Cooperative Driving Automation Alerts During Rainy Weather Conditions

PUBLICATION NO. FHWA-HRT-24-162 OCTOBER 2024

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

Cooperative driving automation (CDA) technology is changing the landscape of traffic incident management. CDA technology can be used in transportation systems management and operations to communicate alerts about traffic flow and nonrecurring events to drivers via vehicle-to-everything communication. Ongoing research is assessing the potential impact and safety repercussions of added information from CDA alerts on driving performance.

This report documents a field experiment using a novel rain simulation system to explore the influence of CDA alerts on driver behavior and perspectives when driving in simulated heavy-rain conditions. This report may be of interest to State and local transportation agencies and traffic incident management responders wanting to understand how CDA communication about adverse weather conditions can affect driver behavior and the deployment of advanced driving assistance systems.

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Recommended citation: Federal Highway Administration, *Cooperative Driving Automation Alerts During Rainy Weather Conditions* (Washington, DC: 2024), https://doi.org/10.21949/1521605.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-HRT-24-162	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Cooperative Driving Automation Alerts During Rainy Weather Conditions		5. Report Date October 2024
		6. Performing Organization Code:
7. Author(s) Robert Sanchez (ORCID: 0000-0002-0763-6146), Ananna Ahmed, Szu-Fu Chao (ORCID: 0000-0002-2037-5200), Michelle Arnold (HRSO-30; ORCID: 0000-0001-5088-8800)		8. Performing Organization Report No.
9. Performing Organization Name and Address Leidos, Inc. 1750 Presidents Street Reston, VA 20190		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Safety and Operations Research and Development Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Final report; April 2022-August 2024
		14. Sponsoring Agency Code HRSO-30

15. Supplementary Notes
Michelle Arnold (HRSO-30; ORCID: 0000-0001-5088-8800), Office of Safety and Operations Research and Development, served as the Task Order Manager for the Federal Highway Administration.

16. Abstract
Cooperative driving automation (CDA) technology can send messages to CDA-enabled devices inside a vehicle to alert drivers to adverse road weather conditions. CDA messages and adaptive cruise control (ACC) have been found to influence driver behavior and increase safe vehicle operation. This study investigated the effects of CDA messages and ACC on driving behavior and perspectives when driving during simulated heavy-rain conditions. The messages informed drivers about potential road surface and visibility conditions impacted by heavy rain. Participants drove a test vehicle in simulated heavy rain while following a vehicle driven by a researcher. Participants drove at two speed limits in either an ACC-enabled vehicle or a vehicle without ACC. Each participant received four CDA message conditions: no CDA message, audio message, visual message, and audio and visual messages. The research vehicle recorded driving performance (i.e., speed, brake pedal usage, steering wheel movement, and following distance from the lead vehicle). Participants were later asked to rate the CDA message and ACC systems for overall usefulness, comfort, and safety. Driving performance measures were statistically analyzed to assess the impact of ACC status and CDA messages on driver behavior. Overall, all CDA messages were effective, especially when paired with ACC. The CDA messages transmitted information without hindering driver performance, and none resulted in abrupt behavior changes among participants. The CDA messages did not adversely affect driver performance in terms of vehicle speed, following distance, brake pedal usage, or steering wheel movement. Adding the ACC feature noticeably improved driving performance through more stable driving when compared to vehicles without ACC. Drivers also had a generally positive view of the usefulness, comfort, and safety improvement of the CDA and ACC systems.

17. Key Words CDA alert messages, ACC, driving performance, rainy weather, wet surface condition, low visibility		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161. http://www.ntis.gov	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 43	22. Price N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACC	adaptive cruise control
CDA	cooperative driving automation
FHWA	Federal Highway Administration
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle

CHAPTER 1. INTRODUCTION

Multiple studies have found that driving in adverse weather conditions, such as heavy rain, can significantly increase the risk and severity of a crash (Andrey and Yagar 1993; Ghasemzadeh and Ahmed 2019; Porter et al. 2019). Andrey and Yagar (1993) examined data from 169 rain events and found that the overall crash risk during rainy conditions was 70 percent higher than normal. Globally, drivers spend, on average, 11 percent of their driving time in rainy conditions (Trenberth and Zhang 2018). Ghasemzadeh and Ahmed (2019) found that adverse weather and lighting conditions were among the most important factors influencing the severity of crashes.

A primary goal of transportation systems management and operations is to ensure the safety and reliability of road networks and provide strategies to enable transportation agencies to manage the impact of nonrecurring events and improve road weather management. The Federal Highway Administration's (FHWA) Road Weather Management Program provides support to the road weather community in developing and deploying such technologies, solutions, and strategies (FHWA 2024). Consistent with the goals of the Road Weather Management Program, various public agencies are leveraging infrastructure-based countermeasures to improve safety by informing drivers about weather-related impacts to road surface conditions and route changes (Stephens et al. 2013). The U.S. Department of Transportation Intelligent Transportation Systems Joint Program Office Connected Vehicle Program has a Spot Weather Impact Warning application to warn drivers about location-specific weather events and broadcast information to vehicles via roadside equipment (Stephens et al. 2013). The National Weather Service can send messages to commercial wireless carriers to broadcast the messages as wireless emergency alerts (National Oceanic and Atmospheric Administration n.d.). The wireless emergency alerts can be displayed as text messages of up to 360 characters on personal wireless devices to inform drivers about the impending hazardous weather events.

COOPERATIVE DRIVING AUTOMATION (CDA)TECHNOLOGY

Cooperative driving automation technology can facilitate vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications as part of the smart transportation ecosystem (Sanchez et al. 2023). CDA-enabled devices inside a vehicle can send and receive messages transmitted from other vehicles to provide information from the infrastructure (such as smart traffic control devices) and traffic incident management centers. This capability enables transportation systems management and operations strategies to be communicated from the infrastructure to drivers (Anderson 2020). CDA technology can also automate specific driving functions such as vehicle cruise control to regulate vehicle speed and following distances (SAE International 2020). Adaptive cruise control (ACC) can use forward-looking sensors to automatically adjust vehicle throttle and brake to maintain a speed and distance to a detected front vehicle (Howard 2013). With speed and following distance automated, drivers using ACC have been observed to have slower speeds compared to drivers without ACC and adopt the lead vehicle speed by changing lanes less frequently (Weaver et al. 2020; Schakel et al. 2017).

CDA MESSAGES

Driving automation technologies, such as ACC and CDA messaging, have been found to influence driver behavior and increase safety. A simulator study of CDA messages for heavy-vehicle operators found that weather and work zone warnings improved truck driver safety in terms of reduced speed and smoother braking. In another study, researchers displayed a visual weather alert message (such as road surface and visibility conditions) on the truck dashboard and found that using notifications improved driver behavior and response (Raddaoui, Ahmed, and Gaweesh 2020). The drivers indicated high approval of the notifications in terms of usefulness and understanding with little to moderate distraction. Participants preferred CDA messages in poor-visibility conditions, with 89 percent stating an improved perception of safety with the presence of CDA messages (Ahmed, Yang, and Gaweesh 2020). These studies show the importance of conveying messages to drivers about adverse weather and the effects on driving behavior (i.e., reducing speed, exercising caution, watching for stopped vehicles).

Various researchers have explored communicating alert messages to drivers via hearing, vision, and touch (Peter, Zsolt, and Aradi 2014; Zhao et al. 2019; Ahmed, Yang, and Gaweesh 2020). Audio messages uses voice messages or beep noises, visual messages display symbols or text, and haptic messages provide sensory input through vibration to the vehicle steering wheel or to the seat to alert the driver. In general, auditory messages do not require splitting attention from the driving task, but visual messages can add to the visual workload (Engström, Johansson, and Östlund 2005). Haptic messages are often associated with immediate response by drivers and are valuable for takeover requests and lane departure warnings (Petermeijer, Doubek, and de Winter 2017). Therefore, acoustic mode is used more often when driver reaction time is limited, and visual mode can be used for noncritical messages. Song, Park, and Oh (2016) found that drivers preferred audio-graphic-text combination messages and repeated audio messages for emergency and cautionary warnings (Song, Park, and Oh 2016).

TRUST IN CONNECTED TECHNOLOGY

Advances in connected technology and driving assistance are designed to increase safety and convenience to drivers. The benefits heavily depend not only on the quality and efficacy of the system, but also the ability of the drivers to successfully understand and use the technology. V2I communication requires developing understandable alerts that share the intended meaning quickly and effectively without adding to the driver's cognitive load. The benefits of V2I CDA-enabled messaging transmitted from the infrastructure to the vehicles heavily depends on driver perception of and trust in the technology. Trust misalignment is the mismatch between a human's trust in the system and the system's actual capabilities (Muir 1987). Trust misalignment can be further characterized as overtrusting and undertrusting. Overtrust can lead to misuse of the system when the driver overestimates the automated system's capabilities. Undertrust can lead to stressful driving experiences for drivers when they do not make full use of the system's capabilities (Azevedo-Sa et al. 2020).

Because there is no standardized CDA message for weather advisories, this study investigates the influence of CDA messages using audio, visual, and both audio and visual messages on driving behavior during controlled simulated rainy conditions. The study also explores the influence of

CDA messages on drivers using ACC and their perspectives related to trust of technology: usefulness, comfort, and safety.

OBJECTIVES

This research study explores the effects of CDA messages and ACC on driver behavior and perspectives when driving in heavy-rain conditions. The objectives of this study are to examine how ACC and CDA messages influence driving behavior; assess driver perspectives of usefulness, comfort, and safety of ACC-enabled vehicles and CDA messages; and identify CDA message preference. In this experiment, participants drove a test vehicle around a closed-course track in simulated heavy rain while following a lead vehicle driven by the researchers. Researchers in the lead vehicle controlled the type of CDA message as the participant vehicles reached the alert points along the route. The messages were designed to inform drivers about potential road surface and visibility conditions affected by heavy rain.

