TECH**BRIEF**

The Effects of Vehicle Automation on Driver Engagement: The Case of Adaptive Cruise Control and Mind Wandering

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INTRODUCTION

Adaptive cruise control (ACC) is a longitudinal control system through which a vehicle can automatically maintain a driver-selected speed and, through the use of radar or light detection and ranging sensors, a preselected gap between itself and a slower-moving vehicle ahead.[(1)] ACC is marketed as a convenience system that reduces stress and workload by relieving the driver of the need to continuously regulate vehicle speed and following gap.[(2,3)] However, if ACC reduces the attentional resources drivers must devote to driving, drivers using ACC may experience increased periods of mind wandering, characterized as thoughts that are decoupled from the external stimulus environment, which could reduce safety for both the driver and other road users. The current study examined the effects of ACC on mind-wandering prevalence and driving performance.

BACKGROUND

Research suggests that ACC may improve driver safety by reducing crash risks associated with speed variability and encouraging longer following gaps.[(4,5)] ACC can also reduce the attentional resources drivers must devote to longitudinal control, potentially leaving resources free to devote to other tasks. If drivers devote the attention they would typically dedicate to maintaining speed to other driving-related tasks, such as hazard detection, there could be safety benefits.[(6)] On the other hand, if drivers direct the extra attention to distracting, nondriving activities, not only will a safety benefit be less likely, but the distraction associated with the nondriving activity may exceed the available attentional resources, resulting in a net reduction in road-user safety.[(7)]

Studies have shown that mind wandering is more frequent during periods of reduced driver workload.[(8,9)] Periods of mind wandering have been associated with increased blink rates and, among drivers, narrowed gaze-scanning patterns, suggesting reduced sensory input and situational awareness.[(10,11)] These reductions in attention are associated with poorer driving performance.[(8,12)] Driving while mind wandering has been associated with greater speed, shorter following gaps, and longer response times to unexpected critical events.[(13)]

As increases in vehicle automation continue to reduce the amount of attention drivers need to direct toward the roadway and vehicle

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functions, mind wandering and its potential associated dangers may become more prevalent.[14,15] However, the direct influence of ACC on mind-wandering rates and the resulting effects on driving performance are unclear.

RESEARCH

This study assessed mind-wandering rates of participants driving on a live road with and without ACC. Because car following has been shown to reduce the attention demanded by driving tasks, the presence or absence of a lead vehicle manipulated the difficulty of the drive.[16] Throughout the drive, the research team used audio probes to assess the frequency of mind wandering in each of the tested driving conditions.

Physiological measures of heart rate and electrodermal activity (EDA), which are sensitive to levels of effort exerted while driving, were also collected.[17,18] The vehicle Controller Area Network bus collected vehicle speed, following gap, and steering variability to assess the effect of ACC on driving performance.

METHOD

Forty-eight licensed drivers (21 females and 27 males) drove a predetermined route twice—once with ACC and once without ACC (table 1). The order of ACC use was counterbalanced across participants. Half of the participants followed a lead vehicle driven by an experimenter, and the other half received verbal instructions from an experimenter in the back seat of the vehicle. Before driving, each participant was briefed on the function of ACC and watched a video that demonstrated the ACC controls within the vehicle.

Participants drove a 28.3-mi route on a highway in Northern Virginia (figure 1). The route was a loop that included both westbound and eastbound travel. Throughout the drive, auditory probes occurred at a random interval between 90 and 150 s. The research team instructed participants to respond to these auditory mind-wandering probes by identifying their immediately preceding thoughts as driving related or other.

Following the drive, participants completed a brief questionnaire wherein they indicated their familiarity with the experimental route and ACC prior to the drive.

RESULTS

Mind-wandering rates were calculated as the proportion of probes in which participants indicated they were thinking about something other than driving. The effect of ACC on mind-wandering rate varied as a function of gender (figure 2). Among female drivers, mind-wandering rates were lower when driving with ACC than when driving manually. Among male drivers, mind-wandering rates did not vary significantly as a function of ACC condition.

The rate of skin-conductance responses (SCRs), characterized by spikes in EDA recordings, in

Table 1. Experimental group conditions.

Group	ACC Order	Lead	Participants
1	First	Yes	12
2	Second	Yes	12
3	First	No	12
4	Second	No	12

Figure 1. Map. Experimental route.

