Training to Improve Drivers' Behavior When Partial Driving Automation Fails

SAFETY RESEARCH USING SIMULATION

UNIVERSITY TRANSPORTATION CENTER

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16. Abstract With the advent of automated vehicle systems, the role of drivers has changed to a more supervisory role. However, it is known that all vehicles with Level 2 (L2) systems have a very specific operational design domain (ODD) and can only function on limited conditions. Hence, it is important for drivers to perceive the situations properly and regain the control from the L2 system when needed. The objective of the current study was to design a training program to increase drivers' situational awareness regarding operational design domain (ODD) and improve drivers performance in transfer of control situations while driving with L2 automation features. A PC-based training program was designed and tested to improve drivers takeover response and situational awareness when L2 systems reach their ODD limits. Results showed drivers in the PC-based training group took back control more effectively when L2 systems reached their ODD limits and had more situational awareness compared to the drivers who received user manual or placebo training.		
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Abstract

With the advent of automated vehicle systems, the role of drivers has changed to a more supervisory role. However, it is known that all vehicles with Level 2 (L2) systems have a very specific operational design domain (ODD) and can only function on limited conditions. Hence, it is important for drivers to perceive the situations properly and regain the control from the L2 system when needed. The objective of the current study was to design a training program to increase drivers' situational awareness regarding operational design domain (ODD) and improve drivers performance in transfer of control situations while driving with L2 automation features. A PC-based training program was designed and tested to improve drivers takeover response and situational awareness when L2 systems reach their ODD limits. Results showed drivers in the PC-based training group took back control more effectively when L2 systems reached their ODD limits and had more situational awareness compared to the drivers who received user manual or placebo training.

1 Introduction

Driver support features (DSF) have changed the role of the driver from an active operator to a passive supervisor (Louw et al, 2017). However these features have a very specific operational design domain (ODD) (SAE International, 2018) and only function at limited roadway types, within finite geographic areas, within certain speed ranges, and under precise environmental conditions (National Highway Traffic Safety Administration, 2018). For example, some of these vehicles may have more sensitivity to road design (e.g., may not work on sharp curves, merge), may not recognize lane markings in poor visibility. Hence, when the automated system reaches the limit of its ODD, drivers may experience unexpected behavior. Considering all the limitations of DSF, it necessary for the driver to perceive the hazardous situation, regain control of the vehicle, and maneuver through the hazardous situation (Greenlee et al, 2019)

As a solution to this issue, training has been suggested by many studies to help drivers to gain knowledge about limitations and capabilities of automated vehicles (Beggiato et al, 2015; Forster et al, 2019; Koustanaï et al, 2012; Payre et al, 2016). Past studies showed that training was helpful to improve drivers performance and knowledge about the automation. For example Koustanai et al (2012) showed that training improved drivers performance while using forward collision warning (FCW) system (Koustanaï et al., 2012). Payre et al (2016) showed that training drivers for using highly automated vehicles (capable of overtaking, accelerating, braking and interacting with other vehicles) improved their response time to emergency take back control situation (Payre et al., 2016). Forster et al (2019) showed that interactive tutorial helped drivers to understand lane keeping system more accurately comparing the owner's manual (Forster et al, 2019).

Despite the important role of training mentioned in previous literature, only a few training programs for L2 vehicles have been designed and tested. Most of the studies depended on self-reported questionnaire to test the effectiveness of their designed training while there was no objective analysis of drivers' performance. There was no study which comprehensively tested different aspects such as trust, situational awareness, and drivers' performance for a designed training program.

The objective of the current experiment is designing and testing a training program to improve drivers' situation awareness when a DSF reaches the limits of its ODD, which eventually help drivers to take back control more sooner and efficiently when it required. To achieve this, a PC-based training program has been designed. Participants were recruited and assigned to three training condition groups (PC-based Training , user manual training and placebo Training). Participants in all groups were presented with a brief explanation of the L2 vehicles. Participants in user manual group further received a document indicating user manual information. Participants in PC-based training went through the PC-based training session. Participants in placebo training group received a training regarding other automated features apart from ACC and Lane Centering System which were the focus of PC-based training. All participants then drove through post-test scenarios on the driving simulator.

