Driver Distraction and Advanced Vehicle Assistive Systems (ADAS): Investigating Effects on Driver Behavior

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Abstract The component technologies of Advanced Driver Assistive Systems (ADAS) are becoming increasingly automated, with systems capable of operating in concert in multiple driving environments. However, how these systems affect a driver's ability to safely, efficiently, and comfortably operate a vehicle remains unclear. We investigated the effects of ADAS [specifically Lane Departure Warning (LDW)] on driving performance while participants performed a secondary task (mental math) designed to simulate cognitive effort while driving. The experiment was conducted on a closed-course test track in an instrumented vehicle. Results suggest that cognitive engagement influenced driver control of the vehicle. Effects of cognitive engagement in a secondary task were not mitigated by the presence of LDW. We discuss our results in the framework of a continued need for active input and control from the human operator in vehicles with assistive technologies.

Keywords Human factors · ADAS · LDW · Distraction

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1 Introduction

With the advent of advanced driver assistive systems (ADAS), such as lane departure warning, blind spot indication, forward collision warning and mitigation, and autonomous braking, drivers will be exposed to novel situations in which they must simultaneously prioritize and respond to vehicle assistive technologies and on-road conditions. ADAS technologies were designed to reduce driver error and enhance the overall safety of ground transportation [1]. Currently available statistics from the Insurance Institute of Highway Safety (IIHS) indicate certain ADAS systems appear to reduce property damage and liability claims [2]. However, understanding the impact of vehicle assistance technologies on driver behavior and vehicle control has lagged behind the evolution of the technology. Much of the current understanding on the behavioral impacts of ADAS has been gained from naïve drivers' initial exposure to systems in driving simulators. These studies show that the presence of assistive technologies has been associated with behavioral changes in drivers including increased complacency, reduced human supervision of the technologies, and increased likelihood of engaging in secondary tasks [1, 3–6]. As a result, there is growing concern that drivers are unable to take control of the vehicle in emergent, safety-critical situations which automated systems are typically unable to handle.

More specifically, scientific studies have investigated the effects of various ADAS technologies on driver performance. For example, several studies have focused Lane Departure Warning (LDW) technologies and their effect on driver behavior. LDW typically consists of a passive audio and/or visual warning that the driver is departing the lane of travel, and requires that the driver maintain both speed and lane position. Studies of driver behavior when utilizing LDW present a generally optimistic view of driver interaction, including that drivers reduce the number and frequency of lane departures [7, 8], increase the use of turn signals [7], and respond more quickly to events even when drowsy [9]. Furthermore, one study showed that intermittent removal of the LDW did not lead to increases in near-misses or collisions [10], suggesting that drivers maintain awareness of lane position independently when LDW is present, though not consistently active.

The performance of secondary tasks while driving typically results in negative effects on performance of the primary driving task. For example, secondary task performance has been associated with increased deviations in lane position with some tasks [8, 11], decreased deviations in lane position with other tasks [12], and reduced or more variable speeds [13, 14]. While drivers have been shown to be significantly more likely to participate in secondary tasks when utilizing ADAS technologies [15–17], it remains to be seen whether ADAS technologies will mitigate the negative effects of such tasks. Furthermore, secondary tasks represent an interesting method by which to study not only the effects of the tasks themselves, such as texting while driving, but more general effects, such as visuomanual distraction while driving. This is important because tasks such as navigation can be considered cognitive or visual distractions from the primary task of controlling the vehicle. Distractions can be categorized as visual, manual, or cognitive [18]. These categories of distractions may differentially affect aspects of driving performance. Similarly, different ADAS technologies may support driver performance in the presence of specific types of distractions by secondary tasks.

Driver response to ADAS has not been thoroughly studied in dynamic, naturalistic conditions where drivers must interact with ADAS systems in the presence of common driver tasks or challenges (e.gs., vehicle following, curve negotiation, maintaining lane position, and performing secondary tasks). Additionally, the impact of assistive technologies on driver input and control of the vehicle (e.g., accelerator position, steering input, and speed) during on-road driving is lacking. Accordingly, of the current study evaluated driver-vehicle interactions under common on-road conditions in the safety of a closed-course test track. We specifically examined how drivers respond to the LDW system while simultaneously performing a task designed to simulate cognitive engagement, and looked at the differential impact on vehicle control metrics. Consistent with existing findings in simulators, the use of LDW was expected to reduce the variance observed in steering wheel position. Similarly, we hypothesized that participants performing a secondary task would exhibit changes in lateral vehicle control and speed. Finally, we predicted that if the LDW system was sufficiently salient and effective, changes in the variance of steering wheel position and potentially speed would be observed when drivers were performing the cognitively demanding secondary task.

