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Driver Visual Behavior While Using Adaptive Cruise Control on Commercial Motor Vehicles

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EXECUTIVE SUMMARY

This study compared whether drivers spent less time looking at the roadway while cruise control was engaged. The trucks in the study were equipped with commercially available systems that provide adaptive cruise control (ACC), which uses radar to regulate headway in addition to speed when following a lead vehicle.

Three metrics were analyzed to assess drivers' eye-glance behavior during periods of traditional cruise control usage, full ACC usage, and manual car-following: total eyes-off-road time (TEORT), durations of glances off-road, and number of glances off-road.

TEORT during Cruise Control Usage and Car-Following Conditions

Based on TEORT, participating truck drivers spent *less* time looking away from the roadway when following a lead vehicle and *more* time looking away from the roadway when cruise control was active. Most importantly, participating truck drivers on average spent *more* time looking away from the roadway while ACC was engaged compared to when manually following a vehicle. These differences in how long participating truck drivers looked away from the roadway can be due to glancing away more frequently, glancing away for longer durations, or a combination of both.

Durations of Glances Off-Road During Cruise Control Usage and Car-Following Conditions

The average duration of glances appeared to contribute to the differences in TEORT for both cruise control usage and car-following scenarios. On average, participating truck drivers had *shorter* off-road glances when following a lead vehicle and *longer* off-road glances when using cruise control. Most importantly, participating truck drivers had longer average off-road glances when using ACC compared to when manually following a lead vehicle.

Number of Glances Off-Road During Cruise Control Usage and Car-Following Conditions

The average number of glances off-road appeared to contribute to the differences in TEORT for car-following scenarios but was not related to cruise control usage. On average, participating truck drivers looked away from the roadway *less* frequently when following a lead vehicle. However, there was no difference in the number of glances off-road when cruise control was engaged compared to manual driving. Most importantly, there was no difference in the quantity of glances off-road when drivers were using ACC and when they were manually following a lead vehicle.

Conclusion

Drivers were observed to spend less time looking at the forward roadway when cruise control was engaged. Drivers were observed to spend less time looking at the roadway when ACC was engaged compared to when manually following a lead vehicle. This difference appears to be due to the truck drivers taking *longer* glances away from the roadway rather than taking more frequent glances away from the roadway. These differences are important for system designers to consider, as drivers are expected to maintain their attention on the roadway while using driver assistance technologies.

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LIST OF ABBREVIATIONS AND SYMBOLS

ACC	adaptive cruise control
ADAS	advanced driver assistance systems
CAS	crash avoidance system
CMV	commercial motor vehicle
DAS	data acquisition system
HMI	human-machine interface
NDS	naturalistic driving study
NSTSCE	National Surface Transportation Safety Center for Excellence
NHTSA	National Highway Traffic Safety Administration
TEORT	total eyes-off-road time
VTTI	Virginia Tech Transportation Institute

CHAPTER 1. INTRODUCTION

In 2013, a new generation of collision avoidance technologies was introduced to heavy commercial vehicles. The new systems, which include the Bendix® Wingman® Advanced™ and Meritor WABCO OnGuard™, offer adaptive cruise control (ACC), which partially automates vehicle longitudinal control. In addition to maintaining a preset speed, as with traditional cruise control, ACC can adjust speed to maintain the headway between the truck and a lead vehicle. Typically, ACC is part of a larger crash avoidance system (CAS) that can automatically de-throttle the truck or engage the brakes in response to a change in headway.

ACC, like many other advanced driver assistance systems (ADAS), can potentially improve safety by providing information to the driver about lead vehicles and automatically intervening to prevent conflicts. In the case of ACC, a human-machine interface (HMI) provides the truck driver with information about the speed or headway of a lead vehicle, if present. However, ACC is not meant to replace driver awareness of the surroundings or driver responses to roadway conditions.(1,2) While ACC could help to mitigate an incident if a driver does not respond properly, the driver is expected to remain alert and engaged with the driving task.

ACC manufacturers provide instructions specifying the driver's essential role in the system. However, it is not well understood if drivers maintain the same level of engagement when ACC is used as they do when driving manually. From 2012 to 2016, the Virginia Tech Transportation Institute (VTTI) conducted a naturalistic driving study (NDS) that collected 87,000 hours and 2.9 million miles of naturalistic driving data from 150 heavy commercial vehicles equipped with the Wingman® Advanced™ or OnGuard™ technologies.(3) The NDS was part of a large project to evaluate the reliability of crash avoidance technology and observe how the technology operated in the real world. VTTI recorded video of the driver and forward roadway, vehicle network data, and parametric data whenever the trucks were in motion. The data from the vehicle network included data on whether cruise control was engaged, and whether the system was in adaptive mode (regulating headway to a lead vehicle) or traditional mode (regulating speed). The vehicle network data also included the speed and headways of lead vehicles detected by the radar even when cruise control was not engaged. This data set provides a unique opportunity to investigate driver visual behaviors across different levels of technology engagement and traffic conditions. This report will address that question by examining a sample of driving epochs from the data set and characterizing the visual behaviors of the drivers.

