Human Factors of Driving Automation: Evasive Maneuver Event Response Evaluation

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16. Abstract

An increasing number of conditionally automated driving (CAD) systems are being developed by major automotive manufacturers. In a CAD system, the automated system is in control of the vehicle within its operational design domain. Therefore, in CAD the vehicle is capable of tactical control of the vehicle and can maneuver evasively by braking or steering to avoid objects. During these evasive maneuvers, the driver may attempt to take back control of the vehicle by intervening. A driver interrupting a CAD vehicle while properly performing an evasive maneuver presents a potential safety risk. To investigate this issue, 36 participants were recruited to participate in a Wizard-of-Oz research study. The participants experienced one of two evasive maneuvers on a test track. The evasive maneuver required the CAD system to brake or steer to avoid a box placed in the lane of travel of the test vehicle. Drivers glanced toward the obstacle but did not intervene or prepare to intervene in response to the evasive maneuver. Importantly, the drivers who chose to intervene did so safely. These findings suggest that after experiencing a CAD vehicle for a brief period, most participants trusted the system enough to not intervene during a system-initiated evasive maneuver.

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Abstract

An increasing number of conditionally automated driving (CAD) systems are being developed by major automotive manufacturers. In a CAD system, the automated system is in control of the vehicle within its operational design domain (ODD). Therefore, in CAD, the vehicle is capable of tactical control of the vehicle and can maneuver evasively by braking or steering to avoid objects. During these evasive maneuvers, the driver may attempt to take back control of the vehicle by intervening. A driver interrupting a CAD vehicle while properly performing an evasive maneuver presents a potential safety risk. To investigate this issue, 36 participants were recruited to participate in a Wizard-of-Oz research study. The participants experienced one of two evasive maneuvers on a test track. The evasive maneuver required the CAD system to brake or steer to avoid a box placed in the lane of travel of the test vehicle. Drivers glanced toward the obstacle but did not intervene or prepare to intervene in response to the evasive maneuver. Importantly, the drivers who chose to intervene did so safely. These findings suggest that after experiencing a CAD vehicle for a brief period, most participants trusted the system enough to not intervene during a system-initiated evasive maneuver.

Acknowledgements

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Introduction

The Society of Automotive Engineers (SAE) defines the roles of an automated driving system and its human supervisor during the driving task for each level of automation (SAE, 2021). Level 2 (L2) or partially automated driving (PAD) vehicles support the driver by providing longitudinal and lateral control inputs (i.e., keeping the vehicle at a set speed, maintaining a set distance to a lead vehicle, and maintaining the vehicle's position between the lane markings). However, during PAD the driver is required to monitor the environment and the automated system performance and must be prepared to always take over vehicle control. Conversely, the driver is not required to monitor the environment or system during Level 3 (L3) or conditionally automated driving (CAD) but must take over control when prompted by the vehicle. Many of today's vehicles offer PAD features, while a limited number of CAD vehicles are being developed by major auto manufacturers, for example, Honda (Etherington, 2020)).

Since drivers are not required to monitor the environment during CAD, they are free to direct their gaze and attention away from the roadway, can keep their hands and feet away from the steering wheel and pedals, and are free to complete non-driving related tasks (NDRTs). CAD systems are able to control the vehicle fully within their operational design domains (ODDs) and alert the driver to take control or resume monitoring in a timely manner.

The shift in driver role and responsibilities from manual driving to reliable supervised automation (i.e., PAD) and unsupervised automation (i.e., CAD) is generally associated with reduced situational awareness or entering an "out-of-the-loop" state (Endsley & Kiris, 1995). Merat et al. (2019) define the out-of-the-loop state as "Not in physical control of the vehicle, and not monitoring the driving situation, OR in physical control of the vehicle but not monitoring the driving situation." Conversely, being in physical control of the vehicle and monitoring the driving is defined as the "in-the-loop" state. Monitoring the environment but not being in physical control of the vehicle is defined as the "on-the-loop" state.

Given the need for the driver to resume control of the vehicle during CAD and revert from an out- or on-the-loop state to an in-the-loop state, much of the human factors research on higher levels of automation has focused on the resumption of manual control (Louw et al., 2020; Seppelt & Victor, 2016). In contrast, there has been limited research on how drivers respond to evasive maneuvers initiated by a CAD vehicle.

Background

In CAD, the automated system is in control of the vehicle within its ODD. This means that during CAD the vehicle is capable of tactical control of the vehicle and can maneuver evasively by braking or steering to avoid objects on the road. During these evasive maneuvers, the driver may attempt to intervene during the maneuver and take back control of the vehicle. The interruption of a properly performed evasive maneuver may reduce safety with CAD. Additionally, unexpected inertial forces might also affect driver inputs on the controls. Previous research has shown that when drivers intervene during vehicle-initiated safety critical braking (Roche, Thüring, & Trukenbrod, 2020) and steering events (Roche, Becker, & Thüring, 2022) there was a potential safety risk caused by driver overreaction. It is important to note that these previous studies required drivers to attempt to intervene and did not examine driver's decision making during the maneuvers. Results from studies examining whether drivers would intervene to avoid an object during PAD have generally found that a subset of drivers will not intervene and will subsequently strike the object despite having their eyes on the road and their hands on the wheel (Pipkorn, Victor, Dozza, & Tivesten, 2021; Victor et al., 2018). To the authors' knowledge, no currently published research indicates how drivers may respond to evasive braking and steering maneuvers initiated by a CAD vehicle.

Currently, CAD autonomous vehicles are not widely commercially available or accessible to researchers. Thus, in order to study CAD vehicles, researchers are often required to use Wizard-of-Oz (WoZ) platforms to simulate automated driving (Bengler, Omozik, & Scheiter, 2019). The WoZ method uses a hidden human (i.e., the "wizard") to simulate the role of a computer system (Fraser & Gilbert, 1991). Initially, WoZ was employed to simulate natural language processing systems and voice interactions (Dahlbäck, Jönsson, & Ahrenberg, 1993). Beyond these initial uses, the WoZ method has been adopted in vehicle research to simulate autonomous vehicle and advanced driver assistance systems that are "not yet existent, or whose implementation would be too costly for the purpose of the experiment" (Jarosch, Paradies, Feiner, & Bengler, 2019). This application of the WoZ method is used both in driving simulators (Schieben, Heesen, Schindler, Kelsch, & Flemisch, 2009) and with real vehicles on test tracks (Pipkorn et al., 2021) and public roads (Jarosch et al., 2019). Researchers have built numerous other WoZ vehicles to simulate Level 2 through 5 autonomous vehicle systems to study a wide range of topics, including pedestrian-vehicle interactions (Currano et al., 2018; Li et al., 2020; Rothenbücher, Li, Sirkin, Mok, & Ju, 2015), external HMIs (Chen, Cohen, Dautenhahn, Law, & Czarnecki, 2020; Faas & Baumann, 2020), secondary task performance during CAD automation (Klingegård, Andersson, Habibovic, Nilsson, & Rydström, 2020), robotic taxi passenger experience (Kim et al., 2020; Meurer, Pakusch, Stevens, Randall, & Wulf, 2020), and takeover performance (Purucker, Berghöfer, Naujoks, Wiedemann, & Marberger, 2018). The widespread adoption of the WoZ method demonstrates the utility and versatility of these platforms for autonomous vehicle research.

Understanding how drivers respond to evasive maneuvers initiated by a CAD vehicle is important to the implementation of these systems and the arbitration of controls between the driver and automation in such situations. To explore this issue, 36 participants (18 males and 18 females) were exposed to a system capable of PAD and CAD using a WoZ vehicle to emulate PAD and CAD. The participants experienced one of two evasive maneuvers (braking or steering at about 3 m/s^2) on a controlled test track. The purpose of the study was to investigate the following research question:

How will drivers respond to an evasive maneuver scenario when in CAD?

- When the event is a swerve initiated by the automated system?
- When the event is a hard braking maneuver initiated by the system?

