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Observed Differences in Lane Departure Warning Responses during Single-Task and Dual-Task Driving: A Secondary Analysis of Field Driving Data

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Abstract

Advanced driver assistance systems (ADAS) are an increasingly common feature of modern vehicles. The influence of such systems on driver behavior, particularly in regards to the effects of intermittent warning systems, is sparsely studied to date. This paper examines dynamic changes in physiological and operational behavior during lane departure warnings (LDW) in two commercial automotive systems utilizing on-road data. Alerts from the systems, one using auditory and the other haptic LDWs, were monitored during highway driving conditions. LDW events were monitored during periods of single-task driving and dual-task driving. Dual-task periods consisted of the driver interacting with the vehicle's factory infotainment system or a smartphone to perform secondary visual-manual (e.g., radio tuning, contact dialing, etc.) or auditory-vocal (e.g. destination address entry, contact dialing, etc.) tasks. Driver physiology and behavior were recorded and analyzed during pre-LDW event and post-LDW event epochs. The percentage changes between pre-event and post-event measures were calculated to normalize for differences between vehicles. Changes in heart rate, skin conductance level, and steering wheel angle were observed after LDW events during single-task and dual-task driving periods. These metrics varied between single-task and dual-task driving, and between pre-event and post-event epochs. These results suggest a relationship between a driver's demand level and the driver's response to a lane departure warning signal.

Introduction

Historically, in-vehicle safety systems were comprised of "passive" mechanisms such as seatbelts, windshield safety glass, airbags, and so forth. One class of ADAS, often referred to as "active" safety systems, are designed to monitor a vehicle's surroundings and detect what the driver cannot. Unlike traditional passive safety systems which intend to limit the damage caused by the accident event itself, active safety systems play a role in preventing accidents and reducing accident severity, either by interceding in vehicle control or alerting the driver to unsafe conditions and behaviors. In order for such systems to succeed, they must convey information and assist the driver in a manner that will facilitate the driver's ability to react promptly and appropriately to the potential situation. One of the more well-known examples of an active safety system is the lane departure warning (LDW) system. This feature is designed to detect when the vehicle is drifting out of a lane and to alert the driver. In such situations, the vehicle will often alert the driver with an auditory signal in the form of a high pitched beep, a tactile signal (pulse vibration) in the steering wheel or seat, a visual signal in the form of a flashing light, or a combination of multiple signals. It is important to engineer these systems to elicit the fastest possible effective response, while not distracting or placing too much demand on the driver from the alert itself. Due to the increasing availability and affordability of active safety systems, there is an imminent need to evaluate the effectiveness of alerts so that consumers who are introduced to these technologies will develop a familiarity and comfort with systems that allow them to best leverage the advantages offered by the technologies (e.g. appropriately respond to unexpected events in the external environment) without being overly drawn to the attentional alert or compensating for the added automation (e.g. increased texting, etc.).

Research on the efficacy of LDWs is sparse, largely due to the relative novelty of these systems at a production level. Initial studies indicate possible advantages to employing these systems, primarily demonstrating that drivers are able to appropriately respond to both auditory and haptic warnings [1,2]. However, much of this research has been conducted in driving simulators, opposed to real world driving conditions. One of the few studies consisting of on-road evaluations of driver's LDW responses suggests that, although drivers respond to both auditory and haptic alerts, haptic alerts elicit a slightly faster response [3].

One drawback to the previous research on LDWs is that it does not take a holistic approach to the modern driving environment. The full complexity of all of the information available to a driver must be considered when evaluating yet another signal that demands a driver's attention on a daily basis. Previous research has focused on how a driver responds to alerts during single-task driving (the driver only focuses on driving), but many drivers on the road today are doing more than just driving, especially with the growth of in-vehicle

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infotainment and telematics devices as well as smartphones and personal mobile technology [4]. It is important to be aware that many vehicles that include active safety systems also include newer multimodal interfaces (i.e., interactive displays and voice interfaces).

Dual-task driving (driving while performing another task) is often correlated with an increase in variability of lane position and velocity compared to single-task driving [5].While such effects on vehicle control metrics are relatively easy to observe, the cognitive demands associated with dual-task driving are still relatively difficult to measure. Research suggests that increased cognitive demand pulls driver attention away from environmental cues and events [6]. As active safety systems become both commonplace and necessary, the effect of safety system alerts should be studied alongside dual-task driving to help elucidate the best ways to convey warning information to drivers that are under single, as well as dual-task demand.