PURPOSE

The scope of this study was to investigate driver visual behavior across two conditions. The first condition is whether the driver was following a lead vehicle. The second condition is whether the driver had cruise control engaged. These two conditions interact with the ACC feature that was equipped on the drivers' vehicles. In order to investigate differences in driver visual behaviors, three visual metrics were chosen:

- Total eyes-off-road time (TEORT)
- Duration of glances off-road
- Quantity of glances off-road

Each of these metrics is related to criteria used by the National Highway Traffic Safety Administration (NHTSA) in its visual-manual driver distraction guidelines.[4] These guidelines are intended to help equipment manufacturers understand if in-vehicle tasks, interfaces, or technologies could lead to distraction. ACC usage is not a visual-manual task in the traditional sense, and therefore the criteria that are set forth in the guidelines may not be directly applicable. However, the metrics laid out in the criteria may still be valuable for understanding visual behavior in conjunction with ACC usage. Specifically, the metrics can give some insight into how drivers attend to the roadway when the technology is engaged.

TEORT between Cruise Control Usage and Car-Following Conditions

TEORT represents the total potential exposure to an incident that could occur in front of the vehicle while the driver is looking away from the forward roadway. It is also related to the potential for cognitive distraction, with greater TEORT being associated with higher levels of uncertainty about conditions in front of the vehicle.[5]

Durations of Glances Off-Road Between Cruise Control Usage and Car-Following Conditions

Durations of glances off-road represent how long the drivers' eyes dwell on each off-road location. Long glances off-road can increase risk by delaying a driver's response to an incident or reducing a driver's certainty about roadway conditions when responding.

Number of Glances Off-Road Between Cruise Control Usage and Car-Following Conditions

The quantity and frequency of off-road glances represent how often drivers disengage from the forward roadway. Glances off-road can include some tasks that are part of normal driving, such as checking mirrors or gauges, but can also include potentially distracting glances. This metric combined with the duration of glances can help to explain whether changes in TEORT are due to drivers disengaging from the forward roadway more frequently, for longer periods of time, or a combination of both.

CHAPTER 2. METHODS

From 2012 to 2016, VTTI conducted an NDS of commercial motor vehicles (CMVs) equipped with the newest generation of crash avoidance technologies available at the time. The NDS consisted of 169 drivers operating 150 trucks from seven different fleets across the U.S. for up to 15 months. VTTI installed its data acquisition system (DAS) in each truck, which collected video of the driver and forward roadway, vehicle network data, and parametric data. The DAS was configured to record data whenever the CMV was in motion, allowing VTTI to capture all driving that took place. In total, the NDS collected 87,000 hours and 2.9 million miles of data. This data set included distance and speed data on any lead vehicles present in front of the vehicle, as well as network variables to indicate when cruise control was active and whether the system was regulating headway (i.e., operating as an ACC) or only speed (i.e., operating in standard cruise control). Using these data, it was possible to examine the visual behaviors of drivers across a combination of conditions in order to see how visual attention differed. VTTI identified four combinations of interest based on cruise control usage and car-following behavior (Table 1).

Table 1. Combinations of cruise control status and car-following status conditions.

		Car-Following Status	
		Following Lead Vehicle	**Not Following Lead Vehicle**
Cruise Control Status	**Cruise Control Active**	Adaptive Cruise Control	Standard Cruise Control
	Cruise Control Inactive	Manual Driving, Car-Following	Manual Driving, No Car-Following

The four conditions of interest explore how drivers manually follow other vehicles, how drivers allow the ACC to follow cars, how drivers manually operate the truck when not following another vehicle, and how drivers operate in cruise control when not following another vehicle. The key concept behind "car-following"—a generic term for following a lead vehicle regardless of vehicle class—is that the driver is attempting to maintain a relatively constant headway behind the lead vehicle for an extended period of time. In order to distinguish this from situations where a lead vehicle is present but the driver is *not* attempting to follow it, three filters were applied to the data. First, all driving below 35 mph was removed in order to eliminate stop-and-go or low-speed traffic. Second, cruise control usage was filtered to identify when drivers actually allowed the ACC to follow a vehicle. Within the vehicle network, a variable determines whether the cruise control is regulating headway (ACC mode) or simply regulating speed (standard cruise control mode). If a slower-moving lead vehicle is present, the system will switch to regulate headway, but this does not mean the driver is necessarily allowing ACC to follow the vehicle. A driver may disengage cruise control shortly afterwards, or override cruise control by pressing the gas in order to pass. Therefore, a filter was applied so that only periods in which cruise control regulated headway for at least 30 consecutive seconds were considered as instances of car-following using ACC. Other periods of cruise control usage that did not meet these criteria were considered standard cruise control, though short periods of headway regulation could be mixed in. Third, a filter was applied to the times when cruise control was inactive (manual driving) in order to distinguish when the driver was attempting to follow a lead vehicle and when a lead vehicle was simply detected by the radar. In order for an epoch to be considered manual car-following, a lead vehicle must have been present for at least 30 consecutive seconds while cruise control was inactive, the headway could not exceed 4.5 seconds during the period, and the distance between the vehicles had to follow a third-degree parabolic curve during the duration. A third-degree parabolic curve models the natural oscillations that occur when a driver manually attempts to maintain headway to a lead vehicle. Essentially, the distance between the driver and the lead vehicle must exhibit a basic pattern of gaining and falling back over time as the driver tries to react to fluctuations in the lead vehicle's speed. Any periods during which cruise control was inactive but did not meet these criteria were considered manual driving without car-following.

