The Effects of a Change in Environment on the Minimum Time to Situation Awareness in Transfer of Control Scenarios

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ABSTRACT

From previous experiments, we know that control must be transferred to the driver in a Level 3 vehicle at least 8s before the driver passes a latent hazard, for the driver to be as aware of the latent hazard as the driver is when glancing continuously on the forward roadway. In these experiments, the driving environment remained consistent throughout the time the ADS was engaged, and immediately after control was transferred to the driver. Considering the fact that drivers expect different categories of hazards in different driving environments, a transition to a different environment while the ADS is engaged may impair a driver's ability to both achieve situation awareness and successfully mitigate hazards. The current experiment examined if 8s was enough time for drivers to achieve situation awareness and appropriately mitigate hazards when the roadway environment changes while the driver is engaged in a secondary activity which takes his or her eyes away from the forward roadway. Drivers' eye movements and vehicle metrics were recorded as they completed one of three conditions in a driving simulator: an automation condition where the driving environment remained consistent throughout; an automation condition that contained some transitions to a new environment while the driver engaged the ADS; and a manual driving condition that also contained the same transitions as the latter automation condition. The results suggest that even 8s is not enough time for drivers to achieve situation awareness and mitigate hazards when the hazards are unexpected.

INTRODUCTION

Level 3 automation in driving presents a unique challenge, as the automated driving suite (ADS) is responsible for all aspects of the driving task in limited situations (*1*). According to the Society of Automotive Engineers, Level 3 automation is a conditional automation mode where the automation performs all aspects of dynamic driving with the expectation of a human response to an appropriate intervention request (*2*). This level of automation presents a problem with respect to situations in which a driver is expected to take-over manual control of the vehicle after an extended period of automation. Specifically, the driver can disengage his or her attention away from the driving task while the ADS is engaged; however, in certain critical situations, the driver is expected to resume manual control of the vehicle and achieve safe levels of situation awareness. These periods of automation engagement leave the driver out-of-the-loop of the driving task, and, thus, require an efficient way of getting the driver back in the loop within seconds. This transfer of control problem has been addressed in driving simulator studies both, from a vehicle control perspective examining take-over durations and quality (*3*, *4*, *5*) and a situation awareness paradigm identifying minimum thresholds for the safe transfer of control from the ADS to the driver (*6*, *7*). Overall, these studies establish the degree of situational and individual difference factors that influence the transfer of control from the ADS to the driver.

One situational factor that is likely to influence whether a transfer of control from the ADS to the driver is successful is the roadway environment where the transfer occurs. Roadway driving environments may be characterized by road geometry, traffic density and terrain features, among other variables. For example, a driving simulator study conducted by Jamson and colleagues found that drivers in a fully automated vehicle allocated more attention to the road in situations with high traffic (*8*). Even in heavy traffic, drivers using the highly-automated system were found to handle the longitudinal control of the vehicle no worse than drivers manually handling the vehicle. While this increased attention to the forward roadway should be associated with safer vehicle behaviors, another simulator study found the opposite, where high traffic density and therefore a greater number of objects leads to extended visual scanning and decision making process overall resulting in less safe vehicle behavior (higher collision rate and shorter time to collision in take-over situations (*9*, *10*).

Beyond the specific influences of traffic density on attention and vehicle behavior in the transfer of control process in semi-autonomous vehicles, the basic visual attention literature suggests that environmental context and observer experience generally are critical in determining where observers allocate their attention. In a classic study by Chun and Jiang, observers searched for their target among various configurations of distractors. Some of the distractor configurations were repeated whereas others were novel. Critically, observers were faster at identifying their target on trials in which the configuration was repeated, suggesting that observers learned to associate specific configurations of distractors (i.e., a context) with specific target locations (*11*). Similarly, in the realm of driving, Borowsky and colleagues showed that drivers rely on previous expectations of sign locations to determine where they will look for the signs. When these signs appeared in unexpected locations, experienced drivers made more errors in identifying these signs (*12*). Another study by Chapman and Underwood demonstrated that visually less complex rural roads elicited the longest fixation durations and the shortest angular saccade distances while the opposite was found to be true for visually complex urban roadways (*13*). This difference in eye movement based behavior across different environment types may be amplified in automated driving situations when the driver is out of the loop for a significant duration and encounters a transfer of control paradigm within an environment different than the one he/she had previously ceded control to the ADS in.