Using existing field data collected from two vehicles (2013 - Volvo XC60 and 2014 - Mercedes CLA250) that employ different LDW systems with different alert modalities, it is possible to begin inquiring about the efficacy of different alert types. Both vehicles have similar, yet distinct, infotainment systems with screens located in the center stack that support both manual and voice interfaces. These vehicles allow drivers to perform a variety of secondary tasks with varying levels of cognitive, visual, and manual demand in a highway driving environment.

The goal of this secondary analysis is to assess the ways that drivers react to LDW alerts during single-task driving, as well as while driving under varying levels of dual-task demand. It was expected that this study would provide further understanding of the influence that specific secondary tasks, and characteristics of secondary tasks, have on LDW occurrences and the way drivers react to LDWs. Additionally, an attempt is made to investigate whether different LDW alert modalities elicit different response characteristics from drivers. This work is presented with a firm appreciation that multiple differences exist between the LDW technologies and vehicles studied and that naturalistic utilization of systems may vary from the experimentally based observations in this study sample.

Methods

Participants

Eighty participants were included in this analysis, drawn from two larger studies on the use of in-vehicle devices during highway driving [7, 8]. Each of the two samples was equally balanced by gender and age group. The age groups were 20-24, 25-39, 40-45, and 55+, following NHTSA guidelines [9]. One dataset consisted of 32 participants who drove a 2013 Volvo XC60; the other dataset consisted of 48 participants who drove a 2014 Mercedes-Benz CLA250. Each participant drove only one of these two vehicles. All participants drove on average three or more days a week, were in reasonably good health for their age, and had possessed a valid driver's license for more than three years. One hundred and fifty dollars in compensation was provided for participation in each study. All participants provided informed consent in accordance with guidelines established by the Massachusetts Institute of Technology's institutional review board.

Apparatus

The Volvo was equipped with a factory installed LDW system, which provided an auditory warning to the driver. The Volvo also had a Sensus infotainment system, drivers interacted with this system though either the voice interface or manual controls on the center stack below the system's display. Drivers in the Volvo also interacted with a Samsung Galaxy S4 smartphone, which was mounted via a stand attached to the center stack by the lower right corner of the infotainment screen. The phone was placed within reach of the participant so they could interact with the touchscreen of the phone as well as manually activate the phone's voice interface (with Hands-Free Mode on) by pressing the "home" button. The Mercedes was equipped with factory installed LDW system, which provided a non-directional vibrotactile warning to the driver through the steering wheel. The vehicle was also equipped with a COMAND infotainment system. The COMAND system utilized both a voice interface as well as manual controls positioned on the center console to control infotainment features.

Both vehicles were instrumented with embedded sensors for time synchronized data collection. The data acquisition configuration consisted of recordings of the vehicle's controller area network (CAN), audio recording from the vehicle's cab, video recording of the driver's hand, head, and eye movements, and a MEDAC System/3 physiological monitoring instrument (NeuroDyne Medical Corp., Cambridge MA). Data was logged at 10 Hz, except for physiological signals, which were logged at 250 Hz.

Procedure

Data was collected north of Boston, Massachusetts on Route I-495. Both vehicles followed the same route. Data collection was conducted during times when high density traffic and weather conditions did not substantially effect steady state driving.

After providing informed consent and passing a final screening of the study inclusion criteria, participants were brought to the research vehicle and trained to perform certain tasks with the vehicle or smartphone's interface. These tasks consisted of using the voice interface to call a stored contact, using the voice interface to enter an address into the GPS navigation system, manually call a stored contact, and manually change the radio station. An overview of the safety features of the vehicle was given, educating the participants on the LDW and forward collision warning systems specific to that vehicle, as well as the blind spot detectors and rear back up cameras.

Prerecorded audio prompts were presented during each drive, instructing participants to perform specific tasks at various points during the trip. Periods of single-task driving were recorded in two-minute epochs before each block of secondary tasks. Participants driving the Volvo performed three navigation address entry tasks with the vehicle's embedded voice interface, four contact dialing tasks with the voice interface, four contact dialing tasks using the embedded manual interface, and four manual radio tuning tasks. These participants also interacted with the smartphone to perform three navigation address entry tasks with the voice interface, four contact dialing tasks with the voice interface, and four manual contact dialing tasks. Participants in the Mercedes performed three navigation entry tasks with the embedded voice interface, four contact dialing tasks with the voice interface, and four manual radio tuning tasks.