1.1 Training program development

Previous studies showed that as training methods become more interactive, the trainee gains more knowledge about the specific subject (Burke et al., 2006). The 3M method has been used in several studies (Fisher et al, 2017; Romoser & Fisher, 2009; Zafian et al., 2016) where drivers were successfully trained for complex driving skills such as hazard anticipation, hazard mitigation and attention maintenance in manual (non-automated) driving context (Muttart, 2013; Pradhan et al, 2005). This training method consists of three modules. First module is 'mistake' where the trainee is put into an unfamiliar setting and is allowed to make errors. Second module is 'mentoring' where the trainee is provided with real-time feedback and also guided to avoid such errors in future instances. Third module is mastery where the trainee is the given the opportunity to correct their mistakes.

The current experiment aimed to use 3M approach to improve drivers performance in complex transfer of control situations in L2 vehicle which require the drivers to recall L2 system limitations, to predict the hazards and to mitigate the hazards (by taking back control as a step of mitigation). The 3M method has been used due to the proven effectiveness of this approach to train drivers for learning and transferring of knowledge to action regarding complex skills and scenarios. To better explain the application of 3M approach in context of training driving for L2 systems, we will explain each of the modules in the context of a take back control scenario.

1) Mistake: In the first attempt, the participant were instructed to click on the automation on/off button when they feel the need to take back control from the L2 system at a particular scenario.
2) Mentoring: If participants did not respond correctly, they would receive real-time feedback regarding their mistake and informed about the solution. They were then asked to try the same scenario again. If they got the answer correct on the first or second tries, they were told that they did a great job and moved directly to the mastery stage.
3) Mastery: Participants were asked once again to show that they have mastered the skill. Thus, they were asked to practice once again in a more complex situation.

The training was delivered through a PC-based training program. PC-based training programs are realistic and economical approaches and they can easily be distributed on electronic media or can be made available on the Internet (Fisher et al., 2002; Pradhan et al., 2005). Hence, it would be an appropriate media for delivering the training. To design the PC-based training program, we used Microsoft PowerPoint which is easily accessible and editable for future use.

Eight types of scenarios were considered in the training program. Among those, seven types were based on those situations where DSF reaches its ODD limit as mentioned in the user manuals of different L2 vehicle models. Another type of scenarios considered was based on those situations where drivers do not need to take back control from the system. This type was included to the training to make sure that participants will be presented with different type of scenarios featuring both takeover and non-takeover situations. This will prevent them from sensing a particular pattern and thus rule out the bias. The eight types of scenarios are as follows:

1) Curve: The L2 system may not manage to keep itself in the lane in sharp curves
2) Intersection: L2 system cannot predict potential hazards at the intersections and also may not detect cross-traffic
3) Invisible lane: L2 system may not keep the car in lane when it reaches areas where lane marking disappear (merges) or not visible (roadway conditions)
4) Vulnerable road users (pedestrian, bikes): L2 system may not detect any object on the road except a moving car in front of the vehicle
5) Stationary objects on the road (stop car, fallen trees, construction zone): L2 system may not detect stationary non-vehicle objects and also may not detect stationary lead vehicle if it was not detected as moving.
6) Non-standard shaped vehicles (Oversized truck, tractors, etc) : L2 system may not detect vehicles with Non-standard shape
7) Unpredictable drivers (Distracted drivers, hidden drivers, etc) : L2 system may not work in the event of erratic behavior of another driver
8) No take-over (Control scenarios with no need to take back control from L2 system)

Considering the 8 type of scenarios above, 14 scenarios were used in our training.