Hypotheses

Based on the objectives, the following hypotheses are investigated in this study:

- Drivers using ACC-enabled vehicles will have lower speeds than drivers in no ACC vehicles.
- Drivers using ACC-enabled vehicles will have shorter following distances than drivers in no ACC vehicles.
- Drivers using ACC-enabled vehicles will have less brake pedal usage than drivers in no ACC vehicles.
- Drivers using ACC-enabled vehicles will have less steering wheel movement than drivers in no ACC vehicles.
- Drivers receiving CDA messages will have higher speeds than drivers not receiving CDA messages.
- Drivers receiving CDA messages will have shorter following distances than drivers not receiving CDA messages.
- Drivers receiving CDA messages will have less brake pedal usage than drivers not receiving CDA messages.
- Drivers receiving CDA messages will have less steering wheel movement than drivers not receiving CDA messages.

CHAPTER 2. METHOD

PARTICIPANTS

Eighty drivers from the Washington, DC, metropolitan area participated in the study. All participants were licensed drivers aged 18-yr old or older with at least 3 yr of driving experience. Forty-six males and 39 females participated in the study. Twenty-six males and 22 females were 46-yr old or younger and 20 males and 17 females were aged 47-yr old or older. Participants were tested and had visual acuity of at least 20/40 in one eye.

EXPERIMENT DESIGN

Table 1 displays the three independent variable mixed factorial design and number of participants for each condition included in the study. The study used a 2 x 4 x 2 mixed factorial design with two levels of vehicle type, four levels of message type, and two levels of speed limit. The vehicle type was a between-subjects independent variable and the message type and the speed limit were within-subjects independent variables. The 80 participants were divided into two groups, with 40 drivers in the no ACC vehicle type and 40 drivers in the ACC-enabled vehicle type. All drivers were tested using all message types (i.e., no CDA message, audio only, visual only, and both audio and visual) and at both speed limit (30 and 40 mph) conditions. Each participant completed a total of eight data collection trials consisting of two speed limits (30 and 40 mph) and four levels of messages (in random order).

Table 1. Experimental design showing the number of participants by condition.

Vehicle Type	CDA Message Type	Speed Limit 30 mph	Speed Limit 40 mph
No ACC	No CDA messages	40	40
	Audio message	40	40
	Visual message	40	40
	Both messages	40	40
ACC-enabled	No messages	40	40
	Signal message	40	40
	Lead vehicle message	40	40
	Both messages	40	40

APPARATUS

Research Vehicle

During the study, participants operated a vehicle equipped with CDA features and ACC capabilities. The vehicle was equipped with ACC and lane-keeping assistance. The vehicle's ACC activated at a minimum of 25 mph and could be set to one of three levels: near, medium, and far. For this study the ACC setting was set as near, which ensured that the participant's vehicle followed the lead vehicle with a 1-s time gap. The vehicle's center console was equipped with a 10-inch tablet used to present CDA visual messages and play audio messages. The vehicle was equipped with a local data acquisition system that recorded data from the vehicle controller area network bus, including speed, steering wheel angle, brake force, ACC status, and following distance from the lead vehicle. A passive two-way audio system allowed researchers to communicate with participants during the experiment.

Rain Simulation

Because this research explored the effects of CDA messages on driver behavior and perceptions during heavy-rain conditions, data collection took place with wet roads and rainy driving conditions. To maintain consistent visibility and pavement conditions, researchers developed a simulated rain and pavement wetting system to keep the impact of rain consistent for all participants.

Rainfall

Rainfall was simulated using a connected network of sprinklers installed on the participant's vehicle, as shown in figure 1. A 30-gallon (gal) water tank and pump were placed on an external rack installed behind the vehicle. The pump pressure sprayed the water through sprinklers to cover the windshield, driver and passenger windows, and driver and passenger side mirrors. Researchers in the lead vehicle initiated the rain using a remote-controlled device. The water tank was refilled after the fourth run of the experiment.

Source: FHWA.

Figure 1. Photo. Sprinkler system used to simulate rainfall.

Wet Pavement Simulation

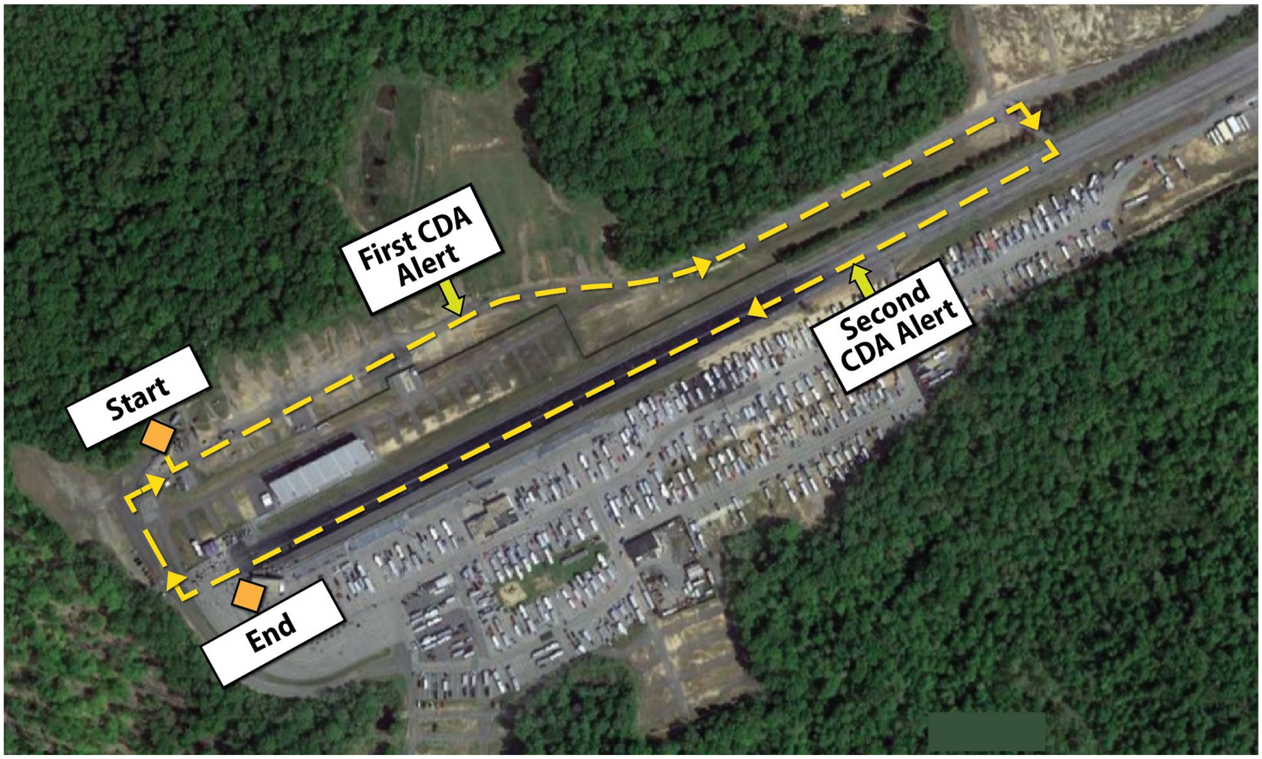
For the study, a 2,500-gal water truck used approximately 1,200 gal of water to wet the pavement on the test track. Figure 2 shows the water truck spraying water to wet the pavement. By controlling the amount of water poured on the road, the researchers controlled the magnitude of skidding. The amount of poured water was kept to a level at which participants would feel slight skidding but would not need to adjust vehicle control.

Source: FHWA.

Figure 2. Photo. Wet pavement simulation.

Experimental Route

The study was conducted on a closed-course track in Maryland. Figure 3 shows the route and the two locations where CDA alert messages were provided to the drivers. The diamond shapes in the figure indicate the start and end locations of the route and the arrows indicate the direction of travel. From start to end, the length of the entire loop was approximately 2.2 mi. The route took 2.5–3.5 min to drive each loop based on the speed limit and complete two data collection trials. As a result, each participant completed four loops to complete the eight data collection trials.



Map data: © 2020 Google® Earth™. Overlay added by FHWA (see Acknowledgements section).

Figure 3. Map. Experimental route (Google 2020).

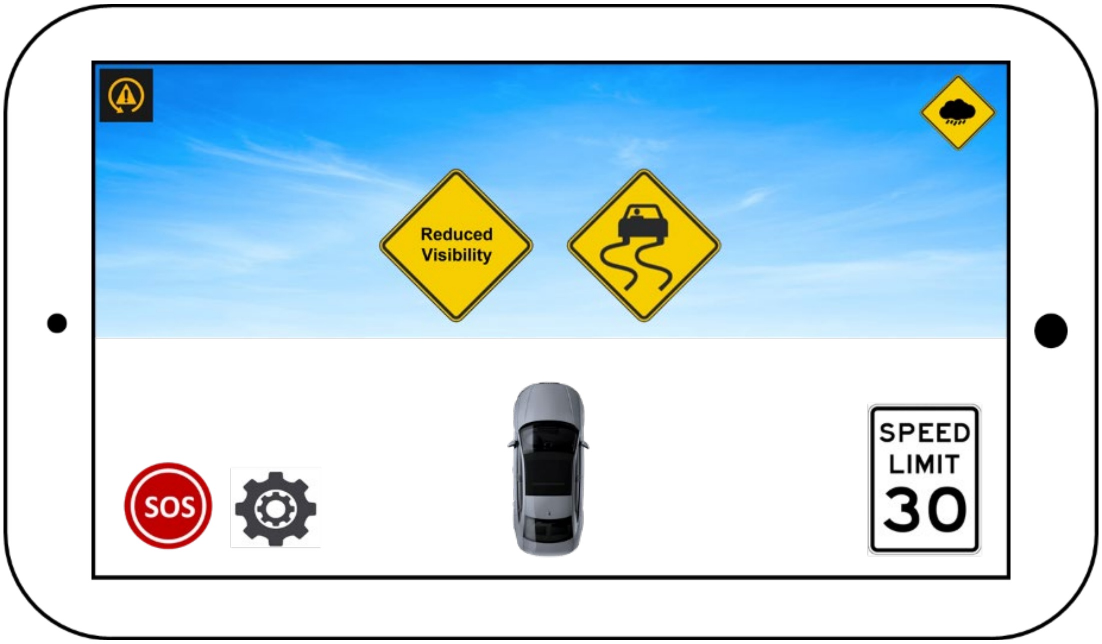
Stimuli

CDA Alert Messages

Three types of CDA messages were provided to participants: audio, visual, or both audio and visual. A researcher in the lead vehicle remotely triggered the messages when the participant vehicles reached designated locations along the route. For each loop around the track, participants traversed two alert locations. The messages stayed on until drivers reached the next alert location or reached the end of the loop. CDA messages were always preceded by a short-duration audio signal to draw participants' attention to the change in the tablet screen.