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The tasks were designed to the extent possible to be consistent across vehicle and interface (e.g. the first address all drivers were presented with was always the same, etc.)

Data Analysis

This analysis focuses on the periods of time before and after the occurrence of LDW events during single-task and dual-task driving, as well as the frequency of LDW alerts and under what conditions they occurred. The driver's heart rate and skin conductance level recordings were edited by trained researchers to remove artifacts and then reviewed to ensure accuracy and consistency. The videos from cameras positioned to record participants' head and eye movements were manually annotated for glance location. Each video was independently annotated by two trained coders and mediated by a third coder, in accordance with established guidelines on the collection and processing of glance behavior from video [10,11]. CAN signals from both vehicles were recorded and queried for steering wheel angle and the occurrence of safety system alerts. Steering wheel angle was analyzed using the raw steering wheel angle recording at 10 Hz to calculate the absolute value of each change in angle. The sum of these absolute values was used in the analysis as a measure of the amount of change in the vehicle's heading irrespective of direction (so that a leftward adjustment does not "cancel" a rightward adjustment, and the total motion of the wheel is represented during key epochs). Each vehicle's data acquisition setup also allowed for researchers to calculate task completion times, or the length of time from when a participant was instructed to begin a secondary task to when the task was completed (or a failure point was reached).

All cases where two or more alerts occurred during the same task or baseline (three cases overall) were excluded from analysis to remove any potential influence of overlapping events. While the occurrence of multiple alerts in one task is worth noting, the frequency of such events was too small to make any reliable analytical assessments. Dual-task periods were categorized by modality and interface, allowing for the comparison of three systems (Sensus, COMAND, and Samsung Galaxy) and two input modalities (auditory-vocal and visual-manual), as well an analysis of specific task type (voice navigation entry, voice call, manual call, manual radio tuning). Situations where LDWs occurred were compared to situations where LDWs did not occur, as well as baseline driving sections. This helps to demonstrate the kinds of effects LDWs have on dual-task driving, and the kinds of effects dual-task driving has on LDWs. Data were post processed and analyzed in R [12]. Repeated measure ANOVA tests were performed on key measures, and statistical significance was defined by a value of $p < .05$.

Results

Single and Secondary Task Sample Time

While driving the Volvo, each participant spent on average 11.25 minutes (SD = 1.45) performing auditory-vocal tasks with the vehicles' embedded interface, 3.37 minutes (SD = .89) performing visual-manual tasks with the embedded interface, and a total of 14 minutes (SD = 0) in designated single-task ("baseline") driving periods. While using the mounted Samsung Galaxy, participants spent an average of 2.69 minutes (SD = .81) performing auditory-vocal tasks, and 1.95 minutes (SD = .81) performing visual-manual tasks. In the Mercedes, participants spent 6.28 minutes (SD = 1.34) on average performing auditory-vocal tasks with the vehicle's embedded voice interface, .85 minutes (SD = .22) performing visual-manual tasks, and 6 minutes (SD = 0) in designated single-task driving periods.

Lane Departure Warning Event Frequency

Fifty-four of 80 participants experienced lane departure warnings during single or dual-task periods (21 in the Volvo and 33 in the Mercedes). For participants driving the Volvo, the LDW alert was triggered 23 times during single-task driving and 38 times during secondary task driving when using the embedded interface. When Volvo drivers were using the smartphone, there were 27 alerts. Mercedes drivers experienced 42 events during single-task driving and 45 during dual-task driving. Table 1 shows the breakdown of LDW events by specific tasks.

Table 1. Total LDW events for all participants by task and interface.

	Voice Navigation	Voice Call	Manual Call	Manual Radio
Smartphone	6	6	15	n/a
Volvo HMI	14	7	12	5
Mercedes HMI	24	7	n/a	14

Figures 1 and 2 show the rate of LDW alert occurrences for each interface during dual-task driving periods and single-task driving periods. LDW rates were normalized by the average number of LDW events per minute for dual and single-task driving across all participants (Figure 1). LDW rates were also normalized by the total number of task periods that occurred (Figure 2). There was a significant main effect of modality (single-task, auditory-vocal, or visual-manual) ($F(2,198) = 9.07$, $p < .001$), with visual-manual tasks having a much higher rate of LDW alerts per minute compared to single-task driving and auditory-vocal secondary tasks. There was no significant main effect of vehicle or interface type (embedded or smartphone).