The results of the above studies demonstrate that environmental context and situational features are critical to what and where observers and drivers will attend to. Thus, we would expect the roadway environment to be critical in determining how drivers anticipate hazards—a process previously validated as a measure of situation awareness in the context of transfers of control from the automation to the driver (*7*). Utilizing latent hazard anticipation as a proxy for situation awareness, Samuel and colleagues determined that a minimum (transfer of control alerting) time of 8 s was required for younger drivers to achieve situation awareness in a take-over situation following a period of Level 3 automation where attention was previously engaged in a driving irrelevant task while the automation was active (*6*). However, this 8s estimate was determined in a controlled setting where the driver relinquishes control of the vehicle and then subsequently takes over control from the ADS in the same roadway environment (e.g., rural). This stability in the environment after disengagement and prior to reengagement, may not always be reflective of a driver's actual experience with these automated systems. It may be the case that even after as little as a minute of the ADS in control, the environment may change drastically (e.g., the vehicle moves from a rural to a suburban environment). As certain hazards are unique to specific environments (e.g., a deer crossing the street is likely to occur in a rural environment but not in an urban one), a change in the environment while the driver is not attending to the roadway will likely leave the driver at a disadvantage for anticipating the appropriate hazard cues and leave him or her less likely to successfully mitigate the potential hazard. It follows that the 8s transfer of control alerting time (critical to regaining situation awareness) determined by Samuel and colleagues when a driver's environment remains stable, may be insufficient when the environment drastically changes.

Samuel and colleagues found that the minimum transfer of control alerting time required for younger drivers (drivers with valid driver's license that are between the ages of 18-22) in a Level 3 automated environment was 8s when the hazard is expected (e.g., the driving environment always remained consistent throughout the transfer of control process). That is, it took 8s for these drivers to anticipate hazards at a rate equivalent to that of drivers in a manual driving condition (*6*). The goal of the current experiment was to examine whether this minimum transfer of control alerting time increases when the hazards are unexpected (when the driving environment can change while the ADS is engaged and the driver is looking away from the forward roadway). In addition to this goal, the current experiment also aims to examine the relationship between vehicle performance measures and situation awareness in the context of transfer of control scenarios.

To achieve these goals, we conducted a driving simulator experiment that contained three between-subject's conditions: a control condition where drivers navigated the vehicle completely on their own and two (change in driving environment or no change in driving environment) transfer of control conditions where the driver took over control from the ADS when alerted to do so. Half of the scenarios used in this study had been used in previous simulator studies such as Samuel and colleagues. The remaining scenarios were tested and developed specifically for this study. The transfer of control alerting times in the transfer condition were set to be 8 s (as shown in Samuel and colleagues) as this was the amount of time required for a sample of younger drivers to achieve situation awareness when expected hazards were encountered (*6*). The expectation was that if more time was required when hazards were unexpected (a change of environment could occur), the rate of hazard anticipation should differ across the two transfer conditions, suggesting 8s was not a sufficient amount of time. In the transfer conditions, the drivers were engaged in an in-vehicle reading task on an iPad while the ADS was in control of the vehicle.

HYPOTHESES

There are two main hypotheses in this study.

1. We hypothesize that under situations requiring a transfer of control from the ADS to the driver, the initiation of the transfer of control in more complex driving environments (e.g., urban) will elicit worse hazard anticipation from the driver, compared to less complex driving environments (e.g., rural).
2. We hypothesize that under situations when a hazard is unexpected (when an initiation of the transfer of control in a driving environment different from that presented previously could occur), drivers will elicit worse hazard anticipation and poorer hazard mitigation performance compared to when hazards are expected (when the driver is in manual control of the vehicle or when a transfer of control is always initiated in an environment that remains consistent throughout).

METHOD

Participants

48 subjects (25 female, 23 male) aged 18-22 were recruited for this study which had full approval from the University of Massachusetts Amherst Institutional Review Board. Data from 3 subjects was dropped due to bad eye tracking calibration while 2 other participants dropped out from the study due to simulator sickness. The 15 participants in the control group (manual driving condition) had a mean age of 20 years (*SD* = 1.464) and a mean driving experience of 4.03 years (*SD* = 1.275). The 14 drivers in the no change group (automated driving condition with no changes in driving environment) had a recorded mean age of 20.2 years (*SD* = 0.893) and mean driving experience of 2.20 years (*SD* = 1.170). The 14 drivers in the change of environment group (automated driving condition with changes in driving environment) had a recorded mean age of 20.1 years (*SD* = 1.351) and mean driving experience of 2.0 years (*SD* = 1.464). All participants were recruited from the University of Massachusetts Amherst and surrounding areas and were remunerated 25 dollars for their participation in the study.

Apparatus

The current experiment utilized a driving simulator, an eye tracker and an autonomous driving suite package.

Driving Simulator

A Realtime Technologies Inc. (RTI) full cab, fixed-base driving simulator was used to conduct this experiment. The simulator cab is a fully equipped 1995 Saturn sedan placed in front of three screens subtending 135 degrees horizontally and 180 degrees visually at a display resolution of 1240 x 768 pixels and at a frequency of 60 Hz. The participants are allowed to control the simulator cab, just like he or she would a normal car. The vehicle dynamics, physics and graphics provide a realistic experience to the participants along with surround audio set-up via a Dolby surround system consisting of side speakers and two sub woofers located under the hood of the car. The current sound setup provides effect of wind, road and other vehicle noises with appropriate direction, intensity and Doppler shift.