In order to investigate the visual behavior of drivers, each of the above driving conditions was randomly sampled from among the participants in the study. In total, 3,000 samples were created, each 30 seconds long. The sample was divided up among the four types of driving as follows:

- 1,000 samples of Adaptive Cruise Control
- 500 samples of Standard Cruise Control
- 1,000 samples of Manual Driving, Car-Following
- 500 samples of Manual Driving, No Car-Following

Each set of samples was stratified across drivers based on the amount of driving exposure, while individual samples for each driver were randomly selected. Some drivers did not have sufficient data to generate samples (i.e., low cruise control usage, or no events that met the car-following criteria) and were excluded from the sampling. Additionally, after inspecting the samples some had to be removed due to issues that made it difficult to determine where the driver's eyes were looking. These issues included sunglasses, glare, or objects obscuring the camera view. After these were removed, the final numbers of each type within the sample were:

- 984 samples of Adaptive Cruise Control
- 494 samples of Standard Cruise Control
- 984 samples of Manual Driving, Car-Following
- 491 samples of Manual Driving, No Car-Following

The final sets of samples included 147 of the 169 CMV drivers in the original data set and 132 of the 150 trucks in the original data set. The timing and location of each eye glance was recorded by VTTI's data reduction group for the entire 30 seconds of each sample. These eye glances provided the data necessary to calculate the metrics for TEORT, glance durations, and glance quantities.

CHAPTER 3. RESULTS

A series of comparisons was made between the different categories of driving that were sampled, four between individual categories, and two between combined categories:

- Comparisons of Individual Experimental Conditions
  - *ACC* vs. *Standard Cruise Control*
  - *Manual Driving, Car-Following* vs. *Manual Driving, No Car-Following*
  - *ACC* vs. *Manual Driving, Car-Following*
  - *Standard Cruise Control* vs. *Manual Driving, No Car-Following*
- Comparisons of Experimental Factor Levels
  - *All Cruise Control* (ACC and Standard) vs. *All Manual Driving* (Manual Driving, Car-Following and Manual Driving, No Car-Following)
  - *All Car-Following* (ACC and Manual Driving, Car-Following) vs. *All No Car-Following* (Standard Cruise Control and Manual Driving, No Car-Following)

The comparisons of individual experimental conditions test conditions that share one factor level, either cruise control usage or car-following status. The factor comparisons test for differences in the factor levels, combining individual conditions within the same factor. The comparisons were applied to each research question in order to determine whether there are differences in driver visual behavior between them.

NO GLANCES OFF-ROAD

Before addressing the main objectives, it is worth exploring the samples in which there were no glances off-road. In these files, the driver was looking at the forward roadway for the entire 30 seconds of the sample. Table 2 shows the number of samples in which this was the case for each individual category and the percentage of the total that these samples represented.

Table 2. Number and percentage of samples in which no glances off-road were observed.

Category	Number of Samples with Zero Off-Road Glances	Total Number of Samples	Percentage of Samples with Zero Off-Road Glances
ACC	53	984	5.4%
Standard Cruise Control	31	494	6.3%
Manual Car-Following	49	984	5.0%
Manual No Car-Following	31	491	6.3%

These quantities were subsequently tested using a binomial regression model with logit link function to see if there was a significant difference between the categories. The driver was included as a random effect in the test. The glances away from the forward roadway were translated to an indicator variable: events were assigned a 0 if the event had no glances away from the forward roadway and a 1 if the event had one or more glances away from the forward roadway. The contrast estimate results from the model are shown in Table 3. There were no significant differences in the number of samples with no off-road glances between individual categories or combined categories.

Table 3. Contrast estimate results from model with no glances from forward roadway.