Visual Messages

Figure 4 shows the in-vehicle display of the visual message. The CDA visual message displayed two road signs to convey reduced visibility and a slippery road. The visual messages were designed to mimic the cautionary or warning road signs. While "Reduced Visibility" was a text-based sign, "Slippery Road Ahead" was a symbol-based sign that is commonly used as a road sign. The visual message was preceded by a short audio signal when drivers had reached the CDA alert location.

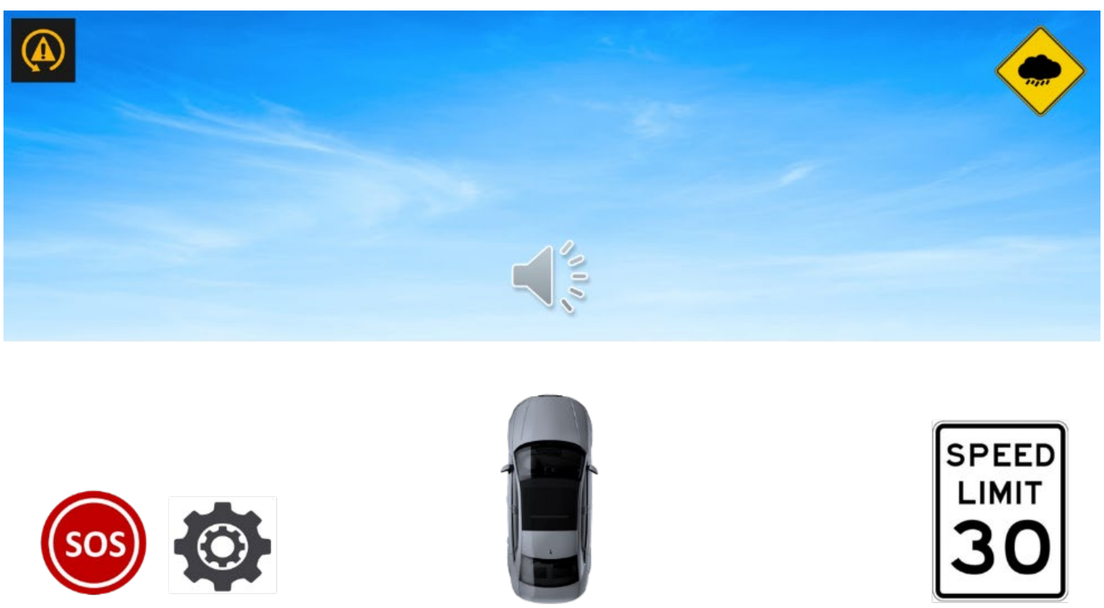


Source: FHWA.

Figure 4. Illustration. CDA visual message.

Audio Messages

Figure 5 depicts the in-vehicle display of the audio message. Instead of displaying the warning signs, recipients received a “Low Visibility and Slippery Road Ahead” audio message, which was preceded by a short audio signal once drivers had reached the CDA alert location.

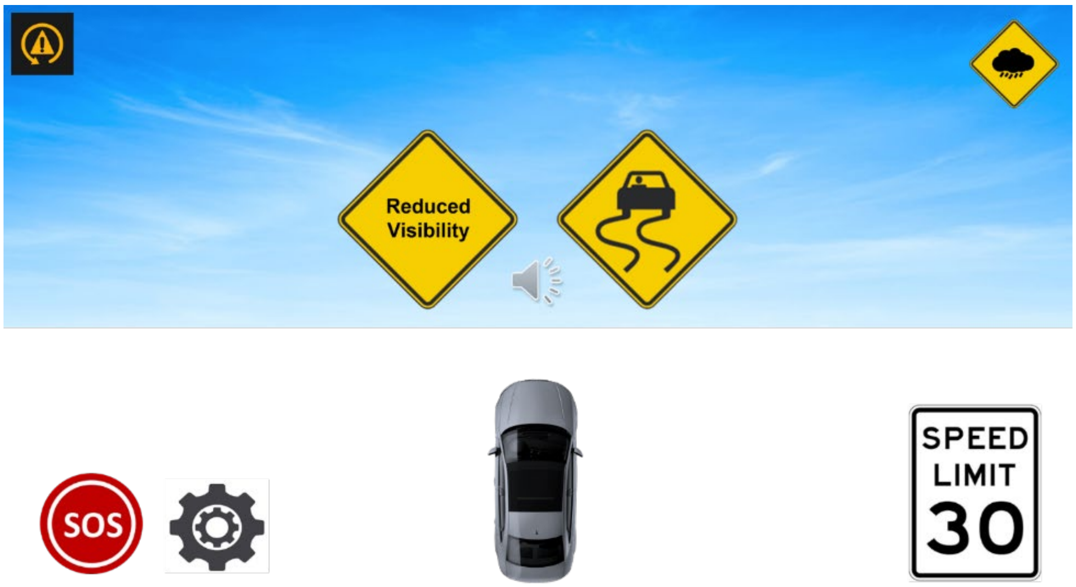


Source: FHWA.

Figure 5. Illustration. CDA audio message.

Both Audio and Visual Messages

Figure 6 shows the in-vehicle display of the combined audio and visual messages. The combined display showed the same warning signs used for visual messages (see figure 4) while the audio message “Low Visibility and Slippery Road Ahead” played at the same time. A short audio signal preceded the combined audio and visual messages when the drivers had reached the CDA alert location.



Source: FHWA.

Figure 6. Illustration. Both audio and visual CDA messages.

PROCEDURE

Participants met at the front office of the track and were then escorted into a conference room to read and sign the informed consent forms. Next, participants provided evidence of a valid driver’s license and their vision was checked using the Freiburg Visual Acuity and Contrast test (Bach 1996). Participants received a brief introduction about ACC and CDA messages and were then escorted to the test vehicle in the parking lot. The participant and a researcher entered the test vehicle and the participant made any necessary seat and mirror adjustments. The researcher explained the vehicle features and how to enable ACC features (if applicable). The participant (with the researcher) practiced driving the track until the participant was comfortable with the features of the test vehicle. Researchers told the participants to drive four loops, take a short break, then drive four more loops (for a total of eight loops). Concurrently, another researcher used the water truck to wet down the experiment route. After the practice drive, the participant parked at the start point behind the researcher’s lead vehicle.

During the study, participants drove eight loops in the test vehicle alone while two researchers drove in the lead vehicle. In the lead vehicle, one researcher drove at an assigned speed limit (30 or 40 mph) while the other researcher controlled the CDA messages and rain simulation. As the lead vehicle reached the assigned speed and the participant vehicle arrived at the designated alert location, the researcher remotely triggered the short-duration signal and a CDA message was provided to the participant. Researchers in the lead vehicle controlled the type of CDA message as the participant vehicle reached the alert points along the route. For each loop around the track, the participant crossed two alert locations. The messages remained on until the participant reached the next alert location or reached the end of the loop. After the fourth loop, the researchers instructed the participant via wireless communication to take a short break. The water tank on the participant's vehicle was replenished. The participant followed the lead vehicle back to the start point and completed the remaining four loops.

After all eight loops were completed, the participant was escorted back to the conference room in the front office. Participants were given a computer-based questionnaire, which included selected-response questions, to assess their perspectives of CDA messages and their preferences. Participants who drove the ACC-enabled vehicles were also asked to complete the ACC questionnaire to assess their perspectives on the ACC system. After participants completed the questionnaire, the research team thanked the participants, compensated them for participating in the study, and escorted them to their vehicle.

CDA Message and ACC Questionnaire

Researchers administered the CDA message questionnaire to all participants after they completed the experimental drive. All participants were asked to rate on a scale of 1–5 their perspectives about the overall usefulness, comfort, and safety of CDA messages . For the usefulness measure, four characteristics were rated: useless to useful, bad to good, superfluous to effective, and worthless to assisting. For the comfort measure, four characteristics were rated: unpleasant to pleasant, annoying to nice, irritating to likable, and undesirable to desirable. Safety was based on the ratings for the sleep inducing to raising awareness scale. Participants were then asked to provide their level of familiarity with the ACC system on a scale from 1 (very familiar) to 4 (very unfamiliar) and to rank order their preferred CDA message types (none, audio, visual, both) from most to least preferred.

Participants who drove ACC-enabled vehicles also completed a second similar questionnaire to explore their perspectives of the ACC system. The participants were asked to rate their perspectives of the ACC feature's overall usefulness, comfort, and safety on a scale of 1–5. Participants were also asked to provide their age and level of familiarity with the ACC system on a scale from 1 (very familiar) to 4 (very unfamiliar).

CHAPTER 3. RESULTS

This chapter describes the analysis of the effects of vehicle type (no ACC or ACC-enabled) and CDA message type on participants' driving behavior and perspectives during simulated heavy rain. The driving behavior analyses examined vehicle speeds, following distance, brake pedal position, and steering wheel movement with 30- and 40-mph speed limits. The driver perspective analyses assessed driver ratings of usefulness, comfort, safety, and CDA message preference from the postexperiment questionnaire.