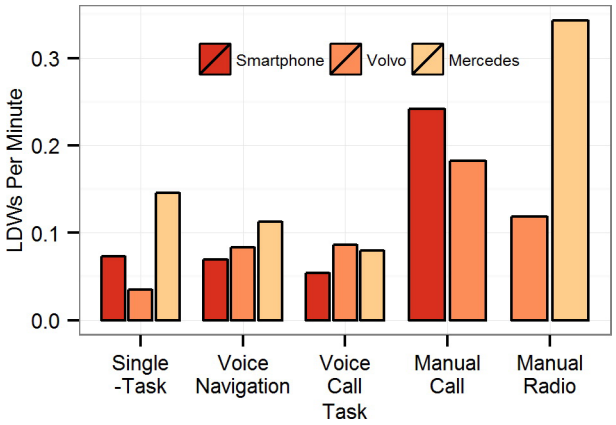

Figure 1. Mean frequency of LDW occurrences per minute of driving for each task type and vehicle.

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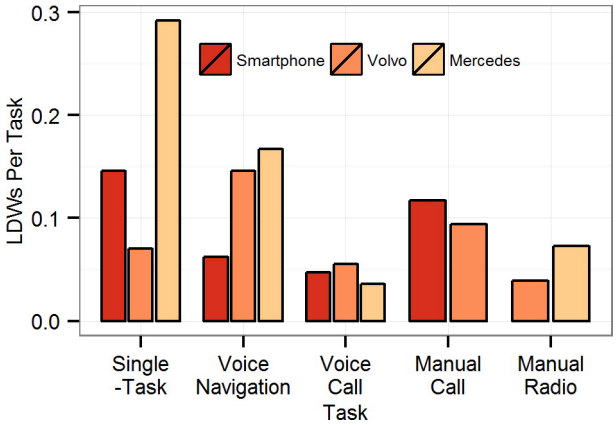

Figure 2. Mean frequency of LDW occurrences per task period for each task type and vehicle.

Task Completion Time

LDWs occurred intermittently throughout each drive, allowing dual-task periods in which LDWs occurred to be compared to periods in which they did not. Participants performed tasks significantly faster in interaction periods when LDWs did not occur ($F(2,130)=91.81$, $p<.001$) regardless of interface type or vehicle. Figure 3 shows the percentage difference between task completion times when LDWs were and were not present by interface and task modality. The two embedded vehicle interfaces were associated with longer relative increases in task completion times for auditory-vocal tasks compared to visual-manual tasks when LDWs were present. The smartphone showed the opposite trend, with longer task completion times with visual-manual tasks when LDWs were present.

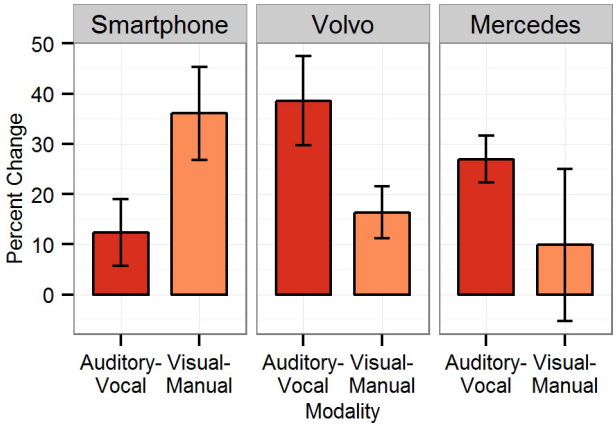

Figure 3. Difference in task completion time between LDW and non-LDW conditions. The positive percentage difference values indicate that the task completion times were longer when an LDW was present. Error bars represent ±1 SEM.