Method

Participants

Participant Recruitment

Virginia Tech Institutional Review Board (IRB) approval, IRB #18-473, was obtained for human participant data collection. News and social media advertisements, including posts to the Virginia Tech Transportation Institute (VTTI) Facebook page, and email were used to recruit participants. In addition, potential participants were identified in VTTI's recruitment database, which is a large database of individuals who have previously participated or expressed interest in participating in VTTI research. Potential participants were provided with information about the study over the phone from a member of the VTTI recruitment team. After receiving this information, those who were interested in participating in the study were screened for eligibility. A recruitment team member obtained verbal consent from the participant prior to administering the eligibility screening.

Participant Demographics

A total of 36 participants (18 females, 18 males) between the ages of 30 and 75 years old were recruited from the New River and Roanoke Valley regions of Virginia. Overall, the mean age of the participants was 53.8 years. The mean age for male participants was 54.7 years (n = 18) and 52.8 years (n = 18) for female participants.

Table 1. Participant Demographics

Gender	*n*	Min Age	Mean Age	Max Age
Male	18	31.0	54.7	74.0
Female	18	31.0	52.8	74.0
Total	36	31.0	53.8	74.0

Materials and Equipment

WoZ Vehicle

A 2019 Ford Edge was modified to serve as the WoZ test vehicle for this study. The vehicle was equipped with a set of driving controls, displays to monitor the surrounding environment, and sensors in the rear-passenger seat that allowed an experimenter to act as rear-seat driver (i.e., the "wizard") and operate the vehicle. The set of controls included a steering wheel, brake and accelerator pedals, turn signals, and buttons to activate the vehicle's adaptive cruise control (ACC) and lane keep assist (LKAS) features (see Figure 1). These modifications allowed the vehicle to be fully controlled from the rear seat and thereby simulate a vehicle capable of CAD. This simulation was achieved when the wizard steered the vehicle and monitored the driving environment while ACC was active. Although the vehicle was capable of PAD through the simultaneous activation of the ACC and LKAS features, PAD mode was simulated in the same manner as CAD.

Figure 1. Photos. Experimenter workstation, rear-seat driver controls, and viewpoint of rear-seat driver.

The vehicle was also equipped with a rear-seat experimenter workstation that allowed a second rear-seat experimenter to control the instrument cluster HMI via a laptop and indicate to the participant when the vehicle was changing between automation modes.

The vehicle was instrumented with the VTTI FlexDAS data acquisition system (DAS). The FlexDAS had cameras that continuously recorded video of the driver's face, the forward and rear roadways, an over-the-shoulder view of the driver's hands and lap area, and the driver's foot placement from key on to key off. The DAS also recorded vehicle speed, throttle position (front-seat control), brake application (front-seat control), acceleration, turn signal activation, GPS position, steering torque (front-seat control), and automation mode state (i.e., manual driving, PAD, CAD).

Lead Vehicle

A 2008 Chevrolet Tahoe was used as the lead vehicle for this study. The lead vehicle was operated by a trained VTTI confederate experimenter. This vehicle was used as a blocking vehicle and drove in front of the test vehicle during the study.

Evasive Maneuver

The evasive maneuver was performed at the end of the study and in a controlled test environment on the Virginia Smart Roads. On the second lap of the test-track part of the drive, the lead vehicle pulled in front of the test vehicle, which was still operating in CAD. Both vehicles were moving at about 45 mph (20 m/s) prior to the maneuver. Once the vehicles reached a predetermined landmark approximately 60 meters from the box, the rear seat experimenter and the lead vehicle initiated opposite evasive maneuvers (e.g., the test vehicle braked and the lead vehicle swerved, or the test vehicle swerved and the lead vehicle braked) in response to a cardboard box in the road (see Figure 1). The participant did not need to intervene in any way to avoid the box.

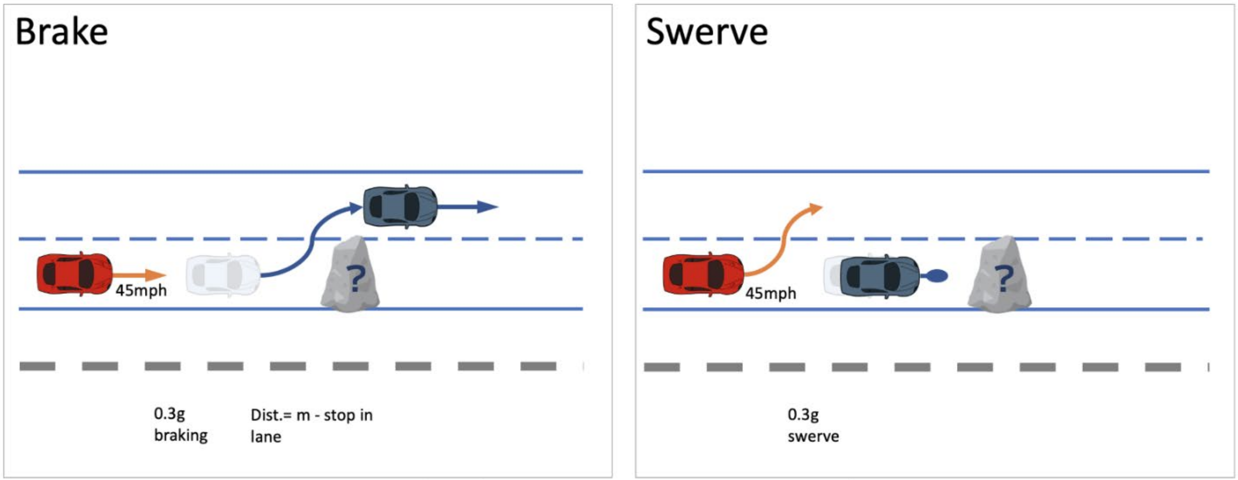


Figure 2. Diagram. Evasive maneuver.

Participants experienced one of two evasive maneuvers (swerving vs. braking). 18 participants experienced the braking maneuver, and 18 participants experienced the swerving maneuver. The braking and swerving groups were balanced by age (braking = 54 years, swerving = 53 years) and gender. Specifically, the evasive maneuver was either a braking or swerving maneuver to avoid the box placed in the lane of travel of the test vehicle. These maneuvers were intended to mimic an evasive action where the CAD system detects an object in the road and brakes or swerves to avoid it, as opposed to a “panic” or “emergency” action. Therefore, the lateral and longitudinal acceleration forces used were scaled to match this evasive nature of the maneuvers, with braking maneuvers of about 0.3 g and lateral swerves of about 0.3 g.

Procedure

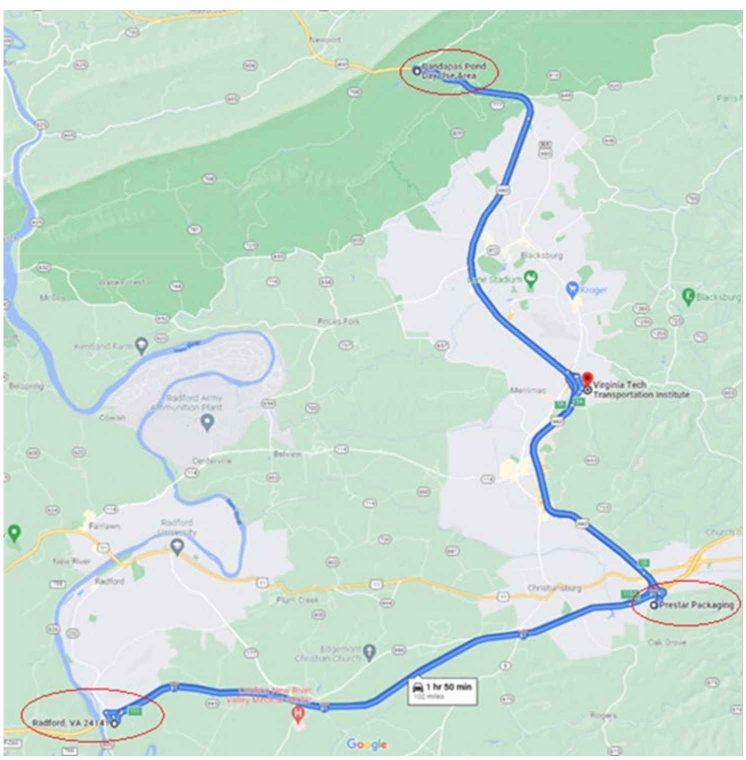
Participation in the study consisted of a single approximately 3-hour session during daylight hours. After a participant arrived at VTTI, a researcher obtained written consent after reviewing the consent form with the participant and answering all of the participant’s questions.