Seven of them were scenarios where participants needed to take back control and seven of them were scenarios where participants did need to take back control from the system (Table 1). *Description of the scenarios for using in PC-based Training Program*

Table 1. Description of the scenarios for using in PC-based Training Program

No	Scenario type	Description	Image
1	Curve	The driver is traveling approaching a S-curved road section (one travel lane in either direction). At the end of the first curve (beginning of the second curve), a car is parked on right side of the curved road section.	
2	Intersection	The driver is approaching towards an uncontrolled intersection (two travel lanes in either direction). The adjacent traffic is controlled by a stop sign. Driver has the right of the way.	
3	Invisible lane	The driver approach the section of the road where the lane marking have been deteriorated	
4	Vulnerable road users	The driver is approaching a bike-trail. A bicyclist in the bike lane crossing the street	

5	Stationary objects on the road	The driver is travelling on a two-way road with two lanes in each side, when they encounter a construction zone	
6	Truck	The driver approaches an oversized vehicle moving at a slower speed than the speed limit. The oversized vehicle takes up an entire travel lane with its leftmost wheels protruding into the driver's travel lane.	
7	Distracted Driver	The drivers is travelling on a two-way road when they encounter a vehicle repeatedly swerving in and out of its lane.	
8-14	No take-over	Seven Control scenarios with no take back control events in different environmental settings (rural, urban, suburban)	

2 Method

In this experiment, first a PC- based training program was designed using 3M approach based on scenarios where DSF reaches its ODD limit and need drivers to take back control from the L2 system. Seven type of scenarios were considered in the training program. After which 36 participants were recruited and randomly assigned to one of the three training condition groups

(User manual, Training and control). Participants in user manual training group received a document indicating user manual information. Participants in PC-based training group went through the training session. Participants in placebo training group received a training regarding other driver support features apart from ACC and Lane Centering System which were the focus of PC-based training. All participant then drove through post-test scenarios on driving simulator.

2.1 Participants

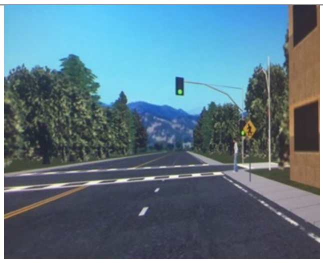
Thirty six participants were recruited from the University of Massachusetts Amherst campus and Amherst town using flyers and email advertisements. Only individuals with a valid United States driving license who did not wear eyeglasses were included in the study.

2.2 Scenarios

To test the effectiveness of the training program, 10 scenarios were designed (Table 2). All these scenarios were designed considering the 8 categories introduced in section 4.

Table 2. Post-drive Scenario Description

No.	Name	Description	Takeover required?	Image
1	Merge	The driver reaches the end of a four-lane road (two travel lanes in either direction) which merges onto a two-lane road (one travel lane in either direction). There is a car following behind the driver into the merge.	Yes	

2	Curve	The driver is traveling along a curved road section, where a truck is parked on right side of the curved road section before a crosswalk. The truck is partly jutting onto the road obscuring a pedestrian.	Yes	
3	Intersection	The driver is approaching towards traffic signal-controlled intersection (two travel lanes in either direction) with a green light in the travel lane. A block of buildings obscures a pedestrian.	Yes	
4	Bike	The driver is driving on the right lane of a roadway and reaches a bicyclist riding on the extreme right side of the same lane	Yes	
5	Construction zone	The driver is travelling on a two-way road with two lanes in each side, when they encounter a construction zone	Yes	
6	Truck	The driver approaches an oversized vehicle moving at a slower speed than the speed limit. The oversized vehicle takes up an entire travel lane with its leftmost wheels protruding into the driver's travel lane.	Yes	

7	Car-cut	The driver approaches a driveway. A car cuts into the drivers pathway	Yes	
8	No takeover 1	This is a scenario in a suburban setting with no hazards	No	
9	No takeover 2	This is a scenario in a rural setting with no hazards	No	
10	No takeover 3	This is a scenario in an urban setting with no hazards	No	

2.3 Equipment

Driving Simulator. A fixed-based RTI (Realtime Technologies Inc.) driving simulator consisting of a fully equipped 2013 Ford Fusion surrounded by six screens with a 330-degree field of view was used for the current study (Figure 1). The cab features two dynamic side-mirrors which provide realistic side and rear views of the scenarios for participants. The car's interior has a fully customizable virtual dashboard and center stack. The simulator system is capable of simulating L2 drives by integrating a lane centering control system along with adaptive cruise control.