	Contrast	Mean Estimate	Standard Error	95% Mean Confidence Interval	Significant
Car-Following Contrasts	*All Car-Following* vs. *All No Car-Following*	0.6690	0.2680	(0.3051, 1.4668)	No
	ACC vs. *Standard Cruise Control*	0.8432	0.2655	(0.4549, 1.5631)	No
	Manual Driving, Car-Following vs. *Manual Driving, No Car-Following*	0.7933	0.1837	(0.5039, 1.2490)	No
Cruise Control Contrasts	*All Cruise Control* vs. *All Manual Driving*	1.0681	0.3695	(0.5422, 2.1040)	No
	ACC vs. *Manual Driving, Car-Following*	1.0655	0.2884	(0.6269, 1.8110)	No
	Standard Cruise Control vs. *Manual Driving, No Car-Following*	1.0024	0.2438	(0.6224, 1.6145)	No

TOTAL EYES-OFF-ROAD TIME

The TEORT was calculated within each 30-second sample. TEORT was calculated by summing the duration of all glances off-road, including partial glances at the beginning or end of the 30-second windows. The analysis also includes those samples in which no glances off-road took place, which had a TEORT of zero. Table 4 shows the average and standard deviations of TEORT for each of the four individual categories.

Table 4. Average TEORT for each individual category.

Categories	Count	Average TEORT (seconds)	Standard Deviation for TEORT
ACC	931	6.1150	4.4609
Standard Cruise Control	463	6.7128	4.6958
Manual Car-Following	935	5.2589	3.9514
Manual No Car-Following	460	6.0601	4.3104

The distribution of TEORT is shown by individual category using box plots in Figure 1. Only samples with one or more off-road glances were included in this analysis. The minimum (range between 0.10 and 0.30 seconds) and 25th percentile (between 2.50 and 3.00 seconds) values were close to equal for all event types. The range for the median values was more than 1 second (between 4.40 and 5.80 seconds). The 75th percentile ranged from 6.80 seconds for Manual Car-Following to 9.40 seconds for Standard Cruise Control. The maximum values differed by several seconds; however, all event types showed a maximum of nearly the entire event duration. The maximum values ranged between 24.69 seconds for Manual No Car-Following and 26.99 seconds for Standard Cruise Control.

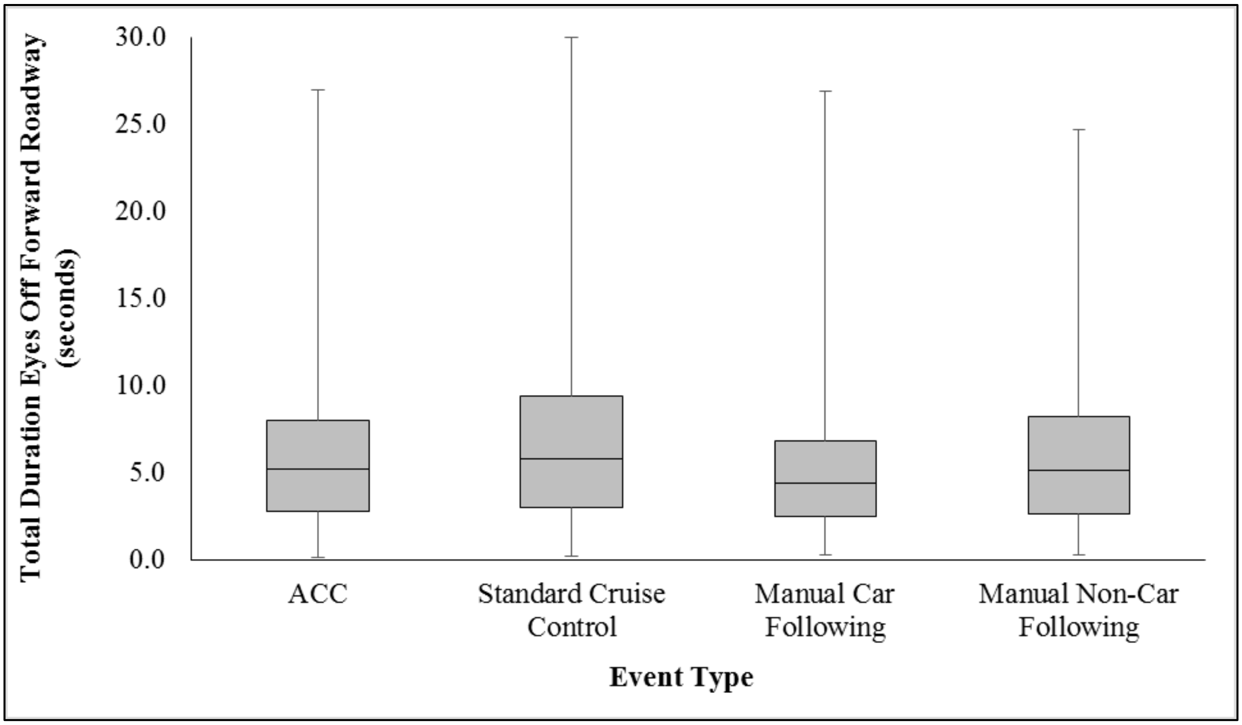

Figure 1. Chart. Box plots of TEORT distributions separated by individual categories