The analyses focused on data from participants' initial exposure to LDW, as studies suggest increased experience may affect the way drivers interact with the systems [19, 20]. Overall, this study serves as a field test of LDW on driver behavior and vehicle control during common driving behavior including, lane maintenance, curve negotiation, car following, and secondary task performance.

2 Experiment

To investigate how LDW may affect driver behavior with and without cognitive engagement, we conducted an on-road, closed-course experiment at Exponent's Testing and Engineering Center in Phoenix, Arizona. The experiment was completed over the course of three visits; for this analysis, we examined driver performance metrics in the first visit only.

2.1 Methods

Participants. Twenty adults (15 female; median age 46.5 years; age range: 32–57) recruited from the Phoenix area participated in this study. Participants all had a valid driver's license, normal or corrected-to-normal vision and were screened to ensure that they did not currently drive a vehicle equipped with ADAS technologies.

Facility and Equipment. The experiment was conducted on a two-mile oval track and a 10-acre skid pad at Exponent's Test and Engineering Center. A single lane was painted on the track for testing. On each straightaway the lane shifted at the halfway point and transitioned either from wide to narrow or narrow to wide (see Fig. 1). The narrow sections of the lane markings were approximately seven feet in width and the wide sections were approximately 11 feet in width. To increase similarity to the natural driving environment, the test track environment included roadway signage and a simulated bus stop placed around the course of the track.

The test vehicle was a 2014 luxury sedan equipped with several driver assistance technologies, including an LDW system. The LDW system consisted of both auditory (series of beeps) and visual (digital display of a vehicle leaving a lane on the instrument cluster when sensors detected the vehicle was moving outside of the lane lines) warnings. The variable width and shifting of the lane was used to maximize the likelihood of participants receiving LDWs. LDW was activated or deactivated by the experimenter on the appropriate laps using the infotainment system in the center stack.

Data Collection Equipment. The test-vehicle was instrumented with four lipstick cameras and a laptop computer equipped with data recording software collecting information from the vehicle's Controller Area Network (CAN) bus. The CANbus recording software was utilized to record status information of the relevant state of various vehicle systems including, but not limited to, activation of ADAS, steering wheel angle, accelerator position, vehicle speed, engine RPMs and brake activation. Cameras were mounted over each side-view mirror, pointed at the ground to provide visual indications of lane position and instances of lane departure. Additional cameras were mounted inside the vehicle and captured the instrument cluster and an over-the-shoulder (driver's left shoulder) view of the roadway. A lead vehicle was driven by an experimenter for all testing laps.

Procedure. The full experiment was completed across three visits, each separated by approximately one week. On each visit, participants completed 12 laps around the 2-mile test track following the lead vehicle. ADAS conditions were varied throughout the laps such that equal numbers of laps were completed with no ADAS, with LDW only, with Adaptive Cruise Control (ACC), and with both LDW and ACC. In the present analysis, we examined only the effects of LDW alone, relative to the effects of no ADAS. Analyses of the effects of ACC or the effects of the combination of various ADAS technologies will be discussed in future publications. During each lap, participants followed a lead vehicle that controlled the pace and driving route. The lead vehicle varied its speed from between 40 and 50 mph during all laps.

Some participants were randomly assigned to perform a secondary task (i.e., cognitive or manual tasks) on every third testing lap. Participants who completed a mental math task, meant to induce cognitive distraction, were examined here here; data from three participants who completed other tasks were not considered for this

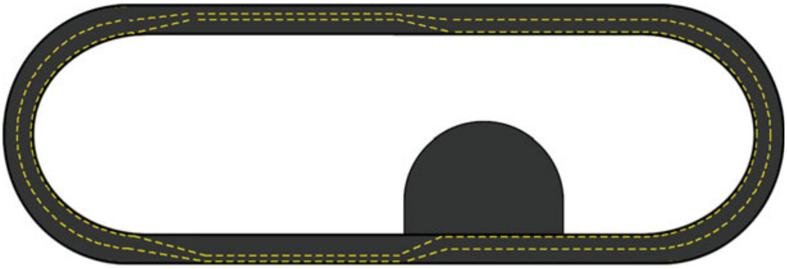

Fig. 1 General layout of test track and lane markings

analysis. The mental math task required participants to verbally answer multiplication problems administered by an experimenter seated in the passenger seat of the test vehicle. The presentation rate of the problems was controlled by how quickly each participant answered them. Mental math was performed only in the straightaways of the testing track.

Analysis. Data from the vehicle's CANbus were extracted for each participant. Data for each lap were manually separated into individual laps. Accuracy of the data separation was confirmed by comparing the data to the videos of each lap. The dependent variables of interest in the current analyses were steering wheel angle and vehicle speed. Vehicle speed was initially recorded in kilometers per hour (kph), and was converted to miles per hour (mph). Data from one subject was removed due to technical difficulties during data collection. Data for two additional participants were removed due to data collection in unusually dark lighting conditions. Data from the remaining 14 participants were submitted for this analysis.