Glance Behavior

Glance behavior during single-task driving in the Mercedes had not been annotated at the time of analysis, and therefore does not appear in this report. Coded glance location data was analyzed for 5 second epochs before and after each LDW alert. This analysis primarily focused on off-road glances, or when the driver was not looking at the forward road scene, in accordance with NHTSA guidelines [9]. The percentage of time spent glancing away from the forward roadway was calculated for each 5 second epoch. In the majority of cases (6 out of 8), participants exhibited a decrease in off-road glance percentage after a LDW alert occurred (i.e. they showed an increased orientation toward the forward roadway as a result of the LDW). Table 2 shows the mean off-road glance percentage of the 5 second epochs before and after each LDW across all periods. Overall, post-LDW off-road glance percentages were significantly smaller than pre-LDW ($F(1,207)=5.05$, $p=.02$). There was also a significant effect of task type (single-task driving, visual-manual, and auditory-vocal) on off-road glance percent both before and after LDWs ($F(2, 112)=5.32$, $p=.006$). Visual-manual tasks had consistently higher off-road glance percentages (mean= 48.99, SD =17.54) before and after LDW alerts, while single-task driving had consistently lower off-road glance percentages (mean = 38.19, SD = 14.95); and auditory-vocal tasks (mean = 42.85, SD= 17.11) fell in between.

Table 2. Mean pre-LDW and post-LDW off-road glance percentage by vehicle and task type.

	Single-task		Visual-Manual		Auditory-Vocal	
	Pre	Post	Pre	Post	Pre	Post
Smartphone	35.76	37.64	51.33	41.73	47.42	37.81
Volvo	46.89	40.02	52.32	54.32	47.50	41.25
Mercedes	n/a	n/a	51.73	41.53	43.73	40.26

Steering Wheel Angle

In order to examine the time course of lateral control immediately after LDW events, steering wheel angle metrics were aggregated across the 1.2 seconds after an event in bins of 0.3s (Figure 4). This style of analysis was chosen to replicate a previous analysis that utilized different portions of this dataset [3].

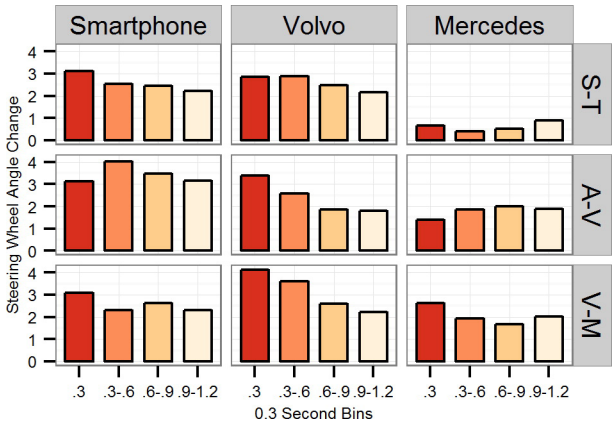

Figure 4. Mean change in steering wheel angle across 0.3 second bins by task modality; single-task (S-T), auditory-vocal (A-V), visual-manual (V-M), and vehicle.

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When performing visual-manual tasks, drivers, on average, showed the largest changes in steering wheel angle during the first 0.3 seconds. For the in-vehicle systems, this initial response to the LDW alert was, on average, larger than the initial responses to LDWs during auditory-vocal and single-task driving periods.

Changes in total steering wheel angle adjustments during 5 second epochs before and after LDWs did not show a clear pattern (Table 3). In some cases there was a higher rate of steering wheel movement after the LDW, and in some cases there was a lower rate. There was no main effect of interface, but there was an overall effect of modality on steering wheel angle changes ($F(2,81)=4.26$, $p=.017$). Single-task driving did exhibit a lower rate of steering wheel movement when combining both before and after LDWs (mean = 7.52, SD= 6.27). Secondary task driving periods also exhibited an overall greater amount of steering wheel angle changes compared to single-task driving before and after LDWs. Visual-manual tasks had a mean steering wheel angle change of 10.94 (SD= 6.93), and auditory vocal tasks had a man of 9.99 (SD=7.33).

Table 3. Pre- and post-LDW steering wheel angle changes for 5-second windows.

	Single-Task		Visual-Manual		Auditory-Vocal	
	Pre	Post	Pre	Post	Pre	Post
Smartphone	5.82	5.24	9.44	6.34	9.14	9.47
Volvo	6.47	8.35	11.06	14.49	8.22	7.77
Mercedes	8.03	8.02	12.85	11.35	10.98	11.59

Physiological Responses

In a similar fashion to the analysis of the steering wheel angle and glance behavior, heart rate and skin conductance measures were extracted for 5-second epochs before and after each LDW alert. The majority of heart rate measurements decreased after each lane departure. The magnitude of post-LDW heart rate was normalized as the percentage change from pre-LDW heart rate. The smallest decreases (and largest increases) in heart rate were observed during the visual-manual tasks. These trends were not significant.