Eye Tracker
An Applied Science Laboratories (ASL) Mobile Eye head mounted, portable, eye tracking unit was used to monitor and record fixations of the driver. The ASL eye tracker provides a visual angle range of 50 degrees in the horizontal direction and 40 degrees in the vertical direction with a system accuracy of 0.5 degrees of visual angle.

Automation Control Suite
The RTI driving simulator is equipped with a Level 3 off-the-shelf, automation package (‘SimDriver’). SimDriver allow engagement and disengagement of automation via the use of the windshield wiper toggle stick on the right side of the steering wheel. When transferred to automated mode, the automation completely takes over control of the car and performs all the requisite steering, braking and acceleration maneuvers for the driver. Please note that when ADS is engaged the steering is stationary. When the ADS is in control, the speed of the ownship (or simulator cab) is set to a default value of 45 mph. There was no form of haptic feedback for the simulator cab when in autonomous mode or otherwise.

Scenarios
All participants navigated twenty simulated scenarios (each scenario lasting approximately two minutes in duration; Table 1). Twenty scenarios were necessary in order to make the limited number of change of environment scenarios. The twenty scenarios were grouped into 10 “mirror” image pairs (e.g., a latent threat would appear either on the right or left sides of a marked midblock crosswalk; a car would merge from the left or the right onto a freeway). We utilized a base/mirror design due to the finite number of hazards that exist in each traffic environment. By using this design, we are able to "double-dip" on hazards while keeping participants naive to the type of hazards that they are likely to encounter. The driving environment was identical within mirror image pairs. The ten mirror image scenarios were representative of five different roadway environments (2 pairs per environment): rural, suburban, commercial, urban and freeway. Of the ten latent hazards in the mirror image pairs, five were programmed to be vehicle hazards, four were pedestrian hazards, and one was an animal hazard. All the scenarios are briefly described along with their perspective views for illustrations in Table 1. The two scenarios in each pair are arbitrarily labeled in the table as either the base scenario or the mirror scenario.

Experiment Design
The experiment utilized a between-subjects design (Table 2). Participants either navigated the virtual environment while in full control of their vehicle (control condition) or they drove through one of the two transfer conditions (experimental condition; change or no change). As stated previously, four scenarios were included for each driving environment and we have 5 different driving environments (20 Scenarios). While the order of the driving environments was consistent across participants, the order of these four scenarios within each driving environment was counterbalanced across participants within each group. The change of environment group received five changes across the entire set of 20 scenarios (one change scenario after three no change scenarios). Each participant received one change scenario of each type of driving

environment (freeway to urban, urban to freeway, rural to suburban, commercial to rural, suburban to commercial). We only presented a limited number of change of environment scenarios (masked by the large number of consistent environment scenarios) in order to ensure that a change of environment violated participants expectations. The occurrence of a change in environment scenario was counterbalanced across subjects across the other fifteen no change scenarios.

Note that in the change scenarios, the two environments appeared in each scenario, in the order indicated. Thus, in the fourth scenario, first the freeway environment appeared when the ADS was in control. Just before the ADS relinquished control, the urban environment appeared (labelled as *F/U* in Table 2).

Procedure

Participants first provided written consent to participate in this study. Following this, the participants were outfitted with an eye tracker and asked to navigate a practice drive to help them become familiar with the simulator controls as well as the engagement features of the automation. The eye tracker was calibrated using a nine-point calibration mechanism, and accuracy was checked by having the observer reexamine each of the nine points and confirming the output of the location of the eye was consistent with where the participant was looking. Next, the driver navigated the twenty experimental scenarios. Subsequent instructions were provided to the participants at the onset of each drive. Specifically, the drivers were instructed they would transfer control to the automation upon hearing the audio alert "transfer control" that explicitly tells them to do so. (The driver received an audio "beep" confirming that a transition to the automation was successful.) Participants were also told they would resume manual control of the vehicle when another audio alert "take over control" is heard. The drivers were asked to maintain the current speed limit when they were in control of the car and were asked to engage in an in-vehicle reading task on the iPad only when the car was controlled by the ADS. Participants were explicitly instructed to stay focused on the iPad while the ADS was engaged and to not look up at the forward roadway. Based on qualitatively examining the eye-tracking video, participants overall listened to instructions very well and stayed engaged on the reading task while the automation was active. As a formal manipulation check, following the completion of the scenarios, participants were shown five videos (one for each of the 5 different environments) and were asked to identify which environment was depicted. In addition, participants filled out a post-study questionnaire comprising basic demographic and driving history-related questions. The entire session lasted approximately an hour long.