Figure 1. RTI Fixed-Based Driving Simulator

PC based training program was designed and presented using Microsoft PowerPoint. The program included 3 parts. In the first part of the training, participants were introduced to the training program and its interface, buttons and the task they would need to perform. They were instructed that they would receive several scenarios in the training and they would need to decide whether they should take back control from the system or not. In the second part, participants were presented with 14 scenarios (Table 1) where each scenario was presented by a sequence of snapshots (7 snapshots in total) from the drivers' point of view. Each snapshot lasted for 2 seconds. Seven of these scenarios included those situations where L2 system reached its ODD limit and the participants would need to take back control while the other seven would not require them to take back control. In cases where participants successfully took back control from the system on their first attempt, they were asked about the reasoning for their takeover action. If their response was incorrect, they were provided by the correct reason. If participants did not take back control for those scenarios where L2 system reached its ODD limits, participants received a message which guided them about their mistake and explained to them why it was necessary to take back control at that situation. Each participants had three attempts to gain mastery over each scenario. This was done to make sure that participants had enough chances to master their skills. Figure 2 shows the interface of the training program designed for this study.

Figure 2. PC-based training program interface

User manual training program included a text-based manuscript prepared based on the owner's manual of a real L2 system. In that manuscript, only those sections of the owner's manual related to the L2 systems and their limitations were included. After which, they received a multiple choice question test regarding the information presented in the manuscript. This was done to make sure they will read and pay attention to the material. The participants were informed that they will receive this test prior to them reading through the manuscript.

Placebo training program designed using Microsoft PowerPoint (Figure 3). This program included slides that informed the participants about the functionality and limitation of other driver support features apart from ACC and Lane Centering system. The features included in these slides were as follows: Automatic Parallel Parking, Automatic Reverse Braking, Anti-Lock Braking System, Drowsiness Alert, High Speed Alert, Back-up Camera, Parking Sensors, Temperature Warning, Hill Start Assist and Hill Descent Assist. The information provided for participants for these slides were adapted from mycardoeswhat.org. (My Car Does What, 2020). After which consistent with the other two training groups, they received a multiple choice question test regarding the same features.

Figure 3. Placebo training program

2.4 Experimental Design

The between-subjects independent variable in the experiment was the training program (PC-based training, user manual, placebo). The within-subjects independent variable in the experiment was the Post-drive scenario. The Post- drive scenarios (Table 2) were used to assess the effectiveness of the training program.

2.5 Dependent Variable and Hypotheses

One dependent variable was takeover reaction of drivers, which was binary coded (Successful takeover was '1' and unsuccessful takeover was '0'). Another dependent variable was the overall SART score, which was derived using the following formula: Situation Awareness (SA) = U - (D - S), where U refers to summed understanding, D refers to summed demand and S refers to summed supply (Selcon & Taylor, 1990).

In this study, our first hypothesis was that the participants in the PC-based training group would take back control more successfully than drivers in user manual training group and placebo training group (H1). The Second hypothesis was that the participants in the training group would have higher overall SART scores compared to the participants in user manual training group and placebo training group (H2).

2.6 Procedure

After participants gave their consent, they were randomly assigned to either the control, user manual or PC based training groups. Participants in all groups were presented with a brief explanation of the L2 vehicles. Participants in user manual training group would further receive a document indicating user manual information regarding those limitations considered in the scenarios mentioned in Table 1 . Participants in PC-based training group went through the training session presented on Microsoft PowerPoint. Participants in placebo training group received the placebo training in the same platform as PC-based training group. All participants then drove through 10 designed scenarios on simulator. After each scenario they will be asked to fill the SART questionnaire. After driving through the scenarios participants will complete the demographics questionnaire.

3 Results

For descriptive purposes drivers average age and average experience in each group (PC-based, user manual and placebo) was calculated. The average age of the drivers were 22.05 (SD = 1.68) for PC-based training, 22.92 (SD =3.28) years for User-manual group and 21.95 years (SD = 0.97) for Placebo group. The average drivers' experience were 4.25 years (SD =2.203) for PC-based training group, 4.67 (SD =3.55) years for User-manual group and 4.79 years (SD = 0.65) for Placebo group.