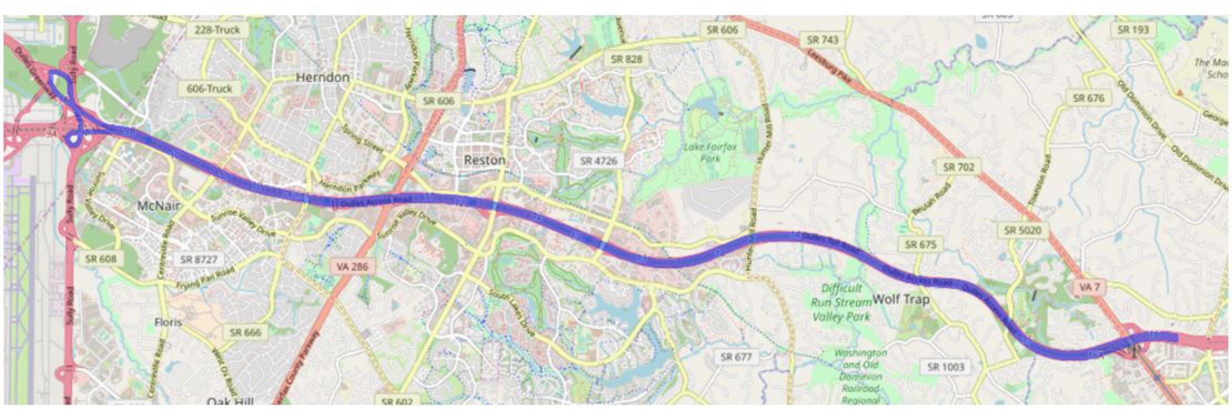
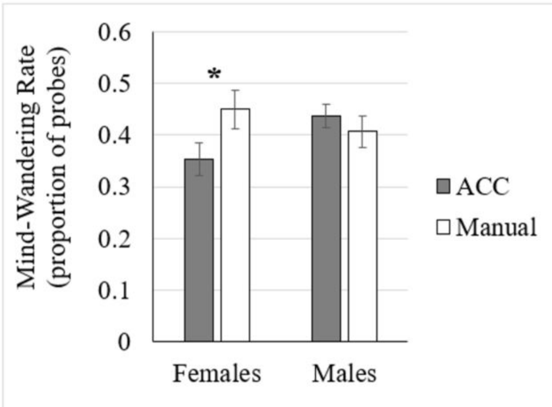


Figure 2. Graph. Mind-wandering rates as a function of gender and ACC.



Source: FHWA.
*Significant difference.
Note: Error bars represent the standard error of the means.

participants was higher when driving with ACC than when driving manually, indicating increased alertness while using ACC. Heart rate (as reflected in beat per minute) did not vary as a function of ACC or lead-vehicle condition.

The study assessed speed as a function of ACC and lead-vehicle condition, with lower speeds generally considered safer.[19] Participants drove more slowly when using ACC than when driving manually (figure 3-A). Because participants in the lead-vehicle condition could not exceed the speed of the vehicle they were following (60 mi/h) regardless of ACC condition, these effects were qualified by a significant interaction between ACC and lead-vehicle condition. Therefore, the effect of ACC condition on speed was only identified in the no-lead condition.

ACC also influenced following gap. Participants had longer following gaps when driving with ACC than when driving manually. The effect of ACC interacted with lead-vehicle condition—following gaps were longer for drivers in the lead-vehicle condition when driving with ACC than when driving manually (figure 3-B).

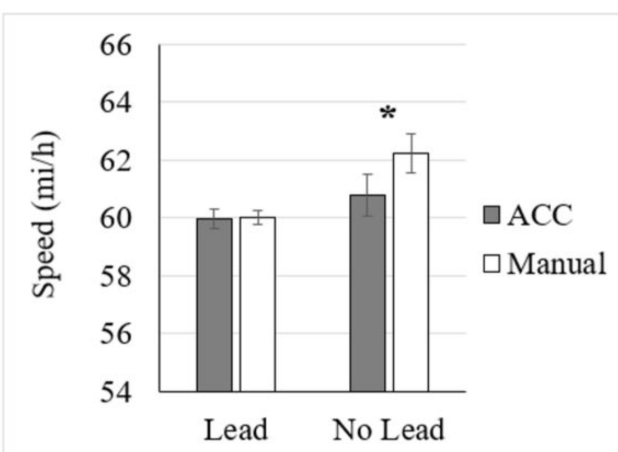
Participants exhibited less variable steering when driving with ACC than when driving manually. Because greater steering variability may lead to lane exceedance and, therefore, increase the risk of collision with other vehicles or roadway features, lower steering variability is generally indicative of safer driving.

A postdrive questionnaire revealed that participants had a mean familiarity with ACC of 1.5 on a scale of 1 (very unfamiliar) to 4 (very familiar), indicating that most participants were not familiar with the technology. In contrast, mean route familiarity was 2.88 on the same scale, suggesting that most participants were somewhat familiar with the experimental route.