Dependent variables

The dependent variables measure both eye and vehicle behaviors. For eye behaviors, the dependent variable for each scenario was whether the driver anticipates the potential hazard or not. The value of the dependent variable for each scenario is determined by the glance location of the driver as he or she approaches the latent hazard (Figure 1). Specifically, a target zone was defined as that area of the forward roadway where a potential or actual threat may be present. A launch zone was defined as that area of the roadway whence the driver should glance towards the target zone in order to be able to successfully detect and mitigate for all latent hazard types. A driver's latent hazard detection for each scenario is binary scored as either a 0 (miss) if they fail to glance towards the target zone in the launch zone or a 1 (hit) if they successfully glance towards the target zone in the launch zone. The launch zone and target zones used in this experiment were previously utilized in other experiments for the evaluation of latent hazard anticipation (*13*} and can be understood better from Figure 1. Vehicle measures such as velocity and acceleration were also collected for each participant.

The standard deviation of velocity and average absolute acceleration were the dependent variables used to measure vehicle behaviors as these measures are predictive of crashes and/or the severity of crashes (*15,16*). These variables were computed for just the 8s prior to a latent hazard (immediately following the audio alert in the automated conditions).

RESULTS

Hazard Anticipation Results

The binary-coded, binomially distributed, eye movement data were analyzed using a logistic regression model within the framework of Generalized Estimating Equations (GEE). The model included participants as a random effect, treatment (3 experimental conditions) as a between-subjects factor, and driving environment (5 unique environments) as a within-subjects factor. A significant main effect of driving environment was observed (Figure 2), Wald $X_4{}^2$ =24.56; $p <$ .001. Consistent with the hypotheses, drivers anticipated the most hazards (M = 81%, SD = 23%) in one of the least complex environments (rural). Moreover, drivers anticipated the fewest hazards (M = 61%, SD = 26%) in one of the most complex environments (commercial). See **Error! Reference source not found.**.

The same model failed to reveal any significant effect of treatment, Wald $X_2{}^2$ =2.79; p = .25; however, planned follow-up contrasts revealed important patterns. **Error! Reference source not found.** presents the gaze data as a function of the three experimental conditions. Replicating Samuel and colleagues (*6*), when drivers were given an 8s alert prior to a hazard and when the driving environment always remained consistent between the time they transferred control to the ADS up until when they took over manual control of the vehicle, drivers anticipated 69% (SD = 13%) of the hazards—a similar level of hazard anticipation as the manual driving condition (M = 73%, SD = 15%). This suggests 8s is enough time to achieve situation awareness when a hazard is expected. However, when a transition to a different driving environment could occur, drivers only anticipated 63% (SD = 14%) of hazards—a 10 percentage point difference from the manual driving group (Figure 3), t (27) = 1.85, p = .08. This result suggests that 8s is not enough time for drivers to achieve situation awareness when the hazard is unexpected (i.e., when there is a change in environment).

Hazard Mitigation Results

The standard deviation of velocity (Figure 4) and the average absolute acceleration (Figure 5) 8s prior to a latent hazard were analyzed with separate ANOVAs, both with treatment as a between-subjects factor. Focusing first on the standard deviation of velocity results, a main effect of treatment was revealed, F (2, 40) = 4.07, p = .03. The pattern is presented in Figure 4. The standard deviation of velocity in the automation consistent (M = 5.51, SD = 1.65) and manual change (M = 5.25, SD = 1.17) conditions, t (27) = .50, p = .62, did not differ significantly, suggesting drivers' ability to mitigate hazards by varying their speed is similar when the hazard is expected. However, in the automation change condition, drivers were less variable in their velocity (M = 4.16, SD = 1.11) than both the automation consistent (t (26) =2.54, p = .02) and manual change (t (27) = 2.56, p = .02) conditions. While the between-subjects ANOVA examining average absolute acceleration 8s prior to a latent hazard did not reveal a significant main effect of treatment, F (2, 40) = 2.34, p = .11, as evident in Figure 5, the pattern of the average absolute acceleration results was consistent with the standard deviation of velocity results. Overall, these results suggest drivers are less likely to notice the latent hazards and, therefore, less likely to vary their speed.

DISCUSSION

Samuel and colleagues found that at least 8s of alerting time was necessary during a transfer of control initiation from the ADS to the driver (following a period of Level 3 automation) for drivers to anticipate hazards with the same likelihood as drivers who are always in control of the car (manual condition). In that study, the hazards were expected in that, the driving environment always remained consistent throughout (*6*). The current study replicated this 8s alerting time finding across broader classes of driving environment scenarios that vary in speed, roadway geometry, and hazards. Critically, however, the current study examined two hypotheses. Hypothesis 1 posited that the more complex driving environments will elicit poorer hazard anticipation from drivers as compared to less complex environments. Results partially validated Hypothesis 1. Drivers in more complex environments anticipated significantly fewer hazards compared to less complex environments (63% in commercial vs. 81% in rural)—a difference of 18 percentage points.

Hypothesis 2 examined situations where hazards were unexpected (when an initiation of a transfer of control in a driving environment different from that presented previously could occur). Specifically, we posited that this violation of expectations would elicit worse hazard anticipation and hazard mitigation performance compared to the other two conditions where the hazard was expected. While no significant main effect of treatment on the proportion of latent hazards was found, contrast analyses showed that the ability of drivers to anticipate hazards was compromised when hazards were unexpected after a transfer of control (10 percentage points less than drivers in the manual condition). This suggests that a minimum transfer of control alerting time of 8s is insufficient when a discernable change in driving environment is possible during the period that the ADS is in control and the driver is engaged in a secondary in-vehicle task.