The variance in steering wheel angle and in vehicle speed was quantified using the standard deviation (SD) for each metric, separately for each testing lap. Standard deviations were then analyzed using a 2 (ADAS Condition) × 2 (Secondary Task) mixed measures ANOVA. T-tests were conducted to further examine the differential effects of mental math with and without LDW.

3 Results

3.1 ADAS Condition

Presence of LDW did not significantly affect SD of steering wheel angle ($p = 0.75$), or SD of vehicle speed ($p = 0.37$).

3.2 Mental Math

Performing mental math marginally affected SD of steering wheel angle (p = 0.076), such that SDs were reduced during mental math (M = 8.019°) as compared to SDs when driving only (M = 8.48°). However, mental math also significantly affected SD of vehicle speed (p = 0.045), such that SD of vehicle speed was *increased* when performing mental math and driving (M = 15.83 mph) when compared to driving only (M = 12.14 mph).

3.3 Interaction Between LDW and Mental Math

Performing mental math did not interact with LDW to affect SDs of steering wheel angle (p = 0.99). Mental math also did not significantly interact with LDW to affect SDs of vehicle speed (p = 0.57), although examination of the data indicates that SDs when performing mental math while utilizing LDW (M = 17.36 mph) were numerically higher than SDs when driving only and utilizing LDW (M = 12.63 mph; p = 0.10); see Fig. 2.

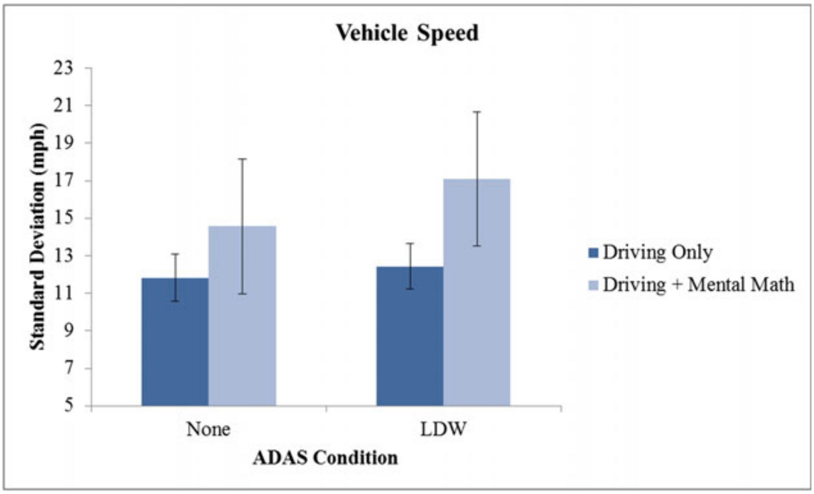

Fig. 2 Standard deviation in vehicle speed

4 Discussion

The present results indicate that LDW did not affect variation in the vehicle control metrics we examined. Consistent with existing scientific literature, we found that performance of a secondary tasks did affect vehicle control, specifically variations in steering wheel angle and speed control. We anticipated that LDW may reduce the effect of the secondary task. This hypothesis was supported by the null effect of mental math on variation in steering wheel angle in the presence of LDW, despite a marginally significant effect of mental math on variation in steering wheel angle overall. However, as shown in Fig. 2, the difference between SDs in speed when performing mental math and when driving only were actually greater in the presence of LDW than without any ADAS. Taken together, our results suggest that passive ADAS technologies such as LDW may not fully compensate for the effects of cognitive distractions on vehicle control. Our results further suggest discrete effects of LDW as a reminder to maintain lateral control, rather than a more general reminder to attend to the vehicle's position.

The current analyses focus on the first day drivers were exposed to LDW. Existing literature suggests that effects of ADAS may change over time and with increasing experience with the technologies. Future analyses will examine how these patterns might change as drivers gain experience and familiarity with ACC and LDW. It should also be noted that we examined relatively few laps with mental math when compared to laps without a secondary task. Thus, while our results indicate several marginal effects or trends, it is likely that with increased observations, the results would show statistical significance. Regardless, the effects of cognitive distraction, such as that experienced when engaged in conversation while driving, on both lateral and longitudinal control when following a lead vehicle are highly relevant in terms of everyday situations.

5 Conclusion

These preliminary results suggest that cognitive engagement affects vehicle control in on-road situations and is not fully compensated by the presence of ADAS. While it may be hoped that ADAS technologies will help reduce driver workload, our results support a growing body of evidence that such technologies cannot replace an alert, attentive driver when considering safe operation and control of a motor vehicle in naturalistic on-road conditions.

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