After the consent process, the researcher assessed the participant’s hearing, visual acuity, and color vision. If the participant did not pass the hearing test or visual acuity test, then they were informed they did not meet the study requirements and compensated $30 for their time.

Following the paperwork and vision and hearing tests, the researcher explained the vehicle’s automated driving features and how to activate and use them safely while driving, including normal operation and possible system limitations. Specifically, participants were instructed that during PAD they must keep their eyes and mind on the driving environment but that they did not need to keep their hands on the steering wheel or feet on the pedals. In addition, during CAD, participants were instructed that they did not need to keep their eyes and mind on the road, their hands on the wheel, or their feet on the pedals.

Next, the participant was given an orientation to the vehicle's controls and the driver's area of the vehicle cabin (e.g., seat controls, steering wheel, and mirror adjustment). During the overview of the driver's area, the researcher informed the participant about the presence of the second experimenter and their role as the rear-seat driver. The researcher explained that the rear-seat driver would be always present during the experiment and that they would have access to a second set of controls. The participant was informed that the second set of controls would be used to take control of the vehicle if necessary, for example during a safety situation, and to augment the automation as needed, but that they were considered the primary driver and were responsible for controlling the vehicle and responding to system prompts as needed during the study. Participants were informed that if at any point they felt fatigued or that they needed a break, a break would be provided. Participants were also instructed that they must follow all roadway signs and keep their seatbelt buckled throughout the driving portion of the study.

Once the participant felt comfortable with the vehicle's controls, they were given an opportunity to practice driving the vehicle in the parking lot at VTTI. When the participant indicated they were comfortable with driving the vehicle, they were directed to the public roadway where they experienced 20 transitions between CAD, PAD, and manual driving modes. Participants drove six laps on public roads over an approximately 2-hour time period (see Figure 3).



Lap	Start Point	End Point	Roads
1	VTTI	PreStar Packaging	US-460 E
2	PreStar Packaging	Pandapas Pond	US-460 W
3	Pandapas Pond	PreStar Packaging	US-460 E
4	PreStar Packaging	Pandapas Pond	US-460 W
5	Pandapas Pond	I-81 Exit 105	US-460 E/I-81 S
6	I-81 Exit 105	VTTI	I-81 N/US-460 W

Total = ~110 min

Figure 3. Map. Overview of study route.

Note: From Google Maps, by Google (https://goo.gl/maps/6YzuTAPYpMLCMEbi8)

Upon completing the sixth and final lap on the public roads, the study continued with a test-track portion on the Virginia Smart Roads. After entering the test track, participants were instructed that the study would continue with a few laps on the Smart Roads Highway to make sure the participant could experience all the maneuvers the system was capable of, and that another vehicle (i.e., the lead vehicle) would also be on the road. The test-track portion of the study consisted of two laps, proceeding from the first turnaround to the fourth turnaround (see Figure 4). During the first lap, the lead vehicle activated its turn signal and pulled to the side of the roadway near the third turnaround while the test vehicle continued to drive past it, turned around at the fourth turnaround, and proceeded back up the road. Once the test vehicle passed out of sight of the lead vehicle, the experimenter in the lead vehicle placed the obstacle in the roadway, drove to the second turnaround and waited for the test vehicle. When the test vehicle arrived back at the second turnaround, the lead vehicle pulled out and drove ahead of it. Once the vehicles reached a predetermined landmark approximately 60 meters from the box, the rear-seat experimenter and lead vehicle initiated opposite evasive maneuvers (e.g., test vehicle braked and lead vehicle swerved or test vehicle swerved and lead vehicle braked) in response to a cardboard box in the road. After completing the test-track portion of study, the participant was thanked for their time and provided with compensation via a MasterCard preloaded with $100.

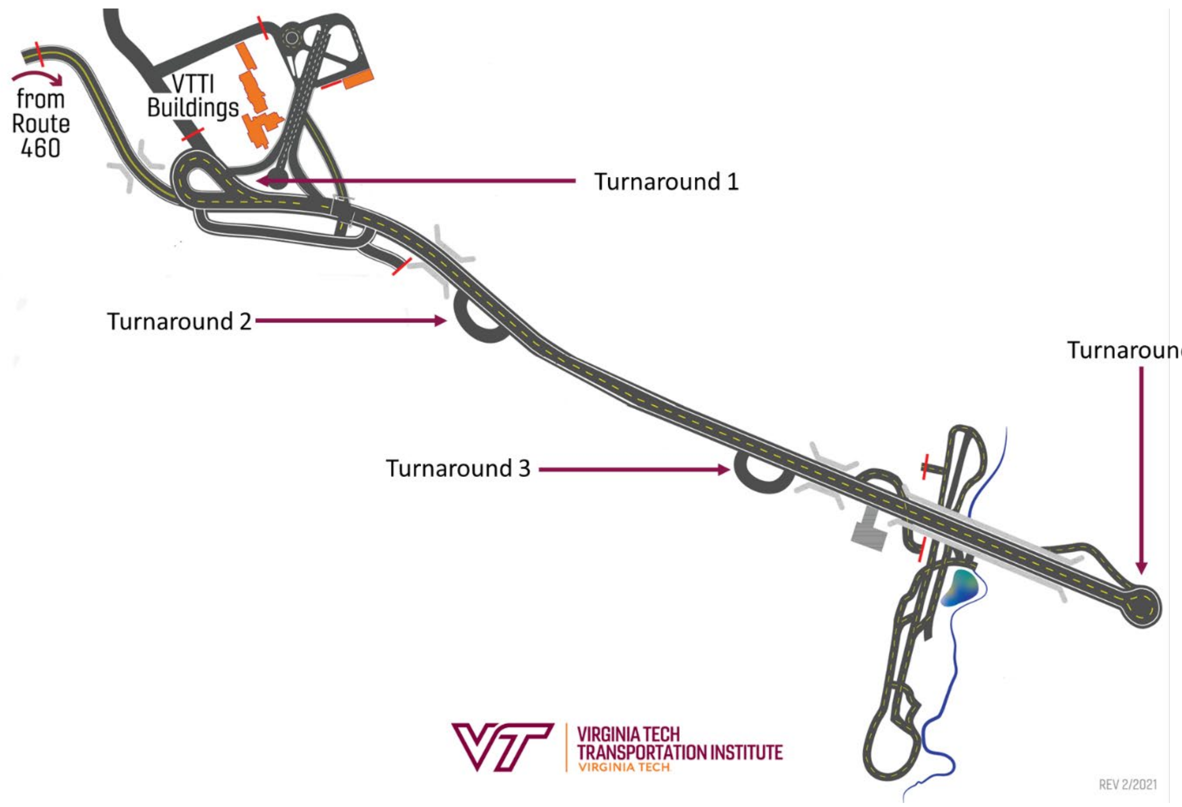


Figure 4. Map. Overview of Smart Road.

Results

Data Annotation and Analysis

Vehicle data from 36 participants were collected and analyzed. For each participant, timestamped data included:

- Acceleration, speed, orientation, latitude and longitude coordinates
- Rear driver (experimenter): brake torque, steering torque, steering angle, throttle percentage
- Front driver (participant): brake torque, steering torque, steering angle, throttle percentage
- Intervention flag – when the automated system was cancelled with a button or brake

In addition, behavioral data from 34 participants were obtained via annotation of the video data. Two of the participants were excluded from analysis because a DAS error made their video data unavailable. The annotation was performed by trained VTTI data reductionists.