The standard deviation of velocity and average absolute acceleration were also examined during the take-over period (8s prior to the hazard) to understand hazard mitigation behavior. Differences in the standard deviation of velocity were also found to be similar across the automation consistent and manual change conditions suggesting drivers' ability to mitigate hazards is similar when the hazard is expected. However, in the automation change condition, drivers were less variable in their velocity compared to the other two conditions, suggesting a compromised ability to mitigate potential hazards when the driving environment was unexpected. While no significant patterns emerged from the acceleration data, results were consistent with the standard deviation of velocity results.

Critically and unique to this study, we demonstrate that driving environment plays an important role in determining drivers' ability to anticipate hazards, as the less complex environments resulted in better hazard anticipation likelihoods than the more complex driving environments. This crucial role of driving environment in hazard anticipation also influenced the amount of time drivers need to achieve situation awareness when they are out of the loop for a significant period. Specifically, results showed that when a change in environment could occur following a period spent by the driver with the ADS in control, even an 8s transfer of control alerting time is insufficient to ensure safety, quantified by an ability to anticipate threats and respond to them. Drivers in the automation condition that included changes in driving environment, anticipated fewer hazards than those in the manual condition that also included these changes. While this decrease in hazard anticipation performance was not statistically significant, it resulted in a significant decrease in drivers' ability to mitigate hazards. Drivers in the automation condition were less variable in their velocity than the other two experimental conditions where the hazards were expected, suggesting they were less likely to brake for upcoming hazards.

One important limitation to acknowledge is that the current work included no formal assessment of the degree to which drivers remained engaged in the iPad reading task. While a qualitative examination of eye-tracking videos suggested drivers overall did not look up at the forward roadway, a reading comprehension test following the experiment would be informative of the extent drivers were cognitively engaged. Future work will consider including this type of cognitive assessment. Moreover, while the work is informative of the amount of time drivers need to both successfully anticipate and mitigate hazards that are unexpected, it is important to note that even the unexpected hazards in this study were expected to some degree. That is, drivers received an audio warning that an upcoming hazard would occur. We would expect that if an audio alert did not warn drivers that a manual take-over was required, that the hazard anticipation and mitigation performance would be further impaired. Critically, though, a change of traffic environment was enough to alter expectations of hazards to some degree, particularly with respect to the drivers' ability to slow down for upcoming hazards, as speed variability was significantly lower for drivers that took-over control in a novel environment after a period of Level 3 automation compared to drivers who either drove manually or took-over control in an expected traffic environment. While the proportion of fixations on latent hazards and average absolute acceleration was not significantly impacted by our experimental manipulation, the fact that the general pattern with these DVs was consistent with the speed variability metric partially confirms our hypotheses. Future work should replicate and confirm the influence of novel traffic environments and unexpected hazards on the transfer of control alerting time.

Future work should also attempt to replicate the results of the current simulator experiment on an open roadway and recruit a more heterogeneous sample with respect to age in order to determine the generalizability of results. As experienced drivers are better overall at anticipating hazards (*7*, *13*), it is possible that this age group is more reliant on driving environment information. As such, this population may perform worse than the inexperienced sample examined in the current study and may require more time to achieve situation awareness and mitigate hazards when the changes in the roadway driving environment are unexpected. The findings of this study have potential implications for automation manufacturers and safety practitioners, with respect to the design of more effective and safer systems.

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TABLE 1 List of Simulator Scenarios