3.1 Binary Takeover Responses

For descriptive purposes, the percentage of participants who took back control in each training group was calculated (Figure 4). In all scenarios, the percentage of successful take back control was highest in the PC-based training group compared to the User manual and Placebo training groups. In total, the percentage of participants who successfully took back control on time were higher for PC-based training group (91.71%) when compared to user manual group (27%) and placebo training group (23.71%).

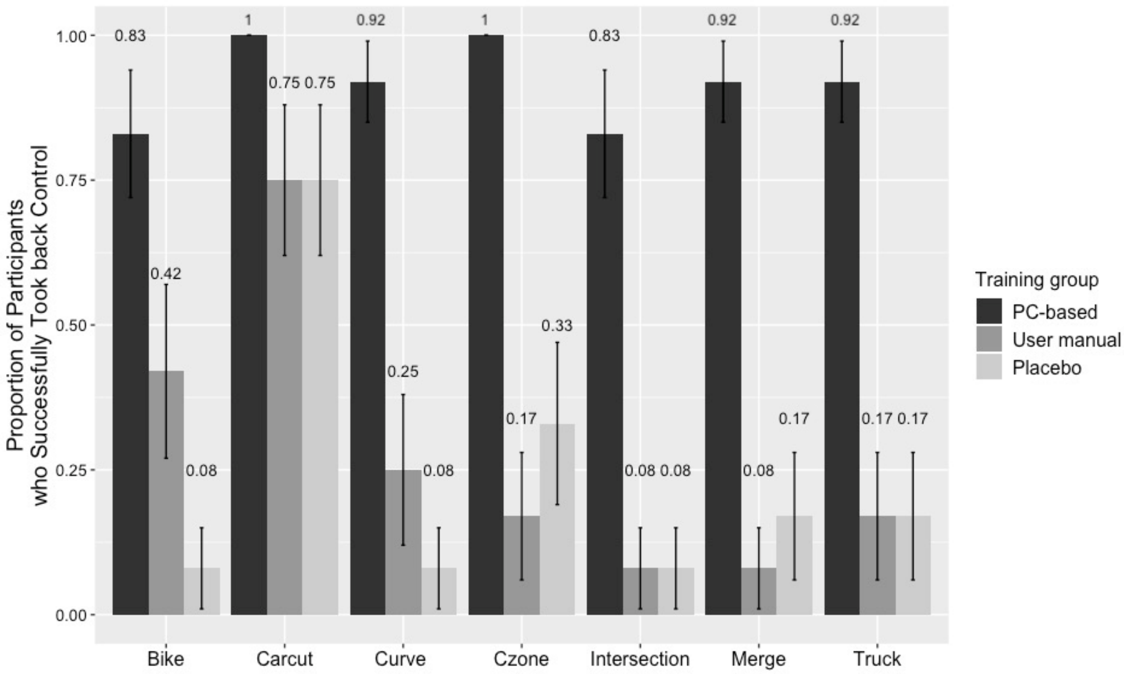


Figure 4. ***The percentage of participants who successfully took back control for each training group***

To determine whether the effect of dashboard was significant , a logistic regression model within GEE framework was used. Here, training group (PC-based , User manual , Placebo) was included as between subject factor, and takeover scenarios were included as within subject factor. Data analysis showed a significant main effect of training group (Wald Chi-Square = 25.732 , p-value < 0.001) and main effect of scenario (Wald Chi-Square = 33.287 , p-value < 0.001).

3.2 Situational Awareness

Overall SART scores of participants were calculated for all training groups. The mean overall SART scores for each group for different scenarios are presented in Figure 5. In all scenarios, participants in the PC-based training group had higher total SART score compared to the User manual and Placebo training groups. In total, the mean total SART score for participants in the PC-based training group was 22.03 (SD =1.41), for participants in the User manual was 15.20 (SD = 2.59) and for the participant in the Placebo was 10.84 (SD = 1.95).