Eye-glance data were captured using the DAS face camera (see Figure 5 below). The location of each glance was measured frame-by-frame by trained VTTI data reductionists (see Appendix A: Eyeglance Locations) and categorized for the glance direction before and after the event using the origin method (ISO, 2020). In addition, the participant's steering wheel and brake pedal behavior (i.e., whether the participant reached toward the steering wheel, had their hands on the wheel) was measured by annotating the over-the-shoulder and foot camera view videos (see Appendix B: Annotation Definitions).

Figure 5. Photo. Example of DAS face camera view.

Data were collected from event start to event end. Event start was defined as when the test vehicle reached a predetermined landmark ~106 meters before the object placed in the roadway. Event end was defined as when the vehicle velocity reached 0 mph for the braking maneuvers or when the front of the vehicle was even with the object, as determined by the front video view, for the swerving maneuvers. The start of the experimenter-initiated braking or steering was identified through the rear driver brake torque and steering torque variables.

The evasive maneuver data was analyzed in the R statistical computing and graphics environment. JMP Pro 16 was used to perform the chi-square tests of independence.

Interventions

A chi-square test of independence showed that there was no significant association between maneuver type and the number of participants who chose to intervene during the evasive maneuver, $\chi^2(1, N = 34) = 0.007$, $p = 0.93$. Only two participants chose to intervene and deactivate the system during the evasive maneuver, one participant each in the swerve and brake conditions. Both participants used the brakes to cancel, and moved their hands to the steering wheel when they deactivated the system. Both participants did not have their hands on the wheel prior to the event.

Reaching for Controls

Steering Wheel

A chi-square test of independence showed that there was no significant association between maneuver type and the participants reaching toward the steering wheel, $\chi^2(1, N = 34) = 0.37$, $p = 0.55$. Thirty-seven percent of the participants in the brake condition ($n = 16$) and 27% of the participants in the swerve condition ($n = 18$) reached for the steering wheel during the maneuver (see Figure 6).

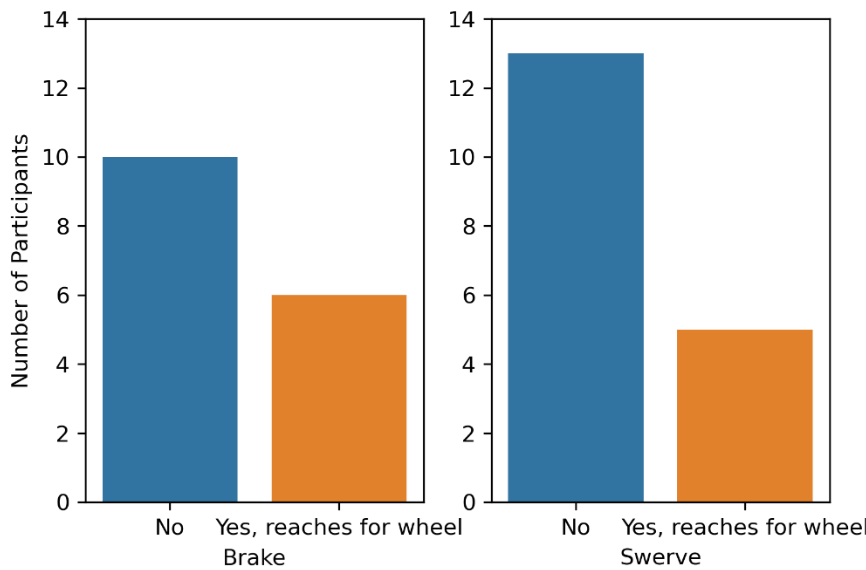


Figure 6. Graph. Number of participants reaching for steering wheel by evasive maneuver condition.

Brake

A chi-square test of independence showed that there was no significant association between maneuver type and the participants reaching their foot toward the brake pedal $\chi^2(1, N = 34) = 0.43$, $p = 0.51$. Specifically, 14% of the participants in the brake condition ($n = 16$) and 22% of the participants in the swerve condition reached for the brake (see Figure 7).

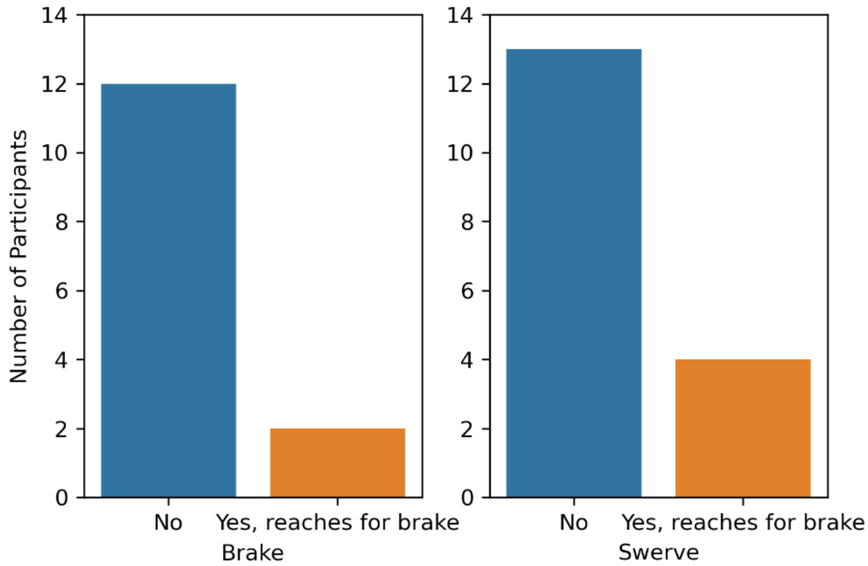


Figure 7. Graph. Number of participants reaching for brake by evasive maneuver condition.

Cancel Button

No participants in either the brake or swerve condition used the cancel button or reached for the cancel button.[1]

Intervention Capability

The number of participants who were capable of intervening was defined as the number of participants who had their hands on the wheel or foot on the brake before the maneuver or who reached to the wheel or brake during maneuver. In total, 13 out of 34 participants were classified as ready to intervene, with six participants in the braking condition and seven in the swerve condition (see Figure 8).

[1] It should be noted that the brake cancellation was emphasized in the initial description of the system to the participants. Therefore, this observation may be due to this initial description.