Hazard (Base /Mirror)	Scenario Description	Environment
Lane Ending (Left and Right lanes)*	The driver is on a six lane freeway. The driver passes a traffic sign (hazard cue) indicating that the leftmost lane is ending ahead. The driver is in the leftmost lane. There is other traffic in the right-most lane, but the center lane is clear to merge.	6 lanes, faster speed limit (65 mph), Median, **Freeway**
Exit (Left and right)*	The driver is on the rightmost lane of a six lane freeway with 3 lanes in either direction. The driver passes a traffic sign (cue) that informs the driver of an exit on the freeway ahead. There is other traffic in the left-most and center lanes, but none on the right lane.	6 lanes, faster speed limit (65mph), Median, **Freeway**
Car pulling out of the parking lot (Left and right side of the road)	The scenario begins with the participant driving down a four lane road. There is a parking lot on the right side of the road. A car pulls out from the parking lot. The car suddenly brakes and its brake lights illuminate about 40 feet after it pulls out, presumably for a little critter crossing the road. The driver needs to mitigate for the potential rear-end crash.	4 lanes Shops, Speed limit (45 mph), Business center, Offices, **Commercial**
Left and right turn*	The driver is navigating a 4 lane road. The driver has to take a left (or right) turn and the hazard (car) is materializing to turn in the same direction in front of the driver. He/she should slow down to control his speed to avoid the head-on collision.	4 lanes, Shops, Speed limit (45 mph), Business center, **Commercial**
Midblock Crosswalk (truck blocking view of potential pedestrian on left and right)	The driver is on a four-lane urban road. The driver passes a traffic sign(cue) that indicates pedestrians may be present. Ahead, a truck (cue) is stopped in the left of the two-lanes at a marked mid-block cross walk for a potential pedestrian that may enter the cross walk.	4 lanes, Speed limit (45 mph), Skyscrapers, **Urban**
Vehicles in parked lane	There is a lane of parked vehicles in a parking lane on a four lane city road (with the two lanes in the either direction). In the parking lane, the third car is positioned 10 degrees off the vertical tilted towards the rightmost lane with its brake lights illuminated.	4 lanes, Speed limit (45 mph), Skyscrapers, **Urban**
Pedestrian	The scenario starts on a two-lane curve road. As the driver approaches the apex of the curve, immediately following the apex there is a truck in the emergency lane with its emergency flashers activated. The truck hides a pedestrian stopped in front of it.	2 lanes, Speed limit (45 mph), Tree, **Rural**
Deer-crossing	The participant is traveling straight on a two-lane rural road with a lead vehicle in front of the participant. The lead vehicle brakes and slows for a deer on one side of the road that might potentially cross over to the other side of the road. The crossing never materializes. There is a deer sign present.	2 lanes, Speed limit (45 mph), Trees, Barn, **Rural**
Pedestrian*	The driver is on a two lane suburban road. A pedestrian (cue) is clearly visible to the left side of the road. Ahead, a vehicle is signaling to turn left, but is stopped (cue; presumably to wait for a 2nd pedestrian to cross). The area with the potential 2nd pedestrian is occluded with vegetation.	2 lanes, Speed limit (45 mph), Houses, **Suburban**
Pedestrian (Right or left side of the road)*	The driver is on a four-lane suburban road. The driver passes a traffic sign(cue) that indicates pedestrians (School area) may be present. Ahead is a bus (cue) that is stopped in the Right of the two-lanes at a marked mid-block cross walk for a potential pedestrian that may enter the cross walk.	2 lanes, Speed limit (45 mph), School, houses, **Suburban**

*Scenarios were developed specifically for this study.

TABLE 2 Design of Experiment

Scenario Number																				
Conditions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Automation consistent (N= 14)	R	S	F	U	C	R	S	F	U	C	R	S	F	U	C	R	S	F	U	C
Automation Change (N=14)	R	S	F	***F/ U***	C	R	S	***U/ F***	U	C	R	***R/ S***	F	U	C	***C/ R***	S	F	U	***S/ C***
Manual Change (N=15)	R	S	F	***F/ U***	C	R	S	***U/ F***	U	C	R	***R/ S***	F	U	C	***C/ R***	S	F	U	***S/ C***

R = Rural, S = Suburban, F = Freeway, U = Urban, C = Commercial,
No Change, ***Change***