A generalized linear mixed model, with a log link function to account for log-normally distributed data, was used to test for differences in TEORT by category. The driver was considered a random effect. Events with no glances off the forward roadway were excluded from the model. The model was used to test significant differences in contrasts of categories. The model contrast results are listed in Table 5. Both contrasts involving combined categories were significant, with All Car-Following associated with *decreased* TEORT compared to All No Car-Following ($t = -4.03$, df = 2639, $p < 0.0001$) and All Cruise Control Usage associated with *increased* TEORT compared to All Manual Driving ($t = 4.18$, df = 2639, $p < 0.0001$). Drilling down into individual categories, ACC was associated with decreased TEORT versus Standard Cruise Control ($t = -2.42$, df = 2639, $p = 0.0154$) and Manual Car-Following was associated with decreased TEORT versus Manual No Car-Following ($t = -3.27$, df = 2639, $p = 0.0011$). This indicates that following a lead vehicle is associated with shorter TEORT, regardless of cruise control usage. Similarly, ACC was associated with longer TEORT versus Manual Car-Following ($t = 4.14$, df = 2639, $p < 0.0001$) and Standard Cruise Control was associated with longer TEORT versus Manual No Car-Following ($t = 2.18$, df = 2639, $p = 0.0291$). This indicates that cruise control usage was associated with longer TEORT, regardless of whether a lead vehicle was being followed.

Table 5. Model contrast results for TEORT.

	Contrast	Mean Estimate	Standard Error	Degrees of Freedom	*t*-statistic	*p*-value
Car-Following Contrasts	*All Car-Following* vs. *All No Car-Following*	-0.2511	0.0622	2639	-4.03	<0.0001
	ACC vs. *Standard Cruise Control*	-0.1065	0.0439	2639	-2.42	0.0154
	Manual Driving, Car-Following vs. *Manual Driving, No Car-Following*	-0.1446	0.0442	2639	-3.27	0.0011
Cruise Control Contrasts	*All Cruise Control* vs. *All Manual Driving*	0.2599	0.0622	2639	4.18	<0.0001
	ACC vs. *Manual Driving, Car-Following*	0.1490	0.0360	2639	4.14	<0.0001
	Standard Cruise Control vs. *Manual Driving, No Car-Following*	0.1109	0.0508	2639	2.18	0.0291

DURATIONS OF OFF-ROAD GLANCES

The mean durations of glances off-road were calculated within each 30-second sample. To obtain an estimate of the average off-road glance duration per individual category without giving any one sample more weight due to more off-road glances, the average off-road glance durations were calculated for each category by taking the average of all samples within the category. In other words, the method used gives each 30-second sample equal weight in calculating the average. Only samples with one or more off-road glances were included in this analysis. Table 6 shows the average and standard deviations of the average off-road glance durations for each of the four individual categories.

Table 6. Average mean duration of off-road glances for each category.

Individual Category	Count	Avg. Mean Duration of Off-Road Glances per Sample (s)	Std. Dev. for Mean Duration of Off-Road Glances per Sample
ACC	931	1.0531	0.3738
Standard Cruise Control	463	1.0705	0.3984
Manual Car-Following	935	0.9526	0.3328
Manual No Car-Following	460	0.9810	0.3135

The distribution of mean off-road glance duration is shown by category using box plots in Figure 2. Similar to the distribution of TEORT, the minimum (range between 0.10 and 0.30 seconds), 25^{th} percentile (between 0.72 and 0.80 seconds), and median (between 0.90 and 1.00 seconds) values were close to equal for all event types. The range of values was also close in the 75^{th} percentile (between 1.10 and 1.25 seconds). The maximum values ranged from 2.58 seconds for Manual No Car-Following events to 3.86 seconds for Manual Car-Following events.