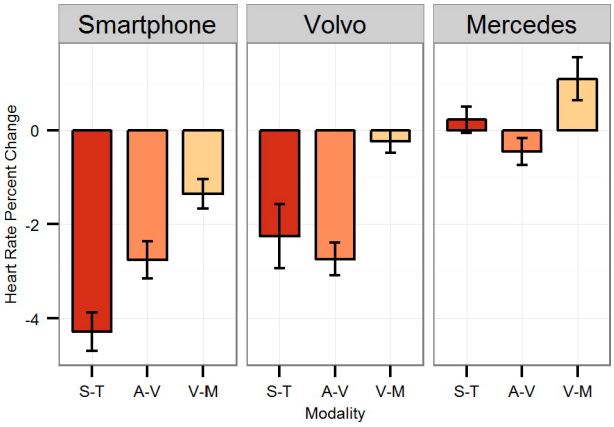

Figure 5. Percentage change in heart rate for 5 second windows after each LDW occurrence by task modality and vehicle.

Skin conductance data show the opposite trend. The percentage change in skin conductance (normalized in the same manner as heart rate) increased after the LDW alert in the majority of cases. This trend was also not significant.

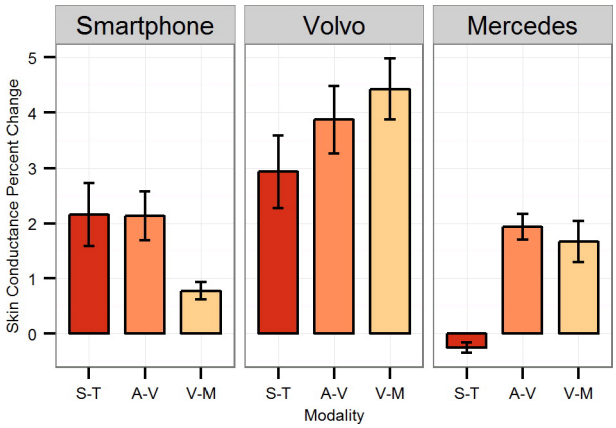

Figure 6. Percentage change in skin conductance level for 5 second windows after each LDW occurrence by task modality and vehicle.

Discussion

The significant differences in lane departure warning frequencies between single-task and dual-task driving periods suggests that there is a correlation between secondary task demand and vehicle control. The higher rate of lane departures during visual-manual tasks is concurrent with previous research. Drivers placed under higher levels of demand, especially visual-manual demand, have more variable rates of steering wheel position [6] which in these data are associated with lane departures. The Mercedes' in-vehicle manual interface had the shortest overall interaction time, and this task (manual radio tuning) had by far the highest rate of LDWs per minute. This demonstrates how strong of an impact a visual-manual task can have on a driver's ability to control lane position, even, or especially, during brief interactions.

Longer task completion times were associated with the presence of LDW events during the task. One can speculate that the intrusion of the LDW alarm into the task context causes the driver to disengage from the secondary task and reallocate attention to the primary task of driving, thus producing longer secondary task completion times. Conversely, it is possible that the LDW occurred *because* of the higher level of demand associated with that specific task or other environmental conditions at that specific time; these factors may have influenced task completion time as well as the lane departure. The available data do not, at present, make it possible to disambiguate the directionality of this effect.

Auditory-vocal tasks performed with in-vehicle interfaces had higher task completion times when LDWs occurred compared to visual-manual tasks. The opposite trend was found with tasks performed with the Samsung Galaxy smartphone. There are several factors that could be responsible for this. The placement of the smartphone and its screen size may have made it more difficult to read. The smartphone also required participants to interact with it through a touchscreen interface, while the in-vehicle interfaces utilized stationary knobs. The presence of the LDW alarm may have a greater impact on the high level of hand-eye coordination required to perform a visual-manual task with a touchscreen device, leading to such a drastic increase in task completion time compared to when no LDWs were present.

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Previous research that examined the subsample of Volvo drivers in this study found that dual-task driving had an impact on the drivers' glance patterns [7]. The present analysis supports these previous findings, demonstrating that visual-manual tasks require a greater percentage of off-road glance time compared to auditory-vocal tasks and single-task driving. The reductions in the percentage of off-road glance time immediately after an LDW indicates that LDWs may help a driver reallocate his or her eyes to the road even when under dual-task driving demand. This reallocation of attention may also be responsible for the increase in task completion time observed when LDWs occur. Moving attention back to the road from a secondary task may inhibit the driver's ability to quickly complete a task.