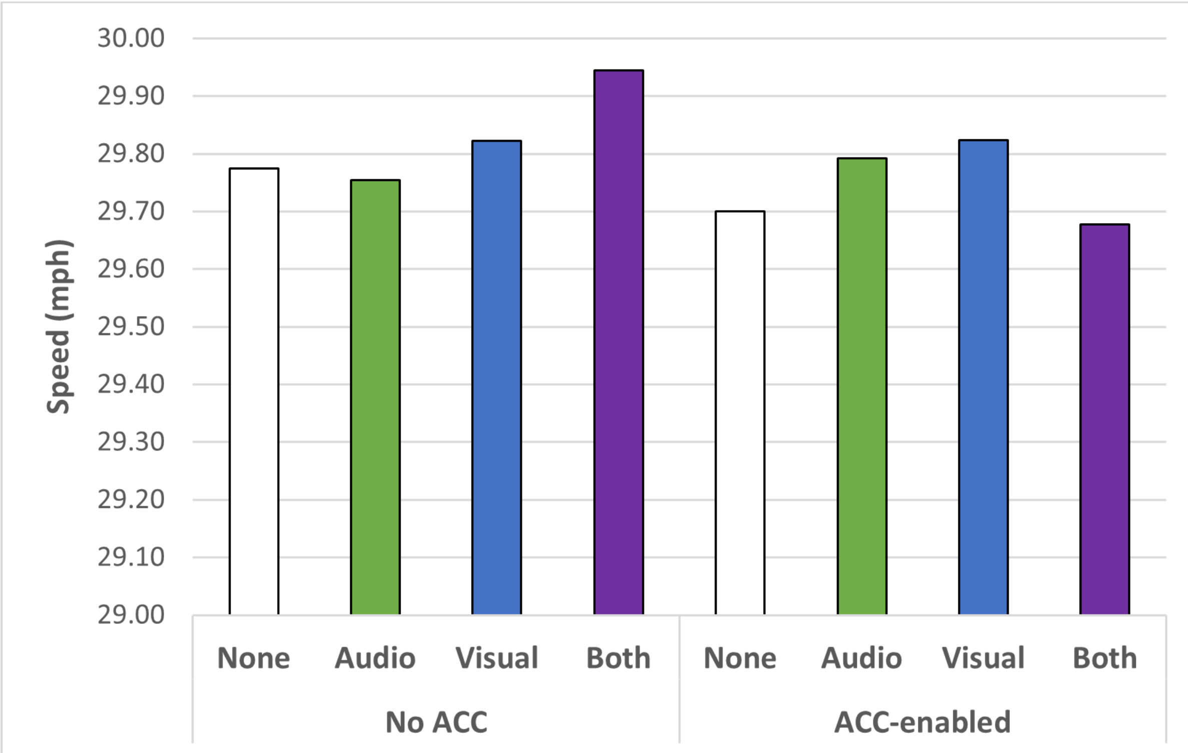
HOW DO CDA MESSAGES AND ACC INFLUENCE DRIVING BEHAVIOR?

Average Speed

Researchers hypothesized that drivers using ACC-enabled vehicles would drive at lower speeds than drivers in vehicles without ACCs. Researchers also hypothesized that drivers receiving CDA messages would drive at higher speeds than drivers not receiving CDA messages.

Average Speed at Speed Limit: 30 mph

The research team examined the average vehicle speed in the 30-mph speed limit condition to determine if vehicle type (no ACC or ACC enabled) or CDA message type had an effect on vehicle speed. Figure 7 shows the average speeds of participants across the different conditions. Overall, the average speeds regardless of vehicle type and CDA message types were similar (a difference of 0.27 mph or less) and the differences were not statistically significant. The average speed of participants in no-ACC vehicles ranged from 29.75 to 29.95 mph, while the average speed of participants in ACC-enabled vehicles ranged from 29.68 to 29.82 mph. The impact of vehicle type and CDA message type on driving speed was statistically assessed using a linear mixed effects model. The results showed that the difference in speed between no-ACC and ACC-enabled vehicle types was not statistically significant. Similarly, the differences in vehicle speeds between CDA message types were less than 0.27 mph and not statistically significant.

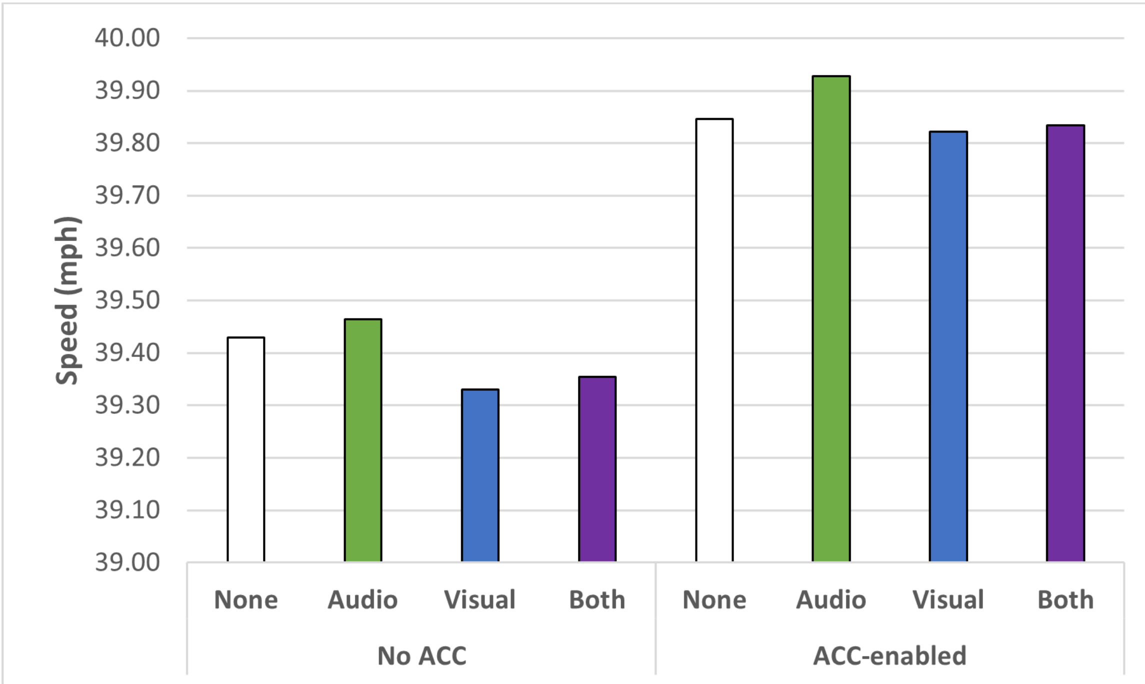


Source: FHWA.

Figure 7. Bar chart. Average speeds at 30-mph speed limit.

Average Speed at Speed Limit: 40 mph

The research team examined the average vehicle speed in the 40-mph speed limit condition to determine if vehicle type (no ACC or ACC enabled) or CDA message type had an effect on vehicle speed. Figure 8 shows the average speeds of participants across the different conditions. In general, the average speed of participants in no-ACC vehicles ranged from 39.33 to 39.46 mph, while the average speed of participants in ACC-enabled vehicles ranged from 39.82 to 39.93 mph. The impact of vehicle type and CDA message type on driving speed was statistically assessed using a linear mixed effects model. The results showed that the difference in speed between vehicle types was statistically significant ($p<0.001$). Drivers in ACC-enabled vehicles were estimated to have 0.5-mph higher speed than drivers of no-ACC vehicles. The differences in vehicle speeds between CDA message types were less than 0.13 mph and not statistically significant.



Source: FHWA.

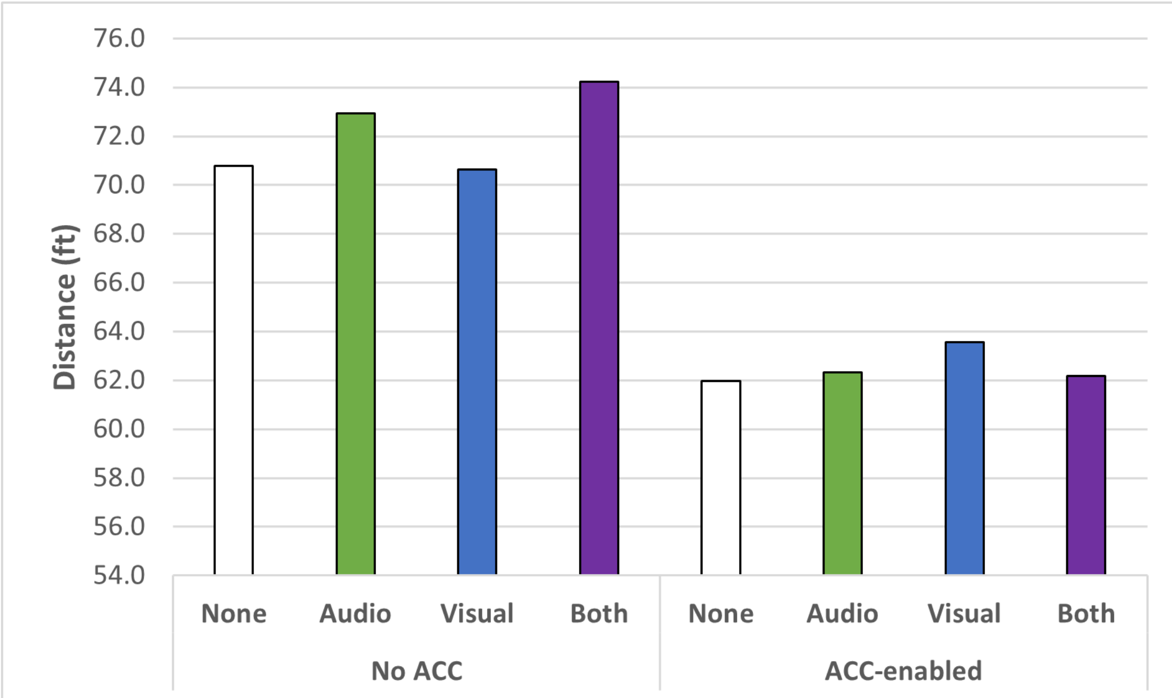
Figure 8. Bar chart. Average speeds at 40-mph speed limit.

