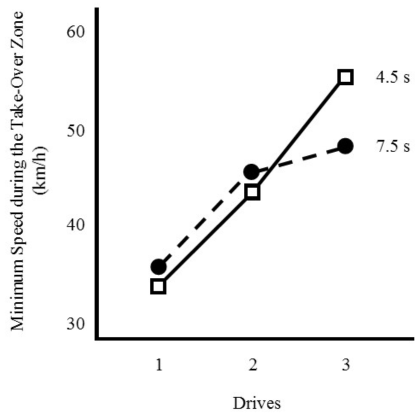

Figure 4: Minimum Speeds (km/h) by the warning to take-over interval over Drives during the Take-Over Zone. The warning is provided .15 km (7.5 s) before the take-over and .09 km (4.5 s) before the take-over.

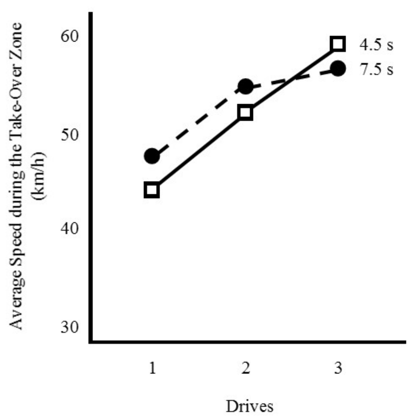

Figure 5: Average Speed (km/h) by the warning to take-over interval over Drives during the Take-Over Zone. The warning is provided .15 km (7.5 s) before the take-over and .09 km (4.5 s) before the take-over.

Standard Deviation of Lane Position

In addition to longitudinal velocity, lane position of the vehicle during take-over is a measure collected to provide insight into the driver's performance at the take-over. A repeated measures ANOVA was conducted to determine the relationship between the standard deviation of lane position during the take-over zone. The results indicate there is no significant difference between the three drives. However, there is a significant difference observed between the two warning intervals (7.5 s or 4.5 s) before take-over, $F(1, 9) = 44.34$, $p < .001$. Further analysis indicated that the standard deviation of lane position for the shorter warning interval was significantly greater than for the longer, ($M_{7.5s} = 6.45$, $M_{4.5s} = 7.94$, $p < .001$).

Brake and Throttle Input

Furthermore, we examined the brake and throttle inputs during take-over. These measures were selected to determine if there were any significant relations as to how a participant decreased their speed. No significant relations were observed between the brake or throttle input across the drives or either warning interval condition.

DISCUSSION

This study aimed to examine driver behavior during a take-over that could take place when driving a semi-autonomous driving vehicle (i.e., level 3 autonomous). We observed drivers' performance during simulated take-over using two warning interval conditions, and over three drives. Despite the small sample size, we observed some patterns and trends. With more data, we will be able to properly examine the significance of these patterns.

One interesting trend was the potential improvement in driver performance during task-over in the three drives, as the speed change became less dramatic over the drives. This may imply the need for training when introducing semi-autonomous driving during which take-overs may occur. This finding further supports suggestions made by NHTSA (2013) that training procedures need to be considered. Although, there does not seem to be any significant difference between the two warning conditions in regards to speed, there is a significant difference in warning condition for lane position. This would imply that the longer warning (7.5 s) leads to better driver control and consistency of the vehicles lane position at takeover.

Moreover, the general trend seen in speed overall by participants cause some concern regarding traffic flow. This decrease in speed that results after take-over could trigger the shockwave effect. The shockwave effect is a traffic phenomenon which occurs when the traffic flow is disrupted by a decrease in speed (e.g. accident, distraction) (May, 1990).

Limitations

While the preliminary results reported in this paper are encouraging, there are a few limitations of the study that we would like to note. First, the STISIM Drive 3 simulator did not support the development of a truly semi-autonomous driving with level 3 automation. As a result, we attempted to mimic this level of automation within the technical possibilities by limiting the possible events during driving. During the autonomous driving portion, there were no events which would trigger a response from the vehicle, considering the only functions we had available were speed control and lane position control. Participants were instructed that the simulated driving was operating as a level 3 vehicle. Therefore, results from this study may not generalize to a real semi-autonomous driving situation given the technical differences and participants' beliefs in whether they were interacting with a highly autonomous driving situation (although our subjective observation of the 10 participants so far seem to indicate that they believe that the simulated drive was semi-autonomous). Validation of the results in a more advanced simulator or even naturalistic driving could significantly improve the generalizability of the results. Second, the preliminary results presented in this paper is based on a very small sample size. Further analyses of data from a sufficient sample size could be informative.