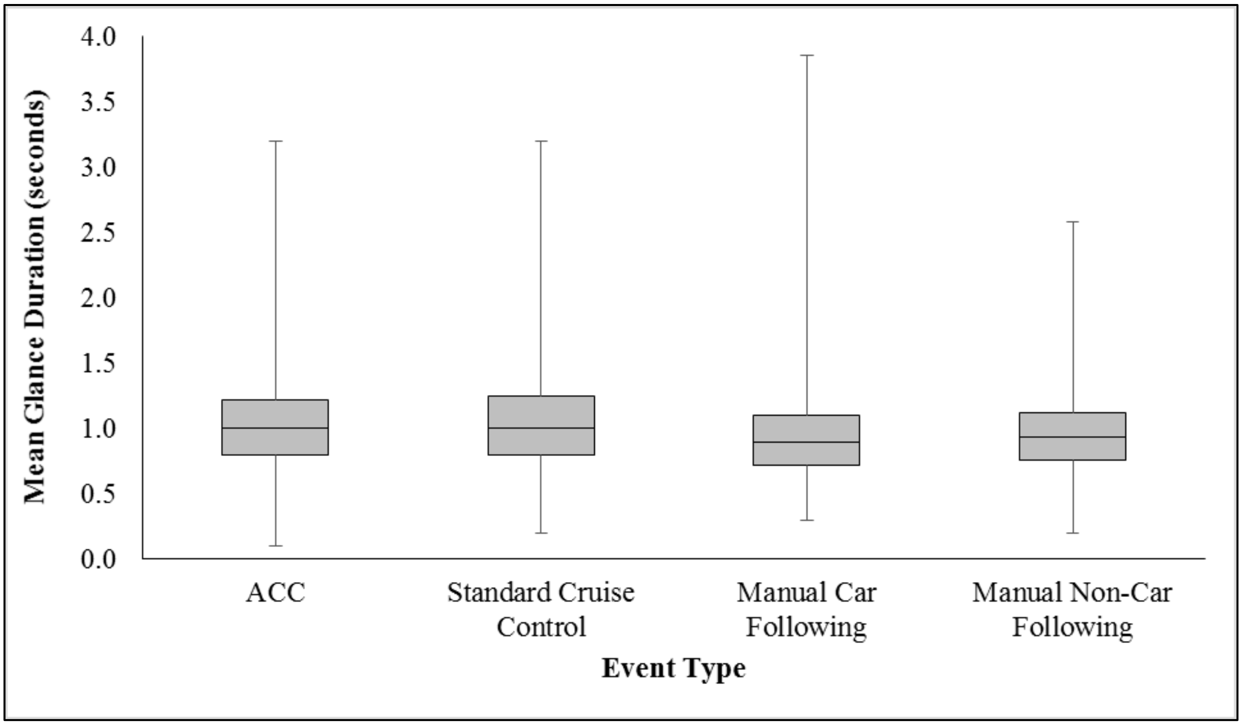

Figure 2. Chart. Box plot of average off-road glance duration by individual category.

A generalized linear mixed model, with a log link function to account for log-normally distributed data, was used to test for differences in average off-road glance duration by category. The driver was considered a random effect. Events with no glances off the forward roadway were excluded from the model. The model was used to test significant differences in contrasts of individual and combined categories. The model contrast results are listed in Table 7. Both contrasts involving combined categories were significant, with All Cruise Control Usage associated with longer average off-road glances than All Manual Driving ($t = 6.89$, df = 2640, $p < 0.0001$), and All Car-Following associated with shorter average off-road glances than All No Car-Following ($t = -2.46$, df = 2640, $p = 0.0138$). Drilling down into the individual categories, ACC was associated with longer average off-road glances versus Manual Car-Following ($t = 6.48$, df = 2640, $p < 0.0001$), and Standard Cruise Control was associated with longer average off-road glances versus Manual No Car-Following ($t = 3.85$, df = 2640, $p = 0.0001$). This means that both versions of cruise control contributed to the longer durations associated with using the technology when contrasted with manual driving in the samples. For car-following, the contrast between average off-road glance durations in ACC and Standard Cruise Control was not significant, while Manual Car-Following was associated with shorter off-road glances on average versus Manual No Car-Following ($t = -2.17$, df = 2640, $p = 0.0302$). This means that Manual Car-Following was likely the main influence behind average off-road glances in All Car-Following being significantly shorter than in All No Car-Following.

Table 7. Model contrast results for average off-road glance duration.

	Contrast	Mean Estimate	Standard Error	Degrees of Freedom	*t*-statistic	*p*-value
Car-Following Results	*All Car-Following* vs. *All No Car-Following*	-0.0623	0.02529	2640	-2.46	0.0138
	ACC vs. *Standard Cruise Control*	-0.0234	0.01782	2640	-1.31	0.1888
	Manual Driving, Car-Following vs. *Manual Driving, No Car-Following*	-0.0389	0.01794	2640	-2.17	0.0302
Cruise Control Results	*All Cruise Control* vs. *All Manual Driving*	0.1742	0.02526	2640	6.89	<0.0001
	ACC vs. *Manual Driving, Car-Following*	0.09483	0.01463	2640	6.48	<0.0001
	Standard Cruise Control vs. *Manual Driving, No Car-Following*	0.07935	0.02061	2640	3.85	0.0001

RATE OF OFF-ROAD GLANCES

The average rate of glances off-road per 10 seconds was calculated for the samples within each category. Table 8 shows the average and standard deviations of the rate of glances off-road for each of the four individual categories.

Table 8. Average rate of off-road glances per 10 seconds for each category.