Average Following Distance

Researchers hypothesized that drivers in ACC-enabled vehicles would have shorter following distances behind the lead vehicle than drivers in no-ACC vehicles when receiving CDA messages. Researchers also hypothesized that drivers receiving CDA messages would have shorter following distances than drivers not receiving CDA messages.

Average Following Distance at Speed Limit: 30 mph

The research team examined the average distance between the participant vehicle and the lead vehicle in the 30-mph speed limit condition to determine if vehicle type (no ACC or ACC enabled) or CDA message type had an effect on following distance. The ACC system was set to allow a minimum following distance of 1 s. At 30 mph, this speed would equate to about 44 ft of following distance behind the lead vehicle. Figure 9 shows the average following distance of participants across the different conditions. Overall, drivers in no-ACC vehicles had longer average following distances (ranging from 70.6 to 74.2 ft) than drivers in ACC-enabled vehicles (ranging from 62.0 to 63.6 ft). The impact of vehicle type and CDA message type on following distance was statistically assessed using a linear mixed effects model. The results showed that the difference between vehicle types was statistically significant ($p = 0.016$). The regression model estimated that drivers in ACC-enabled vehicles had a 9.8-ft shorter following distance than drivers in vehicles with no-ACC. The model also estimated that drivers in no-ACC vehicles receiving both audio and visual CDA messages had the longest following distance (74.2 ft) and the regression model estimated to be 1.8 ft longer than drivers not receiving CDA messages. These results ($p = 0.061$) did not quite reach the $p = 0.05$ level of statistical significance. The differences in following distance between CDA message types were less than 3.6 ft and not statistically significant.

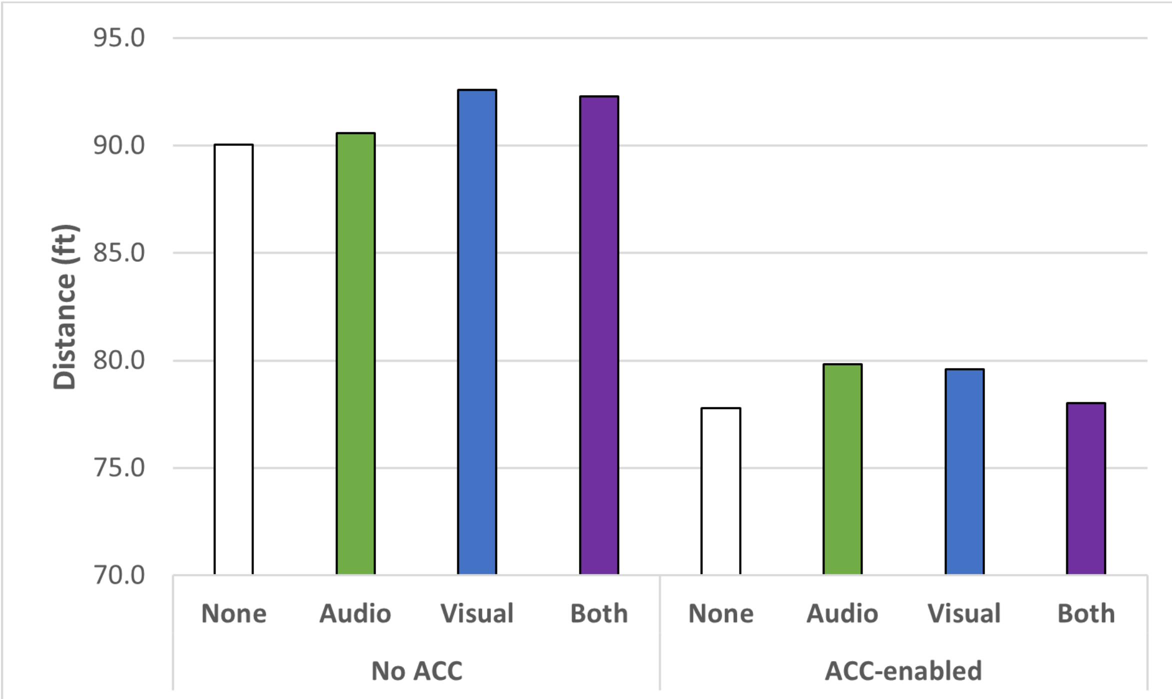


Source: FHWA.

Figure 9. Bar chart. Average following distances at 30-mph speed limit.

Average Following Distance at Speed Limit: 40 mph

The research team examined the average distance between the participant vehicle and the lead vehicle in the 40-mph speed limit condition to determine if vehicle type (no ACC or ACC enabled) or CDA message type had an effect on following distance. The ACC system was set to allow a minimum following distance of 1 s. At 40 mph, this speed would equate to about 59 ft of following distance behind the lead vehicle. Figure 10 shows the average following distance and standard deviations of participants across the different conditions. Overall, drivers in no-ACC vehicles had longer average following distances (ranging from 90.0 to 92.6 ft) than drivers in ACC-enabled vehicles (ranging from 77.8 to 79.8 ft). The impact of vehicle type and CDA message type on following distance was statistically assessed using a linear mixed effects model. The results showed that the impact of vehicle type was statistically significant ($p = 0.014$). The regression model estimated that drivers in no-ACC vehicles had a 12.5-ft longer following distance than drivers in ACC-enabled vehicles. The differences in following distance between CDA message types were less than 2 ft and not statistically significant.



Source: FHWA.

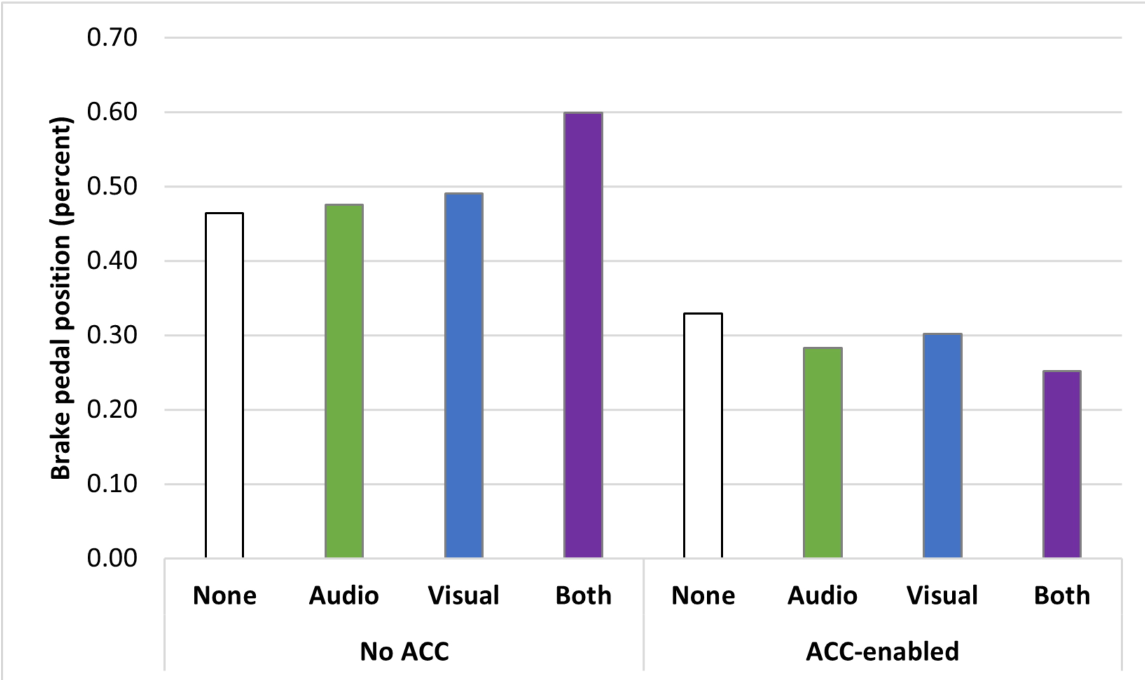
Figure 10. Bar chart. Average following distances at 40-mph speed limit.

Brake Pedal Usage

Researchers hypothesized that drivers in ACC-enabled vehicles use their brakes less than drivers in no-ACC vehicles. Researchers also hypothesized that drivers receiving CDA messages use their brakes less than drivers not receiving CDA messages. Variation in brake pedal position was measured using the standard deviation of the brake pedal positions during and after receiving the CDA messages.

Average Brake Pedal Usage at Speed Limit: 30 mph

The research team examined the variation of brake pedal position in the 30-mph speed limit condition to determine if vehicle type (no ACC or ACC enabled) or CDA message type had an effect on brake pedal usage. Figure 11 shows the brake pedal position variability at the 30-mph speed limit across the different conditions. Drivers with ACC-enabled vehicles had less variability in brake pedal usage (ranging from 0.25 to 0.33 percent) than drivers in no-ACC vehicles (ranging from 0.46 to 0.60 percent). The impact of vehicle type on brake pedal variation was statistically assessed using a gamma generalized linear mixed model with log regression. The results showed that the difference between vehicle types was not statistically significant ($p = 0.36$). The regression model predicted that drivers 46-yr old and younger were twice as likely to have higher brake pedal position variability ($p = 0.022$). Differences between CDA message types were less than 0.14 percent and not statistically significant.