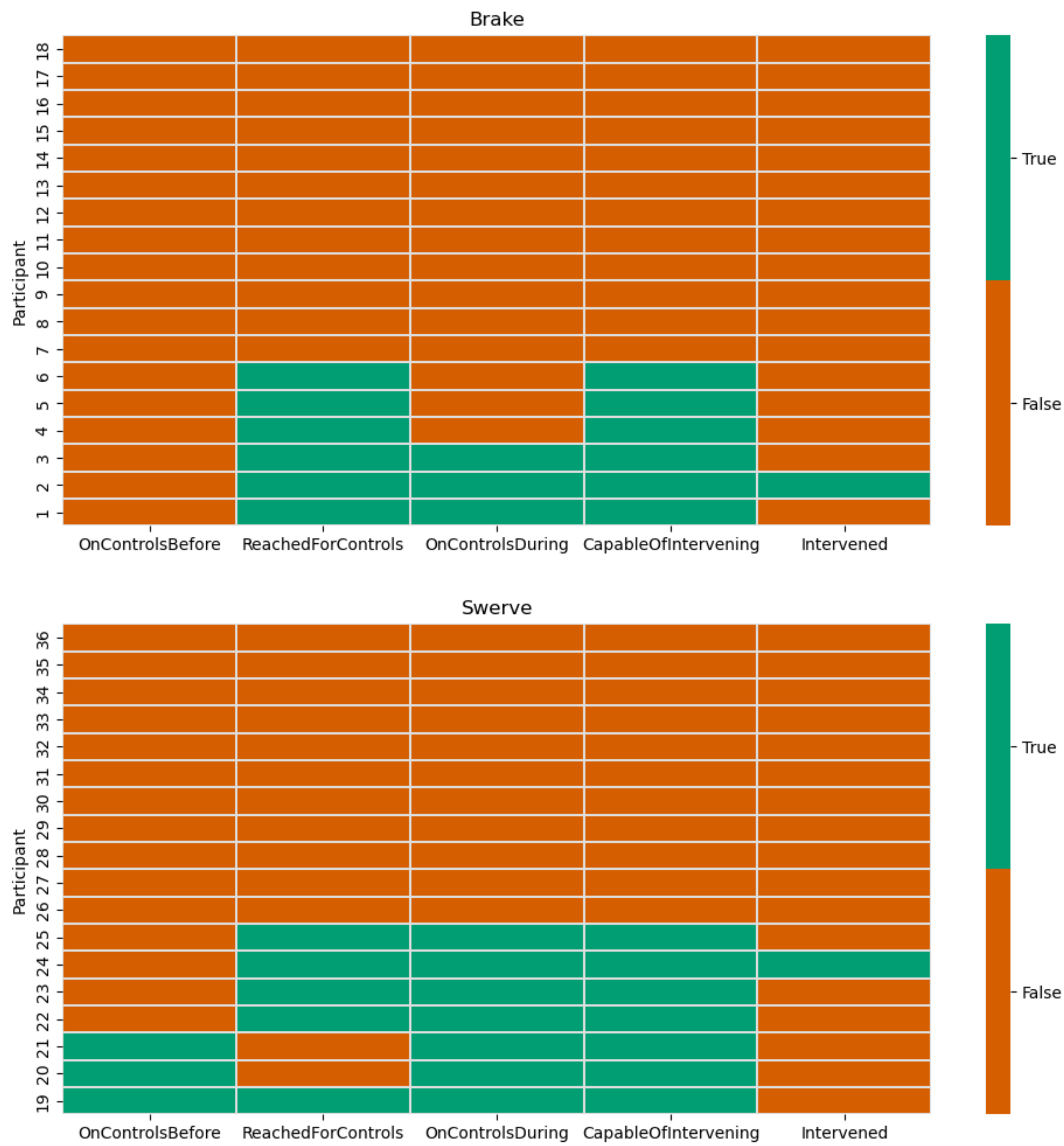


Figure 8. Chart. Participant intervention capability by evasive maneuver condition.

Glance Data

As illustrated in Figure 9, participants in both evasive maneuver conditions primarily looked toward the obstacle and the lead vehicle. This is reflected in the total time spent looking forward in the brake condition (3.6 s; SD = 2.8) and the total time spent looking forward (1.2 s; SD = 1.1) and at the right windshield (1.2 s; SD = 1.4) in the swerving condition.

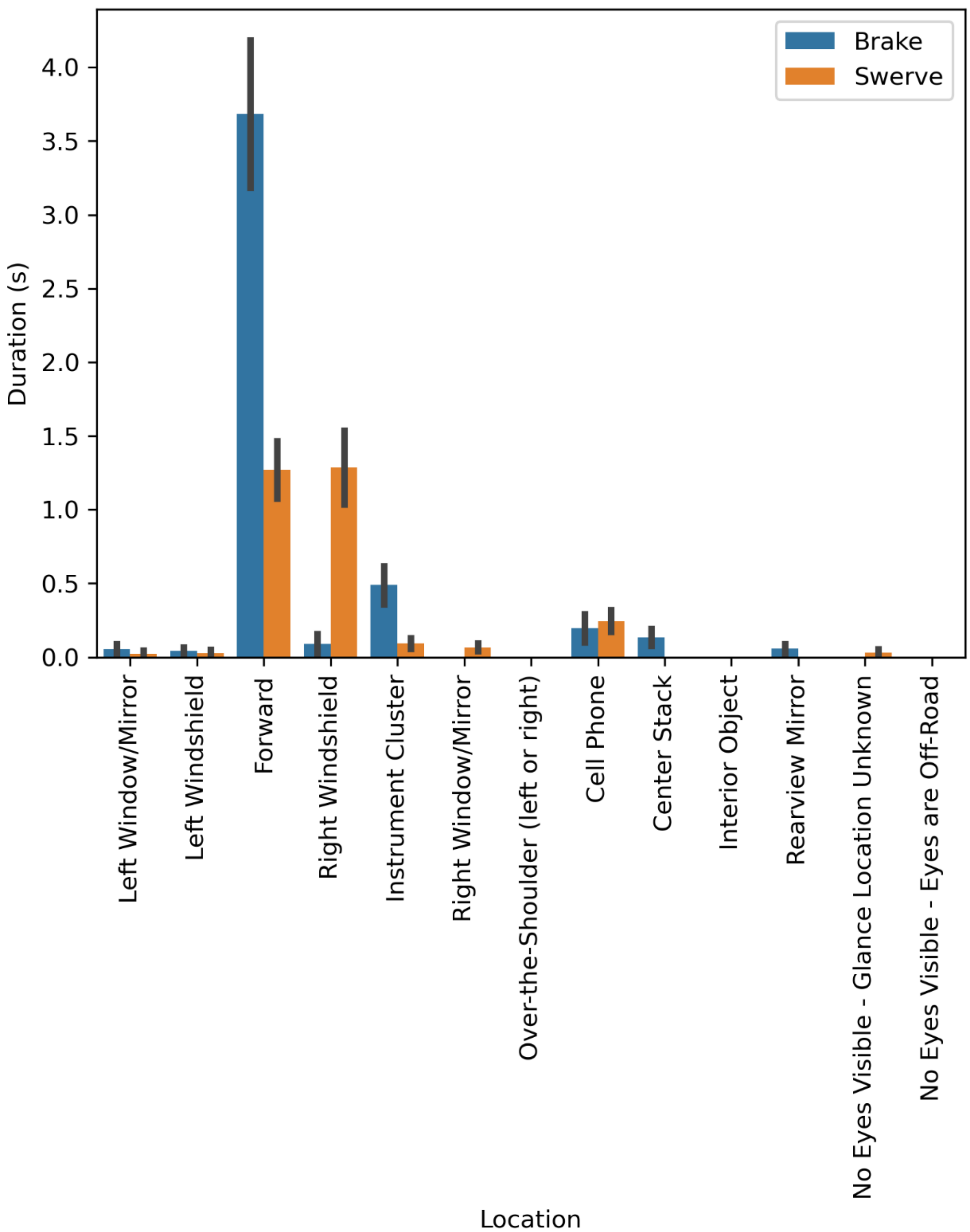


Figure 9. Chart. Mean total glance duration by evasive maneuver condition.

This pattern is further illustrated in Figure 10, which shows the mean glance duration to the areas of interest before and after the maneuver occurred for each maneuver type. Participants in the brake condition had a mean increase of 4.9 seconds spent looking to the forward roadway after the maneuver (6.3 s; SD = 1.1 s) compared to before (1.3 s; SD = 0.7). Participants in the swerve condition had a mean increase of 2.2 seconds spent looking to the right windshield after the maneuver (2.5 s; SD = 1.1) compared to before (0.3 s; SD = 0.3) and 1.1 seconds spent looking to the forward roadway after the maneuver (2.0 s; SD = 1.1) compared to before (0.8 s; SD = 0.4).