Third, our simulator does not collect driver performance during the autonomous portions. As a result, it was difficult to obtain measures of driver performance right after a warning was given and before a takeover happened. We are collecting video recordings of participants' behavior during driving (e.g., facial expression, hands and feet movement). These observational data may provide some insights into drivers' behavior during the take-over period.

Future Study

This study was primarily exploratory, and its main goal was to provide a platform for future experiments and evaluating in-vehicle design proposals. Its results introduce some possible implications of the take-over and also lead to various considerations that could be made in many aspects of autonomous driving (e.g. training, traffic flow). Additionally, comparing results between young participants (current population) and elderly participants would be useful. This would provide insight as to how to design these vehicles with all populations being considered.

Another main aspect of this study that is to be continued is the incorporation of the survey that is administered both before and after the experimental drive. This survey could provide insight into driver's opinions regarding this technology and their performance (e.g., if a driver does not trust the technology, they may perform worse).

REFERENCES

Bergholz, R., Timm, K., & Weisser, H. (2000). *U.S. Patent No. 6,151,539*. Washington, DC: U.S. Patent and Trademark Office.

BMW Group. (2015). Connected Drive: The Future of Connected Drive. Available at: http://www.bmwgroup.com/e/0_0_www_bmwgroup_com/forschung_entwicklung/technologie/connected_drive/zukunft_connected_drive.html

Wickens, C., & Hollands, J. (1999). Complex Systems, Process Control, and Automation. In *Engineering psychology and human performance* (3rd ed., pp. 513-550). Upper Saddle River, NJ: Prentice-Hall.

Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J. D., & Ramsey, D. J. (2006). *The impact of driver inattention on near-crash/crash risk: An analysis using the 100-car naturalistic driving study data* (No. HS-810 594).

Lorenz, L., Kerschbaum, P., & Schumann, J. (2014, September). Designing take over scenarios for automated driving How does augmented reality support the driver to get back into the loop?. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 58, No. 1, pp. 1681-1685). SAGE Publications.

Los Angeles Times. (2015, Feb 19). Volvo to Launch Self-Driving Pilot Program in 2017. Available at: http://www.latimes.com/business/autos/la-fi-hy-volvo-self-driving-cars-20150219-story.html

Litman, T. (2014). Autonomous Vehicle Implementation Predictions. *Victoria Transport Policy Institute*, *28*.

National Highway Traffic Safety Administration (NHTSA). (2013). *Preliminary statement of policy concerning automated vehicles.* Available at: http://www.nhtsa.gov/staticfiles/rulemaking/pdf/

National Highway Traffic Safety Administration (NHTSA). (2014). *U.S. Department of Transportation announces decision to move forward with vehicle-to-vehicle communication technology for light vehicles*. Available at: http://www.nhtsa.gov/About+NHTSA/Press+Releases/2014/USDOT+to+Move+For ward+with+Vehicle-to-Vehicle+Communication+Technology+for+Light+Vehicles

Nissan. (2015). *Nissan and NASA partner to jointly develop and deploy autonomous drive vehicles by end of year.* Available at: http://nissannews.com/en-US/nissan/usa/releases/nissan-and-nasa-partner-to-jointly-develop-and-deploy-autonomous-drive-vehicles-by-end-of-year

Schoettle, B., & Sivak, M. (2014). A Survey of Public Opinion about Autonomous and Self-Driving Vehicles in the U.S., the U.K., and Australia. *The University of Michigan Transportation Research Institute,* (UMTRI-2014-21). Available at: http://deepblue.lib.umich.edu/bitstream/handle/2027.42/108384/103024.pdf?sequence=1&isAllowed=y

U.S. Department of Transportation. (2013). Traffic Safety Facts. *Research Note,* (DOT HS 811 856). Available at: http://www-nrd.nhtsa.dot.gov/Pubs/811856.pdf