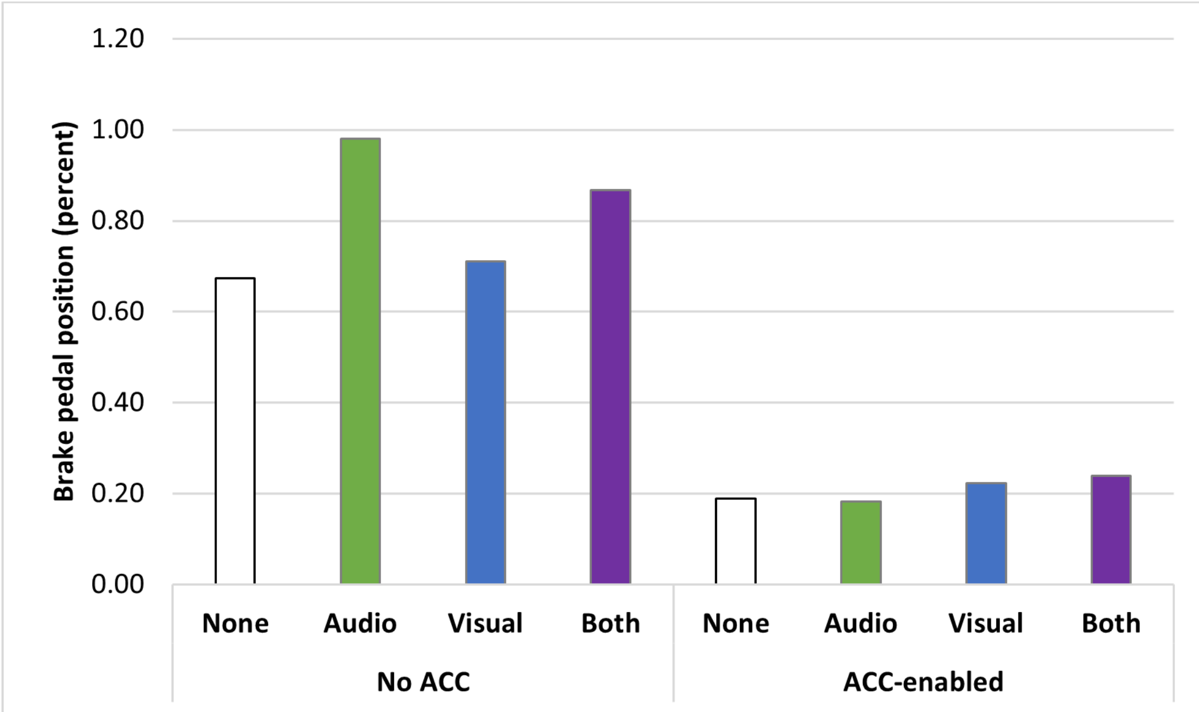


Source: FHWA.

Figure 11. Bar chart. Brake pedal position variability at 30-mph speed limit.

Average Brake Pedal Usage at Speed Limit: 40 mph

The research team examined the variation of brake pedal position in the 40-mph speed limit condition to determine if vehicle type (no ACC or ACC enabled) or CDA message type had an effect on brake pedal usage. Figure 12 shows the brake pedal position variability at the 40-mph speed limit across the different conditions. Overall, drivers in ACC-enabled vehicles had less variability (ranging from 0.18 to 0.24 percent) in brake pedal usage than drivers in no-ACC vehicles (ranging from 0.67 to 0.87 percent). The impact of vehicle type and CDA messages was statistically assessed using a gamma generalized linear mixed model with log regression. The impact of vehicle type was found to be statistically significant (p<0.001). Drivers in no-ACC vehicles were 1.6 times more likely to have higher brake pedal variability. The regression model found that drivers receiving both messages are 1.7 times more likely (p = 0.04) to have higher brake pedal variability than drivers not receiving messages. Differences between CDA message types were less than 0.31 percent and not statistically significant.



Source: FHWA.

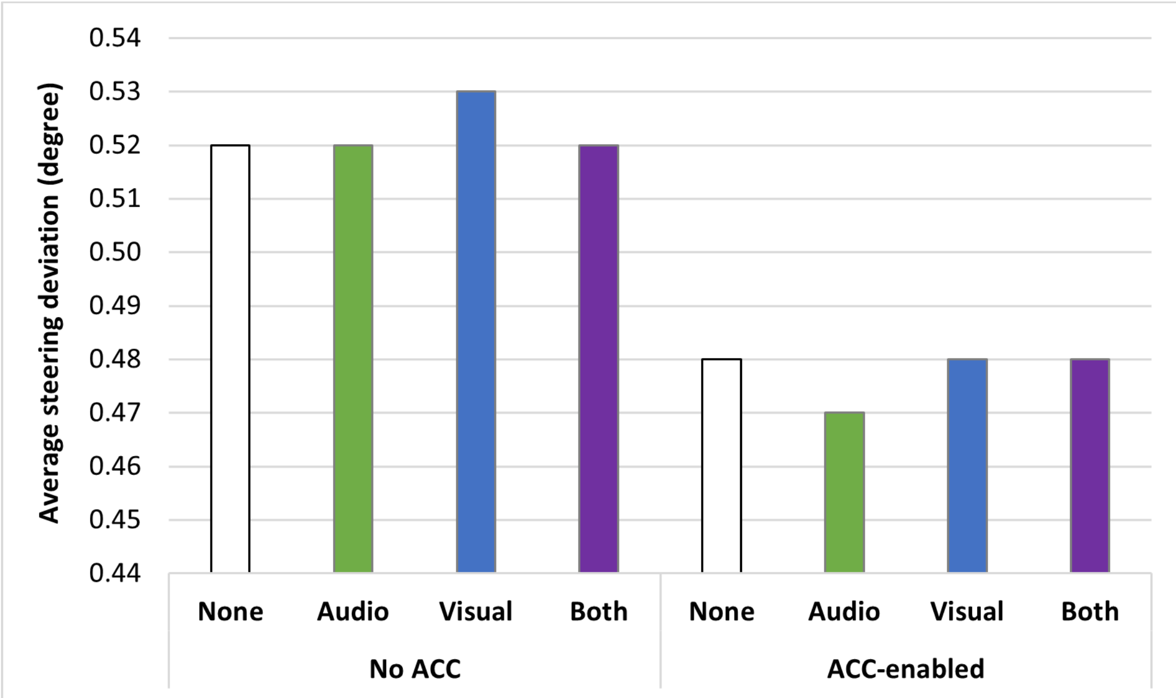
Figure 12. Bar chart. Brake pedal position variability at 40-mph speed limit.

Steering Wheel Movement

Researchers hypothesized that drivers using ACC-enabled vehicles have less steering wheel movement than drivers in no-ACC vehicles. Researchers also hypothesized that drivers receiving CDA messages have less steering wheel movement than drivers not receiving CDA messages. The average deviation from the center (neutral) position of the steering wheel was measured in degrees and used in the analyses.

Average Steering Wheel Movement at Speed Limit: 30 mph

The research team examined the steering wheel deviation in the 30-mph speed limit condition to determine if vehicle type (no ACC or ACC enabled) or CDA message type had an effect on steering wheel movement. Figure 13 presents average steering deviations from center at the 30-mph speed limit across the different conditions. Overall, participants in no-ACC vehicles showed higher average steering wheel variability (ranging from 0.52 to 0.53°) than participants with ACC (ranging from 0.47 to 0.48°). The impact of vehicle type and CDA message type on steering wheel variability was statistically assessed using a gamma generalized linear mixed model with log regression. Although drivers with ACC-enabled vehicles were estimated to have 0.12° less variability, the results showed that the difference between vehicle types was close to reaching statistical significance ($p = 0.06$). Differences between CDA message types were less than 0.01° and were not statistically significant.

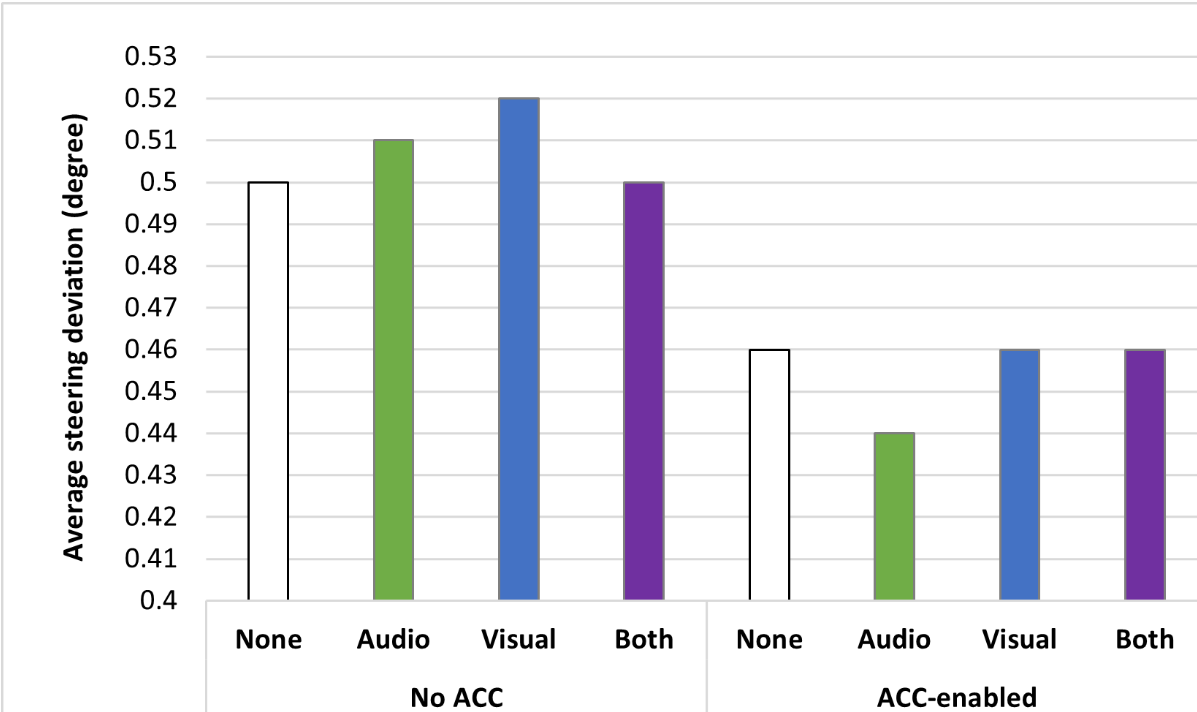


Source: FHWA.