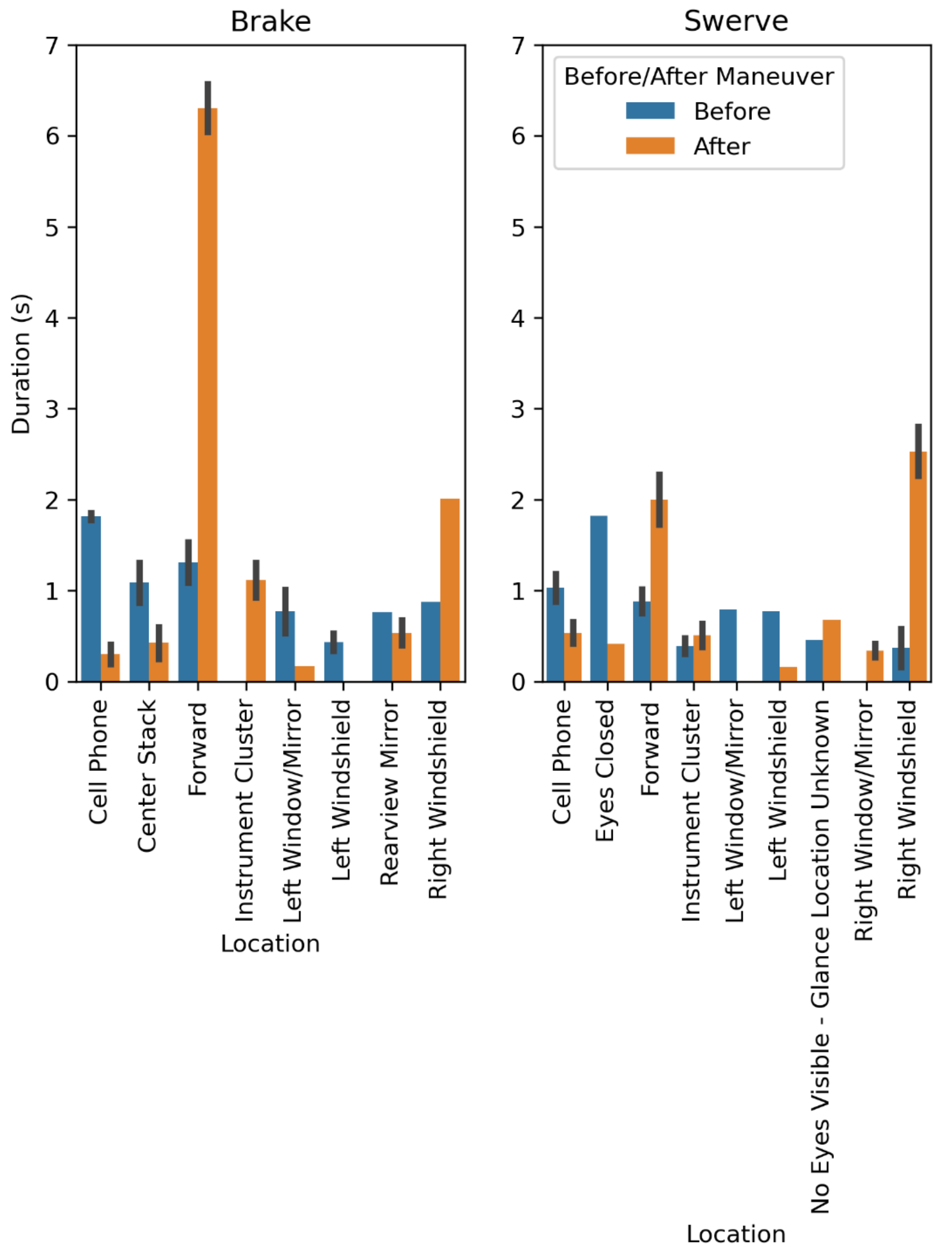


Figure 10. Chart. Mean glance duration before and after maneuver by evasive maneuver condition.

On an individual level, 61% of participants (22/36) were looking toward the forward-driving environment (i.e., glancing to forward, left windshield, or right windshield locations) immediately prior to the beginning of the evasive maneuver, with 11 participants in the brake condition and 11 participants in the swerve condition. Conversely, 33% of participants (12/26) were looking away from the forward-driving environment (i.e., not glancing to forward, left windshield, or right windshield locations) immediately prior to the beginning of the evasive maneuver, with five participants in the brake condition and seven participants in the swerve condition. Thirty-six percent of participants (8/22) who were looking forward prior to the maneuver reached for the wheel (5 brake, 3 swerve), and two of these participants intervened. Twenty-five percent of participants (3/12) were looking away from the forward driving environment reached for the wheel (1 braking, 2 swerving), and 0 of these participants intervened.

Discussion

Overall, the results from this study show that most drivers do not prepare to intervene or intervene in response to a CAD system-initiated evasive maneuver. Indeed, only 11 participants reached toward the vehicle controls (i.e., prepared to intervene) and, of the few participants that did reach for the controls, only two chose to intervene. Driver preparation to intervene, as measured by reaching toward the steering wheel, brake pedal, or cancel button, in response to these maneuvers was similar regardless of whether the vehicle braked or swerved to execute the evasive maneuver. Furthermore, the type of evasive maneuver did not appear to affect the driver's choice to intervene and take control of the vehicle during CAD system-initiated maneuvers. Importantly, the drivers who intervened did so safely.

Interestingly, most drivers were monitoring the roadway (i.e., looking toward the forward roadway, left windshield, or right windshield locations) immediately prior to the beginning of evasive maneuver. In other words, drivers were looking toward the roadway and elected not to intervene or prepare to intervene. The drivers' glance behavior also showed that drivers tended to appropriately attend to the evasive maneuver. Specifically, drivers in the brake condition shifted their visual attention to the forward roadway (i.e., the swerving lead vehicle and box in the lane of travel) in response to the maneuver, while drivers in the swerve condition shifted their visual attention to the forward roadway and the right windshield (i.e., toward the braking lead vehicle and box in the lateral lane).

Taken together, these results suggest that after just a couple of hours of driving on public roads, most participants trusted the system enough to not intervene during a maneuver in response to a sudden-reveal road hazard. The participants who did intervene were safe while doing so. It is important to note, though, that the maneuver, while sudden, was conducted at about 0.3 g and not close to the limit of vehicle handling. No differences were found between driver responses in the swerve versus the brake conditions, other than the direction of glances (aimed at the road hazard)

Conclusions and Recommendations

The purpose of this study was to investigate how drivers would respond to an evasive maneuver scenario when in CAD and how the response would differ when the event was a braking or swerving maneuver. This study found that most drivers visually attend to the event but do not prepare to intervene or intervene in response to such evasive maneuvers. The findings suggest that most drivers trust a CAD enough after a short period of exposure to not intervene. Importantly, when drivers do choose to intervene, they do so safely. Overall, these results show that an acceleration force of around 0.3 g is appropriate for CAD system-initiated evasive maneuvers as it does not lead to unsafe driver interventions. Given the ability of CAD-equipped vehicles to operate in PAD and manual modes and the findings from Pipkorn et al. (2021) and Victor et al. (2018) suggesting that drivers do not intervene to avoid obstacles when in PAD, future research should consider the impact of experiencing CAD system-initiated maneuvers on participants' intervention capability and decision-making during subsequent obstacle avoidance scenarios when in PAD. Future research should also consider driver fatigue, which has a well-established impact on a driver's ability to safely drive. Previous research has found that driving automation systems induce drive fatigue faster compared to manual driving (Schömig et al., 2015). In the context of CAD, Vogelpohl et al. (2019) found that fatigue increased driver takeover time and concluded that driver fatigue could be a serious hazard during takeover scenarios. Future research should investigate the impact of driver fatigue on evasive maneuver responses.

Additional Products

Education and Workforce Development Products

The student supported by this work will prepare an impact statement summarizing the learning opportunities and skills gained through their involvement in the project. In addition, the planned EWD products are to create a module about the research area, the study methodology, and the results and findings.

Technology Transfer Products

Two technology transfer products are planned to be produced as an outcome of this work. First, a final briefing will be given the industry partner. Second, a journal article will be published in a peer-reviewed journal. The final briefing was given to the industry partner on June 14, 2022. The research team is currently working on the journal article submission.

Data Products

The dataset used for analysis will be uploaded to the VTTI Dataverse.

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Appendix/Appendices

Appendix A: Eyeglance Locations

Origin Eyeglance Location Definitions and Codes

Glance: a glance is defined as the location a driver is fixated on for at least 2 consecutive video frames.