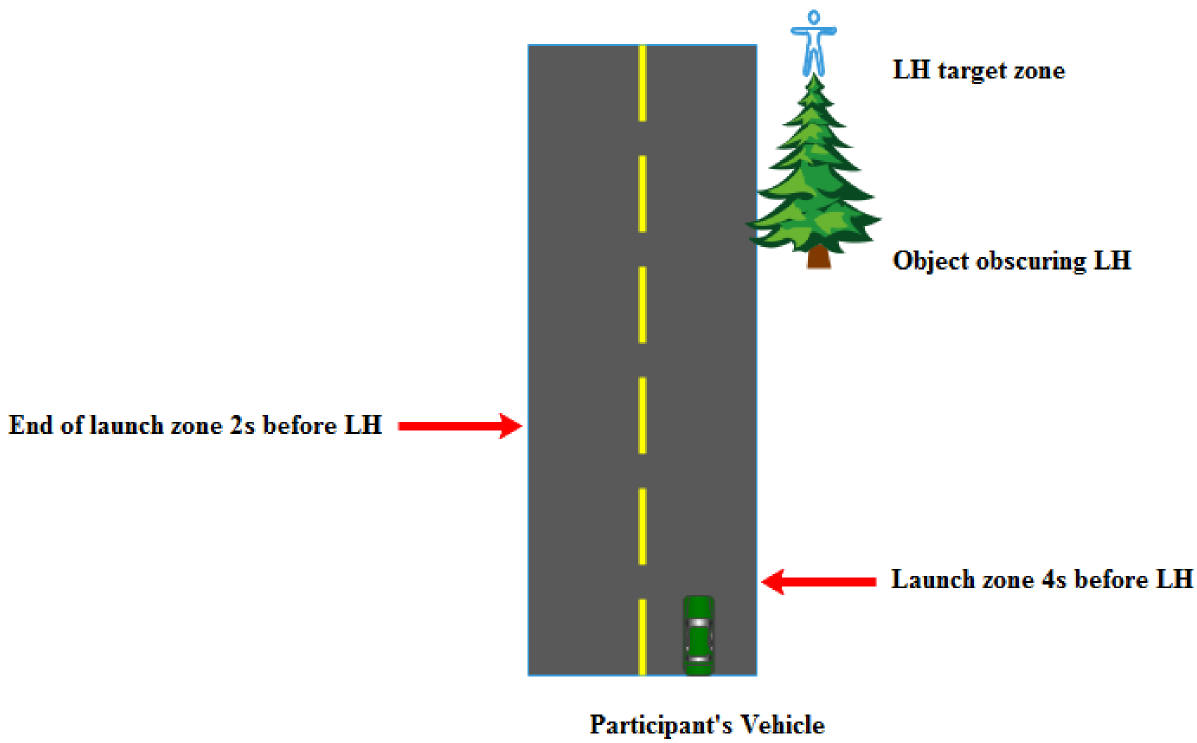

FIGURE 1 Typical launch zone and target zone for a scenario with latent hazards (LH).

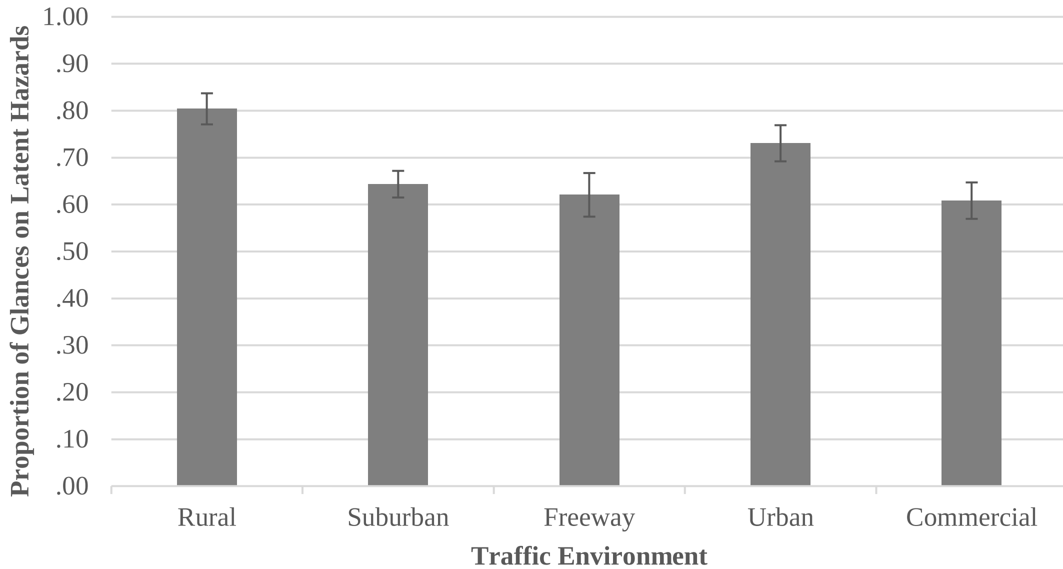

FIGURE 2 Proportion of latent hazards detected in each traffic environment.

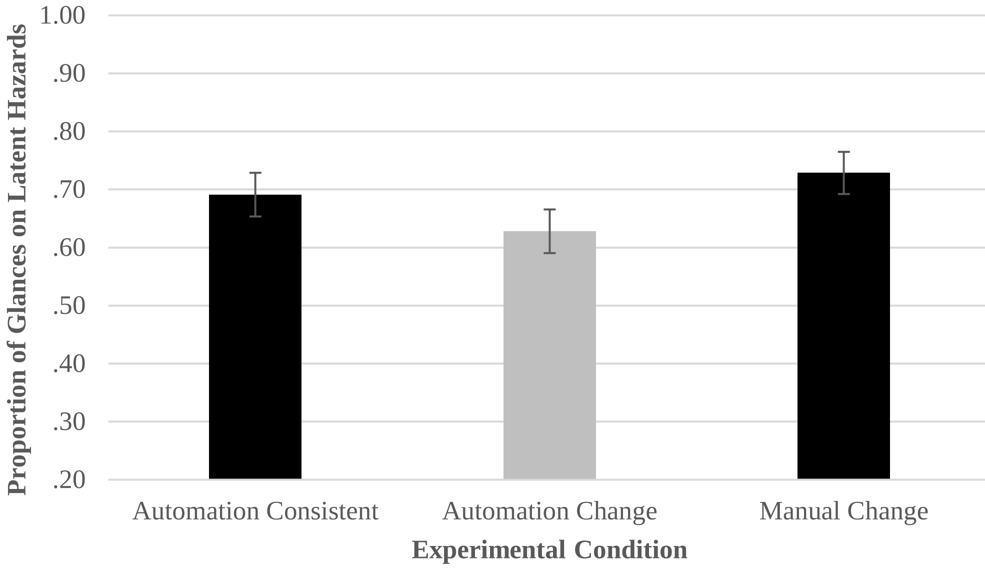

FIGURE 3 Proportion of latent hazards detected in each experimental condition.