Figure 13. Bar chart. Steering wheel variability at 30-mph speed limit.

Average Steering Wheel Movement at Speed Limit: 40 mph

The research team examined the steering wheel deviation in the 40-mph speed limit condition to determine if vehicle type (no ACC or ACC enabled) or CDA message type had an effect on steering wheel movement. Figure 14 presents average steering deviations from center at the 40-mph speed limit across the different conditions. Overall, drivers in no-ACC vehicles showed higher average steering wheel variability (ranging from 0.50–0.52°) than drivers with ACC-enabled vehicles (ranging from 0.44 to 0.46°). The impact of vehicle type and CDA message type on steering wheel variability was statistically assessed using a gamma generalized linear mixed model with log regression. Although drivers with ACC-enabled vehicles were estimated to have 0.10° less variability, the results showed that the difference between vehicle types was not statistically significant ($p = 0.11$). Differences between CDA message types were less than 0.02° and were not statistically significant.



Source: FHWA.

Figure 14. Bar chart. Steering wheel variability at 40-mph speed limit.

WHAT ARE DRIVERS' PERSPECTIVES OF CDA MESSAGES AND ACC?

Participants were asked for their perspectives of the CDA messages and ACC system. All participants completed the CDA message questionnaire. Only the participants who drove ACC-enabled vehicles completed the second questionnaire to rate their perspectives on the usefulness, comfort, and safety of the ACC feature.

CDA Message Ratings

The CDA message questionnaire explored participant ratings of overall usefulness, comfort, and safety. The usefulness measure was derived from four questions about characteristics related to CDA message usefulness. Participants rated the CDA messages on a scale of 1–5 for useless to useful, bad to good, superfluous to effective, and worthless to assisting. For comfort, four characteristics were rated: unpleasant to pleasant, annoying to nice, irritating to likable, and undesirable to desirable. Safety was based on the ratings for the sleep inducing to raising awareness scale.

Familiarity With the CDA System

Participants were asked how familiar they are with CDA systems. Overall, approximately two-thirds (67 percent) of participants reported having at least some familiarity with the CDA message system and about one-third (33 percent) reported no familiarity at all. Examination of the ratings by gender (female versus male) and age (younger versus older) showed a similar distribution, with about two-thirds having at least some familiarity and one-third having no familiarity.

Usefulness

The research team investigated the ratings of the usefulness measures (useless to useful, bad to good, superfluous to effective, and worthless to assisting). The response distributions for the four questions were not found to be significantly different and were assumed to have equal importance. Table 2 shows the average usefulness rating by familiarity level. The Kruskal-Wallis rank-sum test indicated that the usefulness ratings were not statistically different ($p = 0.97$) regardless of ACC familiarity (Kruskal and Wallis 1952). Overall, participants considered the CDA messages useful (4.21 out of 5). Participants in ACC-enabled vehicles were found to have higher usefulness ratings (4.5 out of 5) than participants in no-ACC vehicles (3.9 out of 5). The Kruskal-Wallis rank-sum test confirmed that CDA messages are more likely ($p = 0.01$) to receive higher usefulness rating when drivers used the ACC-enabled vehicles.

Table 2. Average ratings for CDA message usefulness by familiarity level.

Participant Familiarity Level	Average Usefulness Rating
Level 1: Very unfamiliar	4.27
Level 2	4.20
Level 3	4.29
Level 4: Very familiar	4.09
Overall	4.21

Comfort

The research team investigated the ratings of the comfort measures (pleasant to unpleasant, nice to annoying, irritating to likable, and undesirable to desirable). The response distributions for the four questions were not found to be significantly different and were assumed to have equal importance. Table 3 shows the average comfort ratings by familiarity level. The Kruskal-Wallis rank-sum test indicated that the usefulness ratings were not statistically different ($p = 0.87$) regardless of ACC familiarity (Kruskal and Wallis 1952). Overall, participants indicated they we comfortable using the CDA messages (4.19 out of 5). Participants in ACC-enabled vehicles were found to have slightly higher usefulness ratings (4.3 out of 5) than participants in no-ACC vehicles (4 out of 5). The Kruskal-Wallis rank-sum test confirmed that differences in rating were not statistically significant ($p = 0.21$).

Table 3. Average ratings for CDA message comfort by familiarity level.

Participant Familiarity Level	Average Comfort Rating
Level 1: Very unfamiliar	4.33
Level 2	4.23
Level 3	4.14
Level 4: Very familiar	4.05
Overall	4.19

Safety Improvement

The research team investigated ratings of safety improvement using the sleep inducing (rating equals 1) to raising awareness (rating equals 5) scale. Table 4 shows the average safety ratings by familiarity level. The Kruskal-Wallis rank sum test indicated that the safety improvement ratings were not statistically different ($p = 0.44$) regardless of ACC familiarity (Kruskal and Wallis 1952). Overall, participants considered the CDA messages improved safety (3.93 out of 5). Participants in ACC-enabled vehicles reported a similar safety improvement (3.9 out of 5) as participants in no-ACC vehicles (3.9 out of 5). The Kruskal-Wallis rank-sum test confirmed that differences in rating were not statistically significant ($p = 0.971$).

Table 4. Average ratings for CDA message safety improvement by familiarity level.

Participant Familiarity Level	Average Safety Improvement Rating
Level 1: Very unfamiliar	4.25
Level 2	3.75
Level 3	3.75
Level 4: Very familiar	3.96
Overall	3.93

ACC Ratings

Participants were asked to rate their perspectives of CDA message overall usefulness, comfort, and safety on a scale of 1–5. Overall, usefulness was based on the average ratings for questions that ranged from useless to useful, bad to good, superfluous to effective, and worthless to assisting. Overall, comfort ratings were derived from the average ratings for questions that ranged from pleasant to unpleasant, nice to annoying, irritating to likable, and undesirable to desirable. Safety was based on the average rating for sleep inducing to raising awareness. Participants were also asked to identify their preferred CDA message type.

Familiarity with ACC Systems

Participants in ACC-enabled vehicles were asked how familiar they are with the ACC systems. Overall, approximately three-quarters (78 percent) of participants reported having at least some familiarity with ACC systems and about one-quarter (22 percent) reported no familiarity at all. Examination of the ratings by gender showed a similar distribution with 78 percent for both females and males. The familiarity by age results indicated that slightly more younger drivers (45-yr old or younger) than older drivers (46-yr old or older) were at least somewhat familiar with the ACC systems (88 percent versus 71 percent).

Usefulness

The research team examined the ratings of the ACC system usefulness measures (useless to useful, bad to good, superfluous to effective, and worthless to assisting). The response distributions for the four questions were not found to be significantly different and were assumed to have equal importance. Table 5 shows the average usefulness rating by familiarity level. The Kruskal-Wallis rank-sum test indicated that the usefulness ratings were not statistically different ($p = 0.91$) regardless of ACC familiarity (Kruskal and Wallis 1952). Overall, participants considered the ACC system useful (4.6 out of 5). The Kruskal-Wallis rank-sum test confirmed that no other statistically significant differences were found for age or gender.

Table 5. Average ratings for ACC system usefulness by familiarity level.

Participant Familiarity Level	Average Usefulness Rating
Level 1: Very unfamiliar	4.5
Level 2	4.6
Level 3	4.7
Level 4: Very familiar	4.6
Overall	4.6

Comfort

The research team investigated the ratings of the ACC system comfort measures (pleasant to unpleasant, nice to annoying, irritating to likable, and undesirable to desirable). The response distributions for the four questions were not found to be significantly different and were assumed to have equal importance. Table 6 shows the average comfort rating by participant familiarity level. The Kruskal-Wallis rank-sum test indicated that the comfort ratings were not statistically different ($p = 0.89$) regardless of ACC familiarity (Kruskal and Wallis 1952). Overall, participants considered the ACC system useful (4.39 out of 5). The Kruskal-Wallis rank-sum test confirmed that no other statistically significant differences were found for age or gender.

Table 6. Average ratings for ACC system comfort by familiarity level.

Participant Familiarity Level	Average Comfort Rating
Level 1: Very unfamiliar	4.3
Level 2	4.4
Level 3	4.5
Level 4: Very familiar	4.25
Overall	4.39

Safety Improvement

The research team investigated ratings of safety improvement using the sleep inducing (rating equals 1) to raising awareness (rating equals 5) scale to assess if they thought the ACC system helped improve safety. Table 7 shows the average safety rating by participant familiarity level. The Kruskal-Wallis rank-sum test indicated that the comfort ratings were not statistically different ($p = 0.77$) regardless of ACC familiarity (Kruskal and Wallis 1952). Overall, participants considered the CDA messages improved safety (overall average of 3.7 out of 5). The Kruskal-Wallis rank-sum test confirmed that no other statistically significant differences were found for age or gender.

Table 7. Average ratings for ACC system safety improvement by familiarity level.

Participant Familiarity Level	Average Safety Improvement Rating
Level 1: Very unfamiliar	3.8
Level 2	4.0
Level 3	3.5
Level 4: Very familiar	3.8
Overall	3.7

CDA Message Preference

All participants were asked to rank in order the CDA message types (none, audio, visual, or both) from 1 (most preferred) to 4 (least preferred). Table 8 displays the percentage of participants' ranking of each message. Both (audio and visual) was the most preferred CDA message type by 35 percent of the participants. The audio message and visual message were ranked second and third, respectively, by 46 percent of the participants. The least preferred message type was none (no message), selected by 55 percent of the participants.

Table 8. CDA alert preference.