A glance that is coded following the origin eyeglance protocol begins the first frame that the eyes fixate on a location and ends the last frame before the eyes have fixated on a new location. Transitions are included in the origin glance location. For example, if the subject is looking forward and then transitions to right windshield, the transition would be included in the forward glance. Right windshield wouldn't begin until the first frame that the subject's eyes are fixated on right windshield.

Normal blinks (less than 1/3 of a second) are not recorded in eyeglance. Glance location should be coded straight through blinks. NOTE: Blinks are often mistaken for glances to the instrument cluster (speedometer, etc.). Watching the video at full speed is often helpful in telling the difference.

	Glance Location	Standardized Definitions	Additional Information and Tips
F	Forward (Center)	Any glance out the forward windshield directed towards the direction of the vehicle's travel. Note that when the vehicle is turning, these glances may not be directed directly forward but towards the vehicle's heading. Count these as forward glances. NOTE that when the vehicle is driving in reverse, forward will be out the back window (see "Special Cases").	For identifying when the driver is turning, keep an eye on the "Hands Video", and see when the wheel begins to turn. Once they have begun engaging the turn, any glances in the direction of the turn should be coded as "Forward" (see Appendix C). "Forward" glances do not specifically refer to the forward windshield. Unlike other glance categories, "Forward" should be used when the driver is looking in the vehicle direction of travel, including when they are turning or driving in reverse. When there is a passenger present, the driver will sometimes turn their head towards them to show they are listening, but their eyes remain forward. Eyeglance reduction should focus on the direction of their eyes, not the direction of their head. Therefore, this will be coded as "Forward".
M	Rearview Mirror	Any glance to the rear view mirror or equipment located around it. This glance generally involves movement of the eyes to the right and up to the mirror. This includes glances that may be made to the rearview mirror in order to look at or interact with back seat passengers.	For most studies, the camera has been placed right behind the rearview mirror. Therefore, any glance directly at the camera will be a "Rearview Mirror" glance. Depending on the height of the driver, this glance might include a slight upward angle (see Appendix C). *If the camera is mounted somewhere else, that information will be provided in the project-specific protocol.*

	Glance Location	Standardized Definitions	Additional Information and Tips
			When there are passengers in the back seat, the driver may interact with them by looking at the rearview mirror. Code these as "Rearview Mirror" glances, and not as "Passenger" glances. If the driver actually turns physically to look at a passenger in the backseat, then it would be coded as "Passenger".
D	Left Windshield	Any glance out the forward windshield where the driver appears to be looking specifically out the left margin of the windshield (e.g., as if scanning for traffic before turning or glancing at oncoming or adjacent traffic). This glance location includes anytime the driver is looking out the windshield, but clearly not in the direction of travel (e.g., at road signs or buildings).	
G	Right Windshield	Any glance out the forward windshield where the driver appears to be looking specifically out the right side of the windshield (e.g., as if scanning for traffic before turning, at a vehicle ahead in an adjacent lane, or reading a road sign). This glance location includes anytime the driver is looking out the windshield, but clearly not in the direction of travel (e.g., at road signs or buildings).	
L	Left Window/ Mirror	Any glance to the left side mirror or window.	For most studies, the side mirror and side window glances have been merged into a single category.
R	Right Window/ Mirror	Any glance to the right side mirror or window	For most studies, the side mirror and side window glances have been merged into a single category.
S	Over-The-Shoulder (left or right)	Any glance over either of the participant's shoulders. In general, this will require the eyes to pass the B-pillar. If over the left shoulder, the eyes may not be visible, but this glance location can be inferred from context. NOTE: If it is clear from context that an over-the-shoulder glance is being made NOT to check a blind spot but instead to interact with a rear seat passenger (e.g., food/toy is being handed back), then code the glance as Passenger. If context cannot be known with a high level of certainty, then code as Over-the-Shoulder.	B-Pillar is a vertical part of the vehicle frame providing support and separating the front doors from the rear doors of the vehicle (see Appendix B). A common example is when the driver checks their blind spot before merging or changing lanes. Remember to take direction of travel into consideration. If they are looking over their shoulder and the vehicle is moving backwards then the glance would count as Forward (see Appendix C).
A	Passenger	Any glance to a passenger, whether in front seat or rear seat of vehicle. Context is required (e.g., they're talking, or handing something) in order to determine this in some situations.	A way to figure out if there is a passenger in the vehicle is paying close attention to the "Hands Video". Usually the arm or leg of a passenger can be seen at some point in the file.

	Glance Location	Standardized Definitions	Additional Information and Tips
		NOTE: This does NOT include glances made to rear seat passenger via the rearview mirror. Such glances should be coded as "Rearview Mirror". NOTE: If the driver is looking at something that the passenger is handing to them, code the eyeglance as Passenger, until the object is fully in the driver's hand, then code as Interior Object (or Cell Phone or Portable Media device, if applicable). If the driver is looking at something that the passenger is holding (but never hands to the driver), code as passenger glance (not interior object).	If passenger presence is not obvious, the cabin view may also be utilized. Use "Variables" section of Hawkeye and enter "cabin" into the search bar and open the "Cabin" variable under the "Snapshots" section. Not all collections/vehicles have a Cabin snapshot variable available. "Right Window" glances and "Passenger" glances can be hard to differentiate. A good indication for this is be paying attention to the driver's mouth to see if they are talking, laughing, or nodding. Watch the video at full speed to gain context. If the passenger is holding an object and showing it to the driver, code as a "Passenger" glance. Once the passenger hands something to the driver and the driver glance at it in their own hand, then code "Interior Object", "Cell Phone", or "Portable Media Device".
I	Instrument Cluster	Any glance to the instrument cluster underneath the dashboard. This includes glances to the speedometer, control stalks, and steering wheel.	Glances to the speedometer are often mistaken for blinks, because it usually appears as a sudden downward glance. It is a good idea to play the video at full speed to gain better context for differentiation. Glances towards the steering wheel itself also go under this category (including glances associated with the use of steering wheel buttons and controls). Also includes gear shift, when located here.
C	Center Stack	Any glance to the vehicle's center stack (vertical). Not to be confused with center console (cup holder area between driver and passenger), which is discussed under "Interior Object".	"Center Stack" typically includes things like GPS, stereo, and climate control (see Appendix B).
P	Cell Phone (electronic communications device)	Any glance at a cell phone or other electronic communications device (e.g., Blackberry), no matter where it is located. This includes glances to cell phone related equipment (e.g., battery chargers).	
H	Portable Media Device	Any glance at a Portable Media Device (e.g., mp3 player, iPod, other personal music or video device), no matter where it is located. Does not include cell phones with video or music capability (coded as Cell Phone) or any manufacturer installed devices (which would most	If unable to differentiate between "Cell Phone" and "Portable Media Device" glances, it is best to assume it is a "Cell Phone" and leave a note in the spreadsheet with the applicable timestamps.