Event Type	Count	Avg. Rate of Off-Road Glances per Event	Std. Dev. of Rate of Off-Road Glances per Event
ACC	931	1.9052	1.1632
Standard Cruise Control	463	2.0898	1.2389
Manual Car-Following	935	1.88176	1.1377
Manual No Car-Following	460	2.0089	1.2066

The box plots in Figure 3 show the distribution of the rate of off-road glances per 10 seconds by individual category. The minimum and 25th percentile values were equal for all categories (rate values of 0.33 glances per 10 seconds and 1 glance per 10 seconds, respectively). Median values equaled 1.67 glances per 10 seconds for ACC, Manual Car-Following, and Manual No Car-Following, and 2.00 glances per 10 seconds for Standard Cruise Control. The 75th percentile value ranged from 2.34 (Manual Car-Following) to 2.99 glances per 10 seconds (Standard Cruise Control). Manual No Car-Following had the largest maximum value at 7.33 off-road glances per 10 seconds. Manual Car-Following and Standard Cruise Control had maximum values of approximately 6.65 off-road glances per 10 seconds, and ACC had a maximum value of 6.00 off-road glances per 10 seconds.

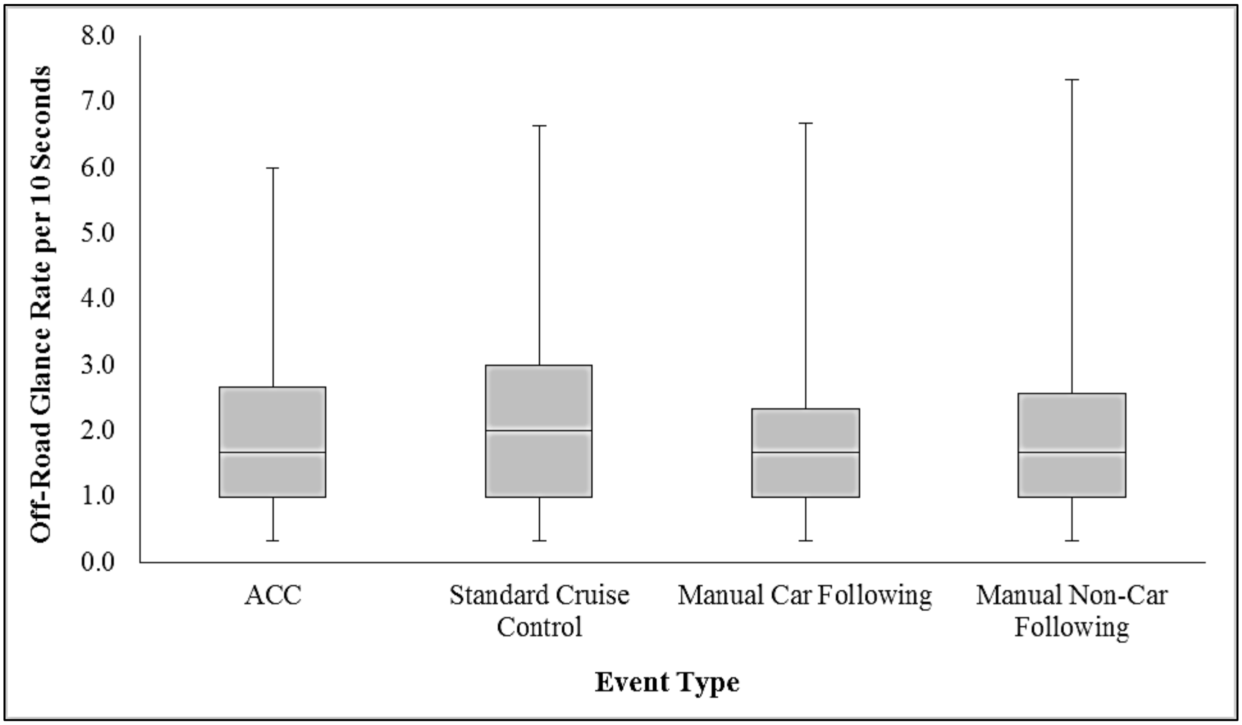

Figure 3. Chart. Box plot of average off-road glance rate (per 10 seconds) for each individual category.

A negative binomial mixed-effect regression model was used to test for differences in the rate of off-road glances per second by category. The driver was considered a random effect. Duration of the sample in seconds was used as an offset (included in the model as the log time of the sample). The model results are listed in Table 9. Since these values are modeled after the rate of off-road glances per second instead of the 10 seconds used above, they may look considerably smaller than the averages displayed in the tables and figures above. All Car-Following was associated with fewer off-road glances per second versus All No Car-Following, while All Cruise Control Usage was not significantly different from All Manual Driving. Drilling down into individual categories, ACC was associated with fewer off-road glances per second versus Standard Cruise Control, and Manual Car-Following was associated with fewer off-road glances per second versus Manual No Car-Following. This indicates that drivers glanced off-road less frequently when they were following a lead vehicle regardless of whether cruise control was active. Neither the contrast between ACC versus Standard Cruise Control nor Manual Car-Following versus Manual No Car-Following was significant, which indicates that cruise control usage does not seem to have a significant impact on the frequency of off-road glances.

Table 9. Model contrast results for number of off-road glances per second.