CDA Message Type	Rank 1: Most Preferred (percent)	Rank 2 (percent)	Rank 3 (percent)	Rank 4: Least Preferred (percent)
None	27	8	10	55
Audio	25	46	24	5
Visual	13	25	46	16
Both	35	20	20	24

CHAPTER 4. DISCUSSION

This study investigated the effects of CDA messages and ACC on driver behavior and perspectives when driving during simulated heavy rain. Participants drove a research vehicle four 2.2-mi loops around a closed-course track at two speed limits—30 and 40 mph—while following researchers in a lead vehicle. Eighty participants drove the research vehicle eight loops around a test track, where each loop consisted of two trials through a CDA alert location. The participants drove either an ACC-enabled vehicle or a no-ACC vehicle. After crossing the alert location, participants received one of four message conditions (i.e., no messages, audio only, visual only, or both audio and visual). The researchers examined the effects of vehicle type (ACC enabled and no ACC) and CDA message type (none, audio, visual, or both) on driving performance using four parameters: speed, following distance, brake pedal usage, and steering wheel movement. After completing the study, participants were given a questionnaire to assess their perspectives of ACC and CDA messages and their preferences.

The following eight research hypotheses were investigated:

- **Drivers using ACC-enabled vehicles will drive at lower speeds than drivers in no-ACC vehicles.** This hypothesis was partially supported by the results. Drivers using ACC-enabled vehicles were found to on occasion drive at lower speeds than drivers in no-ACC vehicles. At the 30-mph speed limit, participants in ACC-enabled vehicles drove at speeds similar to participants in no-ACC vehicles (29.68–29.82 versus 29.75—29.95 mph) and the analyses showed that the differences were not statistically significant. However, at the 40-mph speed limit, participants in ACC-enabled vehicles drove at higher speeds (39.82–39.93 mph) than participants in no-ACC vehicles (39.33–39.46 mph). In general, the drivers in ACC-enabled vehicles drove at speeds about 0.5 mph greater. These results contradict some of the literature showing drivers in ACC-enabled vehicles driving slower than drivers in non-ACC vehicles when following a lead vehicle (Weaver et al. 2021). A possible explanation for this difference is that at the 40-mph speed limit, the ACC-enabled drivers adopted a driving strategy and relied on the ACC system to automatically mirror the lead vehicle's speed, which traveled at the speed limit (Howard 2013; Weaver et al. 2021).

- **Drivers using ACC-enabled vehicles will have shorter following distances than drivers in no-ACC vehicles.** This hypothesis was supported by the results. Drivers using ACC-enabled vehicles had shorter following distances than drivers in no-ACC vehicles. At the 30-mph speed limit, participants in ACC-enabled vehicles had shorter following distances than the drivers without ACC (62.0–63.6 versus 70.6–74.2 ft) and the analyses showed that the differences were statistically significant. The 40-mph speed limit had similar results. Participants in ACC-enabled vehicles had shorter following distances than participants in no-ACC vehicles (77.8–79.8 versus 90.0–92.6 ft) and the analyses again indicated the differences were statistically significant. Consequently, at both speed limit conditions, drivers in ACC-enabled vehicles chose to drive closer to the lead vehicle than drivers in no-ACC vehicles, but not as close as the ACC system setting allowed with a 1-s following distance. (The 1-s following distance equates to a 44- and 59-ft following distance at 30 mph and 40 mph, respectively.) Driver perspective results from this study indicate that drivers with ACC-enabled vehicles may have chosen to drive closer because they thought the system was useful, were relatively comfortable using the system, and thought the system improved safety by raising awareness.

- **Drivers using ACC-enabled vehicles will use the brake pedal less than drivers in no-ACC vehicles.** This hypothesis was partially supported by the results. Drivers using ACC-enabled vehicles sometimes used the brake pedal less than drivers in no-ACC vehicles. At the 30-mph speed limit, drivers in ACC-enabled vehicles had less variability in brake pedal usage than drivers in no-ACC vehicles (0.25–0.33 percent versus 0.46–0.60 percent) but the differences were not statistically significant. However, at the 40-mph speed limit, drivers in ACC-enabled vehicles were found to have less brake pedal movement (0.18–0.24 percent) compared to drivers in no-ACC vehicles (0.67–0.87 percent) and the differences were found to be statistically significant. A possible explanation is that at the 40-mph speed limit, the ACC-enabled drivers adopted an eco-driving strategy and relied on the ACC system to automatically mirror the lead vehicle speed (Howard 2013; Weaver et al. 2013). As a result, drivers in ACC-enabled vehicles did not use the brake pedal as much as the drivers in no-ACC vehicles.

- **Drivers using ACC-enabled vehicles will have less steering wheel movement than drivers in no-ACC vehicles.** This hypothesis was not supported by the results. Drivers using ACC-enabled vehicles did not have less steering wheel movement than drivers in no-ACC vehicles. At the 30-mph speed limit, drivers in ACC-enabled vehicles had less steering wheel movement than drivers in no-ACC vehicles (0.47–0.48° versus 0.52–0.53°) but the differences were not statistically significant. Similarly at the 40-mph speed limit, drivers in ACC-enabled vehicles were found to have less steering wheel movement (0.44–0.46°) compared to drivers in no-ACC vehicles (0.50–0.52°) and the differences were again found to be statistically significant. It is unclear whether this difference was due to the relatively static nature of the driving task (i.e., follow the lead vehicle), related to ACC-enabled drivers adopting an eco-driving strategy, or some other reason.

- **Drivers receiving CDA messages will drive at higher speeds than drivers not receiving CDA messages.** This hypothesis was not supported by the results. Drivers receiving CDA messages did not drive at higher speeds than drivers not receiving CDA messages. At both the 30- and 40-mph speed limits, the differences in vehicle speeds between CDA message types were less than 0.27 and 0.13 mph, respectively, and the differences were not statistically significant.

- **Drivers receiving CDA messages will have shorter following distances than drivers not receiving CDA messages.** This hypothesis was not supported by the results. Drivers receiving CDA messages did not have shorter following distances than drivers not receiving CDA messages. At both the 30- and 40-mph speed limits, the differences in following distance between CDA message types were less than 3.6 and 2 ft, respectively, and the differences were not statistically significant.

- **Drivers receiving CDA messages will have less brake pedal usage than drivers not receiving CDA messages.** This hypothesis was not supported by the results. Drivers receiving CDA messages did not have less brake pedal usage than drivers not receiving CDA messages. At both the 30- and 40-mph speed limits, the differences in brake pedal position between CDA message types were less than 0.14 and 0.31 percent, respectively, and the differences were not statistically significant.

- **Drivers receiving CDA messages will have less steering wheel movement than drivers not receiving CDA messages.** This hypothesis was not supported by the results. Drivers receiving CDA messages did not have less steering wheel movement than drivers not receiving CDA messages. At both the 30- and 40-mph speed limits, the differences in steering wheel movement between CDA message types were less than 0.01° and 0.02,° respectively, and the differences were not statistically significant.

Participants generally had a positive view of both the CDA and ACC systems. Analysis of driver perspectives of CDA message usefulness, comfort, and safety improvement found that a majority of drivers had favorable attitudes toward CDA messages. Regardless of familiarity with the system, drivers had positive opinions of the usefulness (overall rating of 4.21 out of 5), were comfortable using the system (4.19 out of 5) and viewed the CDA messages as a safety improvement (3.93 out of 5). Drivers with ACC-enabled vehicles were found to have usefulness and comfort ratings that were higher than and statistically significant from drivers of no-ACC vehicles. Safety improvement ratings were positive from drivers with ACC-enabled vehicles and drivers with no-ACC vehicles (3.9 out of 5). Driver attitudes toward the ACC system were similarly positive. All drivers of ACC-enabled vehicles, regardless of familiarity with ACC systems, had a very positive opinion of the usefulness (4.6 out of 5). All drivers of ACC-enabled vehicles, regardless of familiarity, had a very positive attitude of ACC system comfort (4.39 out of 5) and safety improvement (3.7 out of 5).

Participants ranked in order their preference for CDA message types (none, audio, visual, both) from 1 (most preferred) to 4 (least preferred). Overall, CDA messages that contained both audio and visual messages were the most preferred CDA message type. The audio and visual messages were ranked second and third with none (no message) being the least preferred message type. These results are consistent with findings by other researchers (Song, Park, and Oh 2016).

CONCLUSION

The analysis of driving performance revealed promising results for the use of CDA messages and ACC. Overall, all CDA messages were effective, especially when paired with ACC. The CDA messages transmitted information without hindering driver performance and none resulted in abrupt behavior changes among participants. The CDA messages did not adversely affect driver performance in terms of vehicle speed, following distance, brake pedal usage, or steering wheel movement. Adding the ACC feature noticeably improved driving performance through more stable driving compared to vehicles without ACC. Drivers also had an overall positive view of both the CDA and ACC systems in terms of usefulness, comfort, and safety improvement.

This study was limited due to the length of the closed track in such a way that higher speeds could not be assessed. The participants were instructed to follow the lead vehicle, limiting driver speed to that of the lead vehicle, and there were no interactions with other or adjacent vehicles. Future studies could investigate the effect of CDA messages and ACC on driving performance at higher speed limits, longer stretches of the roadway, and driving situations that include other vehicles using different maneuvers, such as merging onto the highway or near an intersection. Future studies would also help to better understand the impact of CDA messages in rainy conditions during other common driving situations and the effectiveness of various CDA message content, frequency, and modality.

ACKNOWLEDGEMENTS

The map in figure 3 was modified from its original version, which is the copyright property of Google® Earth™ and can be accessed from https://www.google.com/earth (Google 2020). The map overlays in figure 3 showing the experimental route were developed by the authors of this report for the purposes of this research. Arrows and text were added to show the start and end points, direction of travel, and locations of the designated CDA alert locations.

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Recommended citation: Federal Highway Administration,
Cooperative Driving Automation Alerts During Rainy Weather Conditions
(Washington, DC: 2024) https://doi.org/10.21949/1521605

HRSO-30/10-24(WEB)E