	Glance Location	Standardized Definitions	Additional Information and Tips
		likely be coded as Center Stack if installed in that location).	
W	Interior Object	Any glance to an identifiable object in the vehicle other than a cell phone. - These objects include personal items brought in by the participant (e.g., purse, food, papers) - Any part of their body that may look at (e.g., hand, ends of hair) - Electronic devices other than cell phones (e.g., laptop, PDA) - OEM installed devices that don't fall into other categories (e.g., door lock, window and seat controls). - Glances to the center console (cup holder area between passenger seat and driver seat) will also be included in this category. If the gear shift is located in the center console, glances towards it would also be coded as "Interior Object". The object does not need to be in the camera view for a specific frame to be coded with this category. If it is clear from surrounding video that the participant is looking at the object, this category may be used. This category can be used regardless of whether the participant's hands are/aren't visible. NOTE: If the driver is looking at something that the passenger is handing to them, code the eyeglance as Passenger, until the object is fully in the driver's hand, then code as Interior Object (or Cell Phone or Portable Media device, if applicable). If the driver is looking at something that the passenger is holding (but never hands to the driver), code as passenger glance (not interior object). Individual studies may ask reductionists to identify objects in logs or drop down menus, or may categorize specific objects as Systems of Interest.	"Interior Object" is coded for glances towards the center console or towards items in the center console. Remember, this is the area that starts from the bottom of the "Center Stack" and runs between the driver and the passenger seats where the cup holders are (See Appendix B). The gear shift is often located in this area as well. If a phone is located in this area, it will be coded as "Cell Phone", and not as "Interior Object". This includes cell phone accessories as well, such as chargers, headphones, and the like. All interior controls such as the window buttons, sun visors, and the ceiling lights will be coded as "Interior Object". Sometimes glances towards the window controls on the armrest are mistaken for side mirror glances. Paying attention to the "Hands Video" will provide better context. Sitting idly at a stoplight and looking down into their hands or nails will also be coded as "Interior Object".
Z	Eyes Closed	Any time that BOTH the participant's eyes are closed outside of normal blinking (e.g., the subject is falling asleep or rubbing eyes). As a rule of thumb, if the eyes are closed for five or more frames (1/3 a second) during a slow blink, code it as Eyes Closed. Otherwise, code it as the glance location present before the eyes closed, or	Normal blinks are typically not coded during eyeglance analysis, unless specified to do so by the project-specific protocol. A normal blink is anything up to 5 frames. Anything more than that should be coded as "Eyes Closed". A good tip for differentiating blinks is playing the video at full speed.

	Glance Location	Standardized Definitions	Additional Information and Tips
		as part of a transition if the eyes are fixated on a new location upon opening. If one eye remains open, code the location according to the open eye. If only one eye is visible, code according to the visible eye.	Other common things that fall into the Eyes Closed category are sneezes or the driver actually falling asleep provided that the 5 frame minimum duration criterion is met.
O	Other	Any glance that cannot be categorized using the above codes. Prior to using this category, please inform a supervisor for appropriate follow-up.	Some pre-approved uses of the "Other" option are listed below: - When the driver is looking forward, and then looks straight up at the sky as if watching a plane fly by. - When the driver is tilting head back to drink and the eyes leave the forward glance but do not really focus on anything at all. - Looking distinctly up at a traffic signal - Looking distinctly up at a highway or road sign - When a driver rolls their eyes "Other" should be used when the driver's eyes leave the Forward position but cannot be considered a glance to any other position and are also not a transition.
E	No Eyes Visible – Glance Location Unknown	Unable to complete glance analysis due to an inability to see the driver's eyes/face. Video data is present, but the driver's eyes and face are not visible due to an obstruction (e.g. visor, hand,), or due to glare. <u>Use this category when there is no way to tell whether the participant's eyes are on or off the road</u>. This is the default and most often used "unknown" option, but there may be times with the "off road" option listed below may be appropriate. NOTE: this sometimes occurs for 1-2 frames at a time. If the glance location is the same before and after this occurs and the period is only 1-2 frames long, then code through this period as the glance location present before and after. If the "no eyes visible" period is longer than 2 frames OR it occurs during a transition, use the "no eyes visible" option.	"Glance Location Unknown" can be caused by several things. - The rim of a baseball cap when the driver's head is angled down. - When the sun may be shining directly on the driver's face, and due to the excessive glare the eyes and/or face cannot be seen. - When the driver is going under a bridge or through a tunnel and the shadow falls on their face and the eyes cannot be seen.
T	No Eyes Visible – Eyes Are Off-Road	Unable to enter in specific glance location due to an inability to see the driver's eyes/face. However, it is clear that the participant is not looking at the roadway.	"Eyes Are Off-Road" can be caused by several things. - The sun visor blocking a large portion of the face. - Hands blocking the face or camera view.

	Glance Location	Standardized Definitions	Additional Information and Tips
		Video is present, but the driver's eyes and face are not visible due to an obstruction (e.g. visor, hand), head position, or due to glare. Use this category when the eyes are not visible, the analyst cannot be sure what the participant is looking at, but it is obvious that the eyes are not on the roadway. NOTE: this sometimes occurs for 1-2 frames at a time. If the glance location is the same before and after this occurs and the period is only 1-2 frames long, then code through this period as the glance location present before and after. If the "no eyes visible" period is longer than 2 frames OR it occurs during a transition, use the "no eyes visible" option.	Looking in the vehicle at an unknown object in the backseat.
N	No Driver	The driver is not in the driver seat during the indicated video frame. The vehicle must be in park and the driver must be out of the driver seat (or in the process of getting out or in) to use this category.	-
V	No Video	Unable to complete glance analysis because the face video view is temporarily unavailable. NOTE: this sometimes occurs for 1-2 frames at a time, and a "video not available" message may appear. If the glance location is the same before and after this occurs and the period is only 1-2 frames long, then code through this period as the glance location present before and after. If the "video not available" period is longer than 2 frames OR it occurs during a transition, use the "No Video" option.	

Appendix B: Annotation Definitions

Hand Position

1. LeftHandBefore. **Is the left hand on the wheel just before the braking/steering maneuver?**
    a. Yes, gripping
    b. Yes, resting
    c. Yes, grip unknown
    d. No, off wheel
    e. Unknown if on or off

2. RightHandBefore: **Is the right hand on the wheel just before the braking/steering maneuver?**
    a. Yes, gripping
    b. Yes, resting
    c. Yes, grip unknown
    d. No, off wheel
    e. Unknown if on or off

3. ReachForWheel. **Does the subject driver move an off-wheel hand/hands toward the wheel during the braking/steering maneuver?** (This includes when a hand is added to the wheel or when a hand moves towards the wheel but does not actually touch it.)
    a. Yes, reaches for wheel
    b. No
    c. Unable to determine

4. ReachForWheelTime. **If Yes above, record the timestamp for when the participant started to reach for wheel.**
    a. Textbox for timestamp. Leave blank if No or Unable to determine above.

5. LeftHandAfter. **Is the left hand on the wheel during the response to the braking/steering maneuver?** (e.g., Did they add a hand to help respond?) Use the highest number of hands observed during the response. The response covers the time period starting with the initiation of the braking or steering maneuver through the end of the epoch.
    a. Yes, gripping
    b. Yes, resting
    c. Yes, grip unknown
    d. No, off wheel
    e. Unknown if on or off

6. RightHandAfter. **Is the right hand on the wheel during the response to the braking/steering maneuver?** (e.g., Did they add a hand to help respond?) Use the highest number of hands observed during the response. The response covers the time

period starting with the initiation of the braking or steering maneuver through the end of the epoch.

a. Yes, gripping
b. Yes, resting
c. Yes, grip unknown
d. No, off wheel
e. Unknown if on or off

7. GripChange. **Does grip type/strength of either hand appear to change during the response?**
    a. Yes, right hand grip change only
    b. Yes, left hand grip change only
    c. Yes, both hands grip change
    d. No
    e. Unable to determine
    f. No hands on wheel prior

Feet Position

8. FeetOnBrakeBefore. **How many feet are on the brake just before the braking/steering is initiated?**
    a. None
    b. Left foot only
    c. Right foot only
    d. Both feet
    e. Unable to determine

9. ReachForBrake. **Does the subject driver move an off-brake foot toward the brake during the response to the braking/steering maneuver?** (This includes when a foot is added to the brake or when a foot moves towards the wheel but does not actually touch it.)
    a. Yes, reaches for brake
    b. No
    c. Unable to determine

10. ReachForBrakeTime. **If Yes above, record the timestamp for when the participant started to reach for brake.**
    a. Textbox for timestamp. Leave blank if No or Unable to determine above.

11. FeetOnBrakeDuring. **How many feet are on the brake during the response to the braking/steering maneuver?** (e.g., Did they add a foot to help respond?) Use the highest number of feet observed during the response. The response covers the time period starting with the initiation of the braking or steering maneuver through the end of the epoch.
    a. None
    b. Left foot only

c. Right foot only
d. Both feet
e. Unable to determine

Vehicle Control Input

12. ReachForCancelButton. **Does the subject driver reach toward the cancel button on the steering wheel during the response?**

a. Yes, reaches for button
b. No
c. Unable to determine