Steering wheel angle changes may be a promising metric for monitoring a drivers' response time to a LDW alert. Visual-manual tasks elicit the largest initial steering wheel angle change in response to LDWs. This may be due to the characteristics of the lane departures that occur in these situations. Drivers under high visual-manual demand may commit more severe lane departures, requiring faster responses with a larger magnitude of steering wheel angle changes. For example, a driver under high demand may not be fully aware of a curve in the road due to frequent off-road glances, and they may begin to move into a neighboring lane at a rapid pace. The severity of the unwanted lane change may elicit a larger reaction than if they had gradually begun to drift into a neighboring lane and become aware of the situation early on.

The seemingly reverse patterning of the physiological measures (tendency for heart rate to decrease following the LDW alerts and for skin conductance to increase) is potentially interpretable within the context of the situation and LDW warning modalities. While heart rate generally increases in response to stress or with increased activity, alerting stimuli (a sudden auditory tone, onset of a warning light, sudden movement in the visual periphery) are often observed to produce what is called an orienting response [13,14]. Orienting responses are associated with a brief drop in heart rate, followed within a few seconds by an increase. In the time frame of the 5 second epoch considered, these brief drops in heart rate would likely appear. Conversely, skin conductance level is typically observed to increase as part of an orienting response. It is interesting to note that the relative magnitude of the skin conductance response and the directionality of the heart rate change suggest a more muted response to the haptic stimulation through the steering wheel in the Mercedes vs. the auditory alert in the Volvo (recall here that the smartphone events were also recorded in the Volvo). A tone or warning light would be expected to illicit a neurologically bottom-up type of "what's that?" orienting reaction. Conversely, as a driver is already tactilely engaged with the steering wheel, increased vibratory stimulation to the hands might invoke more of a higher cognitive level, top-down initial processing of the warning stimulation (e.g. "rumble strip sensation, I'm crossing a lane boundary"). The latter might be expected to produce perhaps a more modest, general arousal response.

A direct comparison of the effects of LDW alert modalities is difficult to perform with this dataset. Participants in both vehicles showed similar trends. It is clear that secondary task type has an influence on LDW frequency and how drivers respond to the alert. Unfortunately, there are several confounds when directly comparing the auditory and haptic LDW alerts. Each alert modality occurred in different vehicle types (SUV and Sedan) which affected the range of visibility available to the driver. Also, it is not clear that these proprietary LDW systems function in the same away across vehicles, meaning one system may be more or less sensitive than the other. It is thus unclear if any differences in LDW rates or driver responses are associated with the modality of the alert or other factors of the vehicles the alerts are present in.

Conclusions

These results show potential advantages to the use of lane departure warning systems. Drivers were able to react to these alerts and take corrective actions. LDW alerts occurred more frequently when a driver was under secondary task demand, and the lane departure was likely a result of this increased level of demand. These systems may, in essence, monitor drivers' environmental awareness and enable them to readjust their attention away from the secondary task and back to driving.

What is unclear, however, is how drivers leverage these alerts over a longer period of time. It is plausible, that for some individuals, LDWs in naturalistic driving work to remind drivers that they are exceeding a safety threshold (i.e. the edge of the road) and may serve to support changes in behavior in a safety conscious manner. Alternatively, one could argue that individuals may leverage the alerting mechanism (e.g. infusion of automaton) as an alleviation of workload associated with lane maintenance and, as such, devote fractionally more time to non-driving activities. Further evaluation of these and other concerns around unintended adaptation is critical to developing a cohesive understanding of the influence of LDW on driver attention management and overall safety efficacy. Similar efforts are needed in the context of other ADAS.

From an assessment perspective, LDWs have the potential to function as a proxy for the driver's level of physical/cognitive demand. The present results show clear correlations between frequencies of LDW alerts and known high-demand periods. It may be possible to use a calculated frequency of LDW alerts during a period of driving to measure demand, in the same way that changes in heart rate, skin conductance, standard deviation of lane position, or changes in velocity have been used as demand proxies.

This analysis was also able to show the different ways that drivers react to LDW alerts when under different driving conditions. Dual-task driving with visual-manual demand elicited a very distinct response from drivers across three different interfaces. This information is potentially useful when designing these systems. Drivers may underreact or overreact to LDWs, depending on what else they are doing while driving. Awareness of these factors may help manufacturers to develop more efficient and less demanding systems, as well as more effective alerts based on the driver's potential state of awareness.