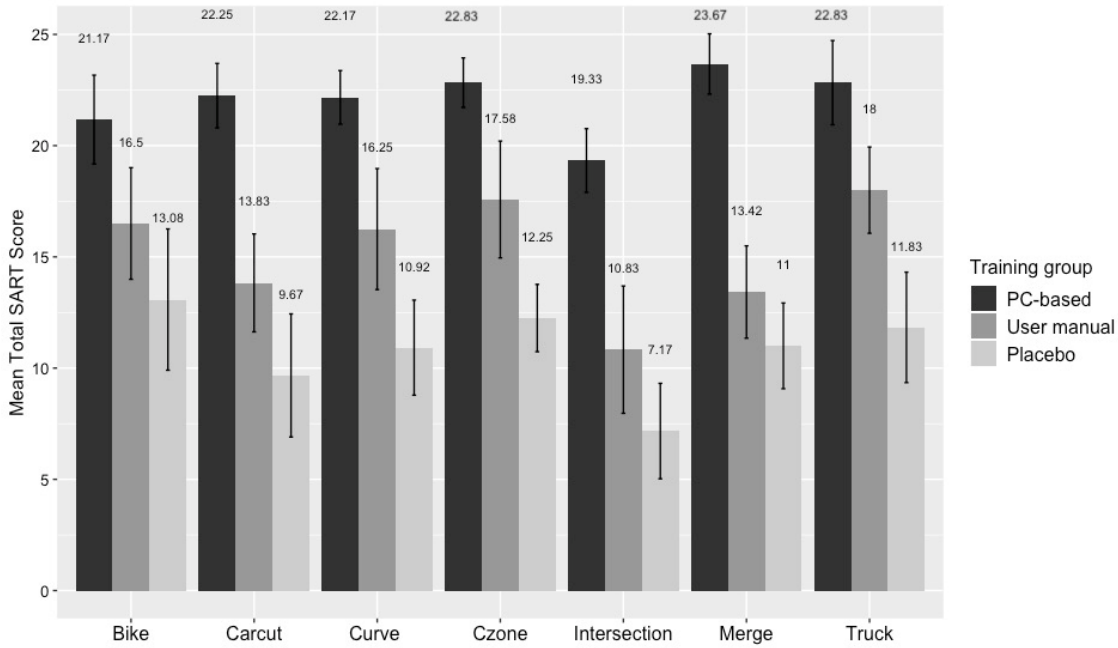


Figure 5. ***Mean overall SART scores for each training group***

To determine if there was a significant difference between mean overall SART scores of participants between groups, A 3 (training group) × 7 (scenario) factorial ANOVA was performed. Results showed that there was a significant main effect of training ($F(2,231) = 48.20$, P-value<0.001). There was no significant effect of scenarios. Bonferroni post hoc analysis showed that there was a significant different between all the combination of the trainings (P-value <0.001).

4 CONCLUSION

The objective of this experiment was to determine whether a PC-based training program using 3M approach could help drivers to take back control successfully when L2 system limitations are reached, improve their situational awareness as well as increase their trust in automation. Three different training program were conceptualized and designed for the purposes of this experiment : PC-based training program, user manual training program and placebo training program. In the PC-based training program, participants had an opportunity to practice, make mistake, learn and become master in taking back control situations where L2 systems reached it limitations. In the user manual training program, participants were provided with a text-based manuscript based on a real world owner's manual of an L2 system. Placebo training program was designed by including several other driver support feature rather than ACC and Lane Centering system which were the focus of our PC-based training program.

After completing their respective training programs, participants drove through ten scenarios on a fixed based driving simulator to test their response to different scenarios featuring both takeover and non-takeover situations during automated driving. Non-takeover scenarios were presented to the participants to make sure that did not develop a biased expectation to take back control for all the presented scenarios and to make sure their experience with L2 system was similar to real world situations where takeover situation may not be as prominent. Their takeover response was collected through the vehicle output of the driving simulator. To assess their situational awareness, and trust in automation, they were provided with SART (Selcon & Taylor, 1990).