	Contrast	Mean Estimate	Standard Error	95% Mean Confidence Interval	Significant
Car-Following Results	*All Car-Following* vs. *All No Car-Following*	0.8434	0.0394	(0.7696, 0.9242)	*
	ACC vs. *Standard Cruise Control*	0.9239	0.0369	(0.8595, 0.9931)	*
	Manual Driving, Car-Following vs. *Manual Driving, No Car-Following*	0.9129	0.0280	(0.8597, 0.9693)	*
Cruise Control Results	*All Cruise Control* vs. *All Manual Driving*	1.0961	0.0534	(0.9962, 1.2059)	
	ACC vs. *Manual Driving, Car-Following*	1.0532	0.0294	(0.9972, 1.1124)	
	Standard Cruise Control vs. *Manual Driving, No Car-Following*	1.0407	0.0418	(0.9619, 1.1260)	

CHAPTER 4. DISCUSSION

The results can be summarized first using the factor-level comparisons. In the TEORT analysis, truck drivers spent less time looking off-road when they were following a lead vehicle, and more time looking off-road when they had a form of cruise control engaged. Glances off-road were shorter when truck drivers were following a lead vehicle and longer when some form of cruise control was engaged. The number of glances off-road was less when following a lead vehicle, but did not appear to change when cruise control was active. In other words, the smaller TEORT when following a lead vehicle is the result of both fewer off-road glances and shorter off-road glances, while the longer TEORT when cruise control is active is only the result of longer off-road glances.

The effect described above is also present when the data are separated to specifically isolate periods when the adaptive functionality was active. ACC was associated with longer TEORT and longer off-road glance durations compared to manual car-following samples. However, as noted above, the number of glances off-road did not appear different during ACC usage compared to manual car-following. Intuitively, the result makes sense, as ACC may reduce the workload on the driver by taking over small adjustments in longitudinal control. However, these off-road glances are not necessarily productive. Drivers could be surveying their surroundings and increasing their situation awareness, or the off-road glances could be forms of inattention. Among the general population in 2015, inattention was a factor in 10% of fatal crashes.(6) Inattention is similarly important in heavy vehicles, being documented in 6% of heavy vehicle drivers involved in fatal crashes in 2015.(7) Previous research from naturalistic data has also found that inattention is a major factor in crashes.(8,9) The effects found in this study are relatively small, and more research would be required to determine if any changes in visual behavior are associated with changes in risk. It will be important to investigate in more detail whether distraction, drowsiness, or other factors leading to inattention are more prevalent during ACC and other ADAS usage as the systems become more prevalent.

Currently there is a new generation of CAS technologies available for heavy vehicles. The new CAS technologies advertise improved sensors, fusion of multiple sensors, and additional alerts to improve truck driver awareness. These new features may address concerns about inattention by either improving the vehicle's ability to respond autonomously or providing feedback to the driver when certain behaviors are detected (speeding, poor lane keeping, etc.). However, the additional capabilities may not address an underlying issue of drivers spending less time looking at the roadway. These new technologies have great potential for preventing crashes, but their impacts on driver behavior must be understood in order to understand their benefits.

CHAPTER 5. CONCLUSION

The results showed that the participating truck drivers on average spent more time looking away from the roadway with cruise control engaged. This difference was mostly due to an increase in the duration of glances away from the forward roadway, rather than a change in the frequency of glances away from the forward roadway. Specifically, truck drivers using the ACC functionality (adaptive cruise control while a lead vehicle was present) were observed to have slightly greater TEORT and slightly longer glance durations compared to truck drivers manually following a lead vehicle. The manufacturers of ACC and other ADAS technologies state that drivers must remain vigilant and attentive to the forward roadway while using their products. While the average differences found in this study are relatively small, they show that visual behaviors could be different when using low levels of automation in trucks. If truck drivers spend less time looking at the forward roadway, it could be due to distraction or drowsiness, which indicate a lack of attention. Spending less time looking at the forward roadway also has the potential to reduce response windows for conflicts in front of the truck. With additional research it may be possible to understand the degree to which visual behaviors change, the reasons that visual behaviors change, and the risks that may be associated with these changes.

ACC is capable of initiating limited responses, such as de-throttling the truck. The ACC is also part of a wider crash avoidance system that is capable of applying engine brakes and foundation brakes. However, these systems are designed to engage with the driver in the loop and in conjunction with driver responses to conflicts. The systems also provide feedback to the driver regarding any lead vehicles, such as speed or headway. In order to fully realize the potential safety benefits of ACC and ADAS technologies, designers must consider how to keep the user's attention focused on the driving task. In particular, there is the possibility that multiple independent ADAS technologies or multiple integrated ADAS technologies (i.e., technology, sensor, or alert fusion) could further impact visual behaviors or attention. As ADAS technologies in heavy vehicles rapidly develop, it will be important to consider the role of the driver and how they interact with these technologies in the real world.

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