Limitations

The available data do not allow a direct assessment of the benefits of one LDW alert modality over the other to be made. The main reason for this was that each dataset was produced from a different vehicle with a different interface and lane tracking system. Results from one modality are therefore not directly comparable to the other. It is unknown whether and to what extent lane markings on the roadway

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may have changed between the fielding of the two studies in successive years. These results do demonstrate that both modalities are effective in eliciting desired results, reactive steering correction of lane position.

It should be noted that LDWs were relatively rare events during the driving periods studied. No attempt was made to manipulate vehicular control or to simulate artificial alerts during the drive, and all LDWs occurred naturally. The variable number of LDWs per participant and task also limits the statistical power of the analysis.

References

1. Scott, J.J. and Gray, R., "A Comparison of Tactile, Visual, and Auditory Warnings For Rear-End Collision Prevention in Simulated Driving," *Human Factors* 50(2): 264-275, 2008.
2. Suzuki, K. and Håkan, J., "An Analysis of Driver's Steering Behaviour During Auditory or Haptic Warnings for the Designing of Lane Departure Warning System," *JSAE Review* 24(1): 65-70, 2003.
3. Brown, D., Reimer, B., Mehler, B., and Dobres, J., "An On-Road Study Involving Two Vehicles: Observed Differences Between an Auditory and Haptic Lane Departure Warning System," Proceedings of the 2015 International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Nottingham, UK, September 1-3, 2015. doi:10.1145/2809730.2809747
4. Zhao, N., Reimer, B., Mehler, B., D'Ambrosio, L. A. et al., "Self-Reported and Observed Risky Driving Behaviors Among Frequent and Infrequent Cell Phone Users," *Accident Analysis & Prevention* 61: 71-77, 2013.
5. Maciej, J., and Vollrath, M., "Comparison of Manual vs. Speech-Based Interaction with In-Vehicle Information Systems," *Accident Analysis & Prevention* 41(5): 924-930, 2009.
6. Reimer, B., Mehler, B., Dobres, J., McAnulty, H. et al., "Effects of an 'Expert Mode' Voice Command System on Task Performance, Glance Behavior & Driver Physiology," 6th International Conference on Automotive User Interfaces and Interactive Vehicle Applications (AutoUI 2014), Seattle, WA, 2014.
7. Mehler, B., Kidd, D., Reimer, B., Reagan, I. et al., "Multi-Modal Assessment of On-Road Demand of Voice and Manual Phone Calling and Voice Navigation Entry across Two Embedded Vehicle Systems," *Ergonomics*, 2015, doi:10.1080/00140139.2015.1081412
8. Mehler, B., Reimer, B., McAnulty, H., Dobres, J. et al., Assessing the Demands of Voice Based In-Vehicle Interfaces -Phase II Experiment 2 - 2014 Mercedes CLA (2014t). MIT AgeLab Technical Report 2015-8, 2015. Massachusetts Institute of Technology, Cambridge, MA.
9. NHTSA, *Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices (Docket No. NHTSA-2010-0053)*. U.S. Department of Transportation National Highway Traffic Safety Administration (NHTSA), Washington, DC, 2013.
10. Angell, L., Auflick, J., Austria, P. A., Kochhar, D. et al., *Driver Workload Metrics Task 2 Final Report & Appendices* (DOT HS 810 635) (pp. 1-460). Washington, DC: National Highway Traffic Safety Administration / US Department of Transportation, 2006.
11. Smith, D. L., Chang, J., Glassco, R., Foley, J., and Cohen, D., "Methodology for Capturing Driver Eye Glance Behavior During in-Vehicle Secondary Tasks," *Transportation Research Record: Journal of the Transportation Research Board* 1937(1): 61-65, 2005.
12. R Core Team, *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing, 2015, retrieved from http://www.R-project.org/
13. Soklov, E. N., "Perception and the Conditioned Reflex," Oxford: Pergamon, 1963.
14. Mehler, B., Reimer, B., Pohlmeyer, A.E., and Coughlin, J.F., "The Association Between Heart Rate Reactivity and Driving Performance Under Dual Task Demand in Late Middle Age Drivers", *Advances in Transportation Studies an International Journal. Special Issue*, 53-70, 2008.

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