Results from the analysis of binary coded takeover responses showed that there was a main effect of training program on successful takeover control instances whenever the L2 system reached its limitations. PC-based training group took back control significantly more (91.71%) when compared to user manual training group (27%) and placebo training group (23.71%). This was consistent with our first hypothesis (H1). This may indicate that participants who received PC-based training recognized and took back control successfully when needed far more than their contour parts in other training groups. These results are consistent with past studies which showed that there user manuals were not sufficient to improve drivers knowledge regarding drivers support features (Boelhouwer, van den Beukel, van der Voort, & Martens, 2019; Jenness, Lerner, Mazor, Osberg, & Tefft, 2008). Past studies also showed that many drivers do not read the user manuals completely (Leonard & Karnes, 2000). Considering the fact that the drivers in this study received only a specific section of the user manual and were given enough time to read through it before driving through post-test scenarios right after, one could argue that drivers in the real world may have gained/recalled less information from the user manuals. It should be noted that none of the participants in the training group did not take back control for No-takeover scenarios. This indicates that PC-based training did not cause people to be overly sensitive.

In order to investigate the situational awareness of the participants during their post-test drives on the simulator, their overall SART scores derived from their responses on the SART questionnaire were analyzed. The results indicated that participants in PC-based training group had significantly higher overall SART scores when compared to user manual and placebo training groups. As mentioned earlier, drivers in PC-based training group took back control more successfully that the other two groups. These results along with those from SART scores are consistent with past studies which have shown that drivers who had higher SART scores were more likely to successfully take back control from automated systems (Van Den Beukel & Van Der Voort, 2013). This could serve as another indicator about the effectiveness of the PC-based training program and is consistent with our second hypothesis (H2). No significant differences were observed between user manual and placebo training groups during the post hoc analysis. It should be worth pointing out that owner's manual were not at all sufficient to help drivers be situationally aware regarding the presented scenarios which featured some of the critical L2 system limitations.

This study adds to the literature regarding the effectiveness of training program to improve drivers interaction with L2 systems. This study showed that a PC-based training program using 3M approach could help drivers learn from their mistake in a safe and controlled environment using an interactive PC-based platform. The tests showed that they performed significantly better than drivers who only received information from owners' manual or those who were receiving placebo training. The results from this study can shed a light on new approaches to design training and user education methods with regards to vehicle automation which is much needed considering unfortunate accidents reported due to the drivers lack of situational awareness and knowledge regarding the limitations of these type of vehicles.

4.1 Limitation and Future work

The study has some limitations as noted here. First, the driving session of the study was conducted on a driving simulator and despite the high fidelity of the driving simulator, to analyze constructs such as situational awareness, the external validity could be improved by conducting an on road study. Second, due to the fact that the current study incorporated a between-subject design, it could be argued that complete homogeneity was not maintained across the groups despite random assignment. Third, a larger sample size would be helpful to generalize the findings. Initial sample size considered for this experiment was larger but due to the onset of the COVID-19 pandemic, the sample size had to be reduced. Fourth, the number of the takeover scenarios consider in this study were limited. Despite the effort to consider examples of all important types of takeover situation scenarios, there are many scenarios with difference in details, locations, road geometries, etc., which could not be included in this study due to the limited timing of each session. Modifying the PC-based training and testing it for more scenarios could further improve generalization of this study's results. Fifth, In this study, pre-test simulator drives were not included due to the time limitations for each session. Having baseline drives before exposing the participants to training could further show how a training program affected ones' response before and after receiving it.

4.2 Implications

The findings from this study could have several practical implications in the real world. This study sheds light on inherent problems regarding the information presented in the owners' manual specially those related to the limitations of these systems which is critical safety related information for new owners. Both researchers and manufacturers could understand the urgency of looking into new ways to effectively transfer knowledge to the drivers. Alternatively they could build upon our PC-based training program to design a comprehensive and advanced training program to deliver at dealerships, driving schools, etc.

This effort showed that 3M approach of training was efficient in transferring safety critical information to the drivers with regards the ODD limitations of L2 systems. Future research works could focus on delivering training using 3M approach in context of L2 systems for other important constructs such as hazard perception, attention maintenance, etc. They could also design and test this training program using more advanced platforms such as virtual reality and augmented reality or even deliver the training inside the vehicle.

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