The major findings of the study included the following:

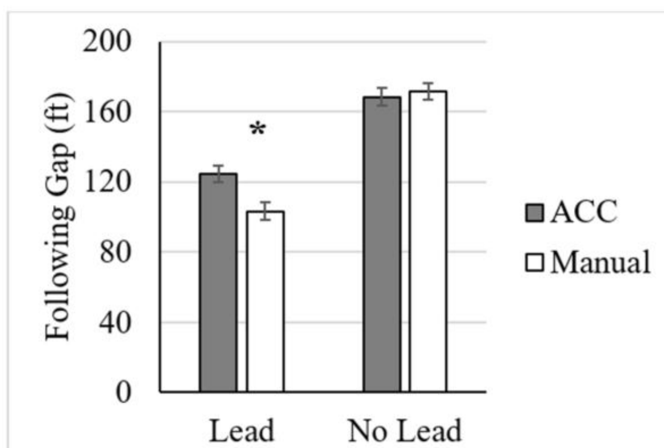
- Mind-wandering rates while using ACC were not higher than those during manual driving.
- Measures of EDA suggested increased physiological arousal during ACC use compared to manual driving.

Figure 3. Graphs. Speed and following gap as a function of ACC and lead-vehicle condition.



Source: FHWA.
*Significant difference.
Note: Error bars represent the standard error of the means.

A. Speed as a function of ACC and lead-vehicle condition.



Source: FHWA.
*Significant difference.
Note: Error bars represent the standard error of the means.

B. Following gap as a function of ACC and lead-vehicle condition.

- ACC use was associated with decreased speed, longer following gaps, and reduced steering variability compared to manual driving.
- Most participants were unfamiliar with ACC prior to completing the study.

DISCUSSION

The study did not find evidence of increased mind wandering in drivers using ACC. In fact, female drivers reported reduced rates of mind wandering when driving with ACC relative to manual driving. Similarly, drivers' physiological arousal increased when driving with ACC, with a greater number of SCRs occurring in drivers using ACC than those driving without it. Driving with ACC also tended to be associated with improved driving performance, including reduced speeds, increased following gaps, and reduced steering variability. Together, the results suggest that ACC did not negatively affect driving performance and may even have positive effects on driver safety.

The current findings, which indicate drivers experienced similar and even decreased rates of mind wandering and increased arousal while using ACC, stand in contrast with previous work that suggests increases in vehicle automation are associated with reduced situational awareness.[20–22] There are several potential explanations for this difference, including the following:

- The lack of increased mind-wandering rates associated with ACC use in this experiment may be due to the low level of automation that was tested. Previous studies exploring the effects of automation on driver awareness and performance have tended to examine more highly automated vehicles.[3,20,21] Drivers who are still responsible for the majority of driving functions, including lateral control, may be more likely to remain engaged in the driving task than drivers who use higher levels of automation.[22]
- Whereas the majority of previous studies on ACC and mind wandering were conducted in driving simulators, the current study was conducted in a field-research vehicle traveling on a live roadway. Drivers, in the safety of a simulation, may test the limits of the automation to learn more about the system without the risk of crashing. However, when interacting with the same technology on a real roadway, drivers who are unfamiliar with a technology may exercise extra caution until they learn more about the automation. Simulator studies that reported reduced safety with automated systems typically used drivers who were unfamiliar with the technology.[13] As a result, the reductions in performance identified in previous studies may have been due, at least in part, to participants' failure to fully understand the automation rather than their reduced attention to the roadway.[23] In the current study, 67 percent of drivers reported being very unfamiliar with ACC. These drivers may have increased their alertness to monitor the ACC system. Thus, the potentially negative effects of vehicle automation suggested by driving simulator findings may be overexaggerated for drivers on live roads who have limited familiarity with the technology.
- Lack of familiarity with ACC may have led to reduced levels of trust in the system. In turn, this circumstance could have influenced levels of physiological arousal. It is unclear whether these same effects would be found among drivers with greater familiarity with ACC. Consequently, if the current findings are a product of distrust in automation, mind-wandering rates may increase as drivers gain experience using ACC.
- Further experience with ACC may result in drivers' mind-wandering rates aligning with those found among manual drivers. Alternatively, drivers with increased trust in ACC may over-rely on the technology, such that mind-wandering rates and associated reductions in driving performance would come to exceed those found among manual drivers.[24] The lack of variability in experience using ACC among participants in the current study prevented empirical assessment of this issue.

CONCLUSIONS

Overall, the results of this experiment provide evidence for possible safety benefits associated with ACC use in drivers who are unfamiliar with the technology. When ACC was engaged, drivers exhibited improved driving performance, increased physiological arousal, and no evidence of increased mind wandering relative to when driving without ACC. The study highlights the value of conducting research on vehicle automation on live, public roadways to assess the potential risks and safety benefits associated with advanced driver-assistance systems. In addition, these findings suggest that drivers' familiarity with and trust in ACC should be considered in future research, and further study of the potential long-term effects of ACC on mind wandering is warranted.

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