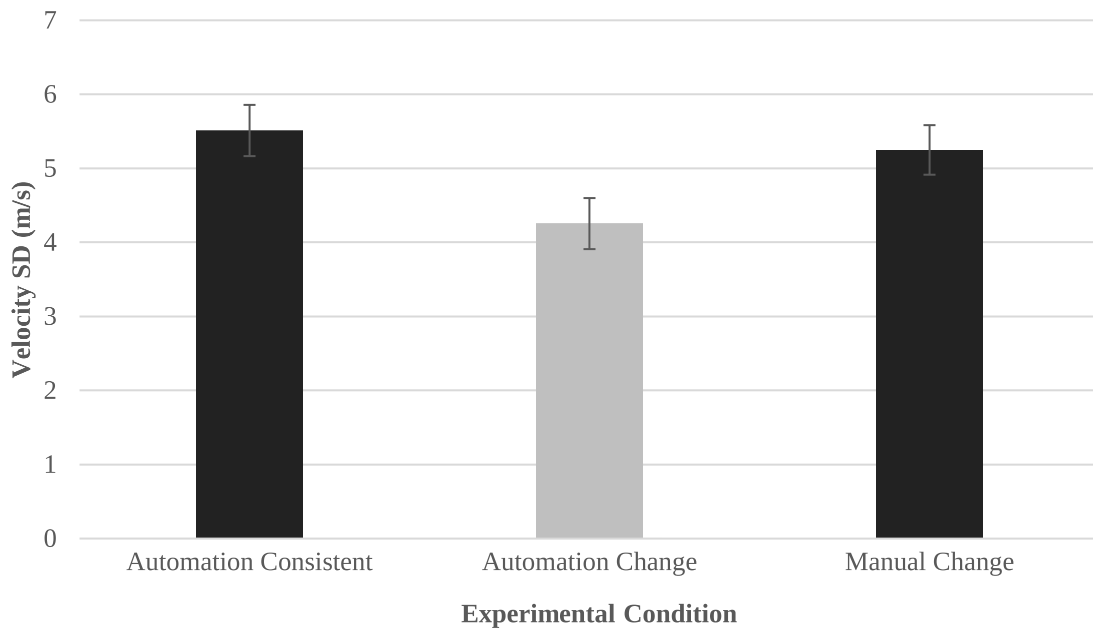

FIGURE 3 Velocity standard deviation (SD) during the 8 s following a take-over request for the three experimental conditions.

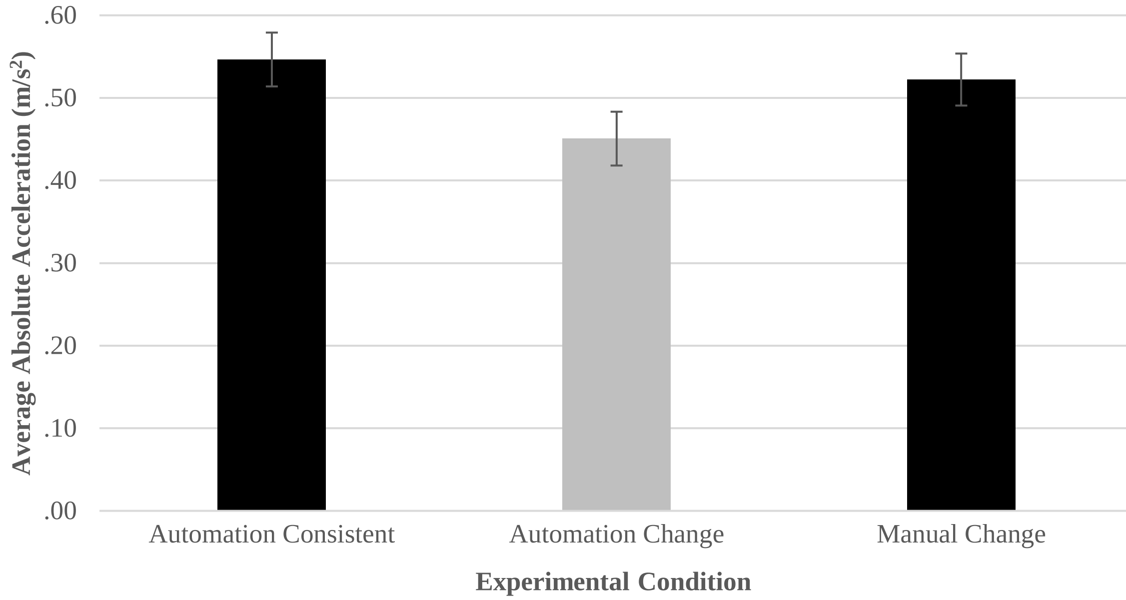

FIGURE 4 Average absolute acceleration during the 8 s following a take-over request for the three experimental conditions.