Distraction Becomes Engagement in Automated Driving

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As vehicle automation proliferates, the current emphasis on preventing driver distraction needs to transition to maintaining driver availability. During automated driving, vehicle operators are likely to use brought-in devices to access entertainment and information. Do these media devices need to be controlled by the vehicle in order to manage driver attention? In a driving simulation study (N=48) investigating driver performance shortly after transitions from automated to human control, we found that participants watching videos or reading on a tablet were far less likely (6% versus 27%) to exhibit behaviors indicative of drowsiness than when overseeing the automated driving system; irrespective of the pre-driving activity, post-transition driving performance after a five-second structured handoff was not impaired. There was not a significant difference in collision avoidance reaction time or minimum headway distance between supervision and media consumption conditions, irrespective of whether messages were presented on the tablet device, or only presented on the instrument panel, or whether there was a single or two-stage handoff.

INTRODUCTION

In the near future cars will have the capability to drive on the highway with limited oversight; however, adverse conditions will require human control of the vehicle, hence driver availability and performance following engagement in non-driving activities is a central concern. One of the main attractions of an Advanced Driver Assistance System (ADAS) is that it allows drivers to trade engagement in driving for other activities, such as rest or visual media use. If drivers are to engage in alternate activities, but still will be required to control the vehicle at some times, understanding transitions of control will be critical to system development and thus for the success of partially automated driving (Lee, Joo, & Nass, 2014). With many of the situations requiring driver control being easily predicted ahead of time (e.g. approaching one's exit on a highway), structured transitions, with time for the driver to engage in full control of the vehicle will be common. As a result, characterizing transitions between media interaction, and driving, and sleep and driving, will be important, so systems can be designed with respect to human capabilities.

Brought-in devices, such as smartphones and tablets, provide a platform for information and entertainment delivery potentially independent of the vehicle's systems. If drivers use brought-in devices in an automated vehicle while the vehicle is under automated control, will the driver be easily able to redirect attention to driving when required? Will it be necessary to control brought-in devices to ensure visual attention is broken from media which may compete with critical real-world demands? Furthermore, will a pre-advisement allowing additional time for a driver to establish situation awareness in advance of a possible handoff improve post-transition driving performance?

Prior Research

The deliberate introduction of non-driving activities (such as visual media consumption) into the driver's environment represents a break from prior research, which focused on the hazards of distracted driving. The National Safety Council (2012) estimates that 21% of automobile crashes in the US involve the use of a mobile phone, and that an additional 3% involved text messaging. The common assumption is that the increased prevalence of personal electronics and the wider array of activities offered on these devices will cause the problem of distracted driving to worsen. Paradoxically, overall accident rates are decreasing, even as electronics proliferate and in-car use increases (Farmer, Braitman, & Lund, 2010).

Near-future automated driving systems may allow for drivers to engage in alternate activities, with some advance warning being given before a structured transition to driver control (NHTSA level 3) (National Highway Traffic Safety Administration, 2013). These structured transitions can be initiated well in advance of the driver needing to take over; they are distinct from unstructured transitions which may occur in the event of vehicle system failure or unanticipated events (Mok et al., 2015). Even planned transitions will be impacted by the driver's readiness to resume control; automation will decrease workload, and as a result increase boredom and decrease vigilance, thus impacting situation awareness maintenance and the ability to regain control if required to do so (Endsley & Kiris, 1995; Mkrtchyan, Macbeth, Solovey, Ryan, & Cummings, 2012; Sheridan & Verplank, 1978). Absorption into media consumption will reduce a driver's situation awareness, and may make it more difficult to safely take control of the vehicle after a prolonged period of engagement in an alternate activity or sleep. If drowsiness or disengagement from the ambient environment is nearly inevitable, managing the driver's attention may present a solution to the challenge of reengaging a driver whose attention has been occupied by an alternate source of stimulation, such as visual media. Redirecting attention to the ambient environment and to the driving task will take time and require breaking concentration, possibly necessitating communication between the ADAS and media device(s) in order to achieve a well-structured transitions.

Sleepiness is a major hazard in driving—up to 20% of road accidents have driver drowsiness as a contributing factor (MacLean, Davies, & Thiele, 2003); and approximately 3% of accidents are directly attributable to drowsiness or sleepiness (National Highway Traffic Safety Administration, National Center for Statistics and Analysis, & U.S. Department of Transportation, 2012). The risks of sleep deprivation are increased when understimulated. As a result, engagement in stimulating activities, such as those currently considered to be hazardous during driving, may be desirable to keep drivers alert and able to take control of the vehicle if necessary (Neubauer, Matthews, & Saxby, 2014).

If automated driving reduces the risk of distracted driving, then a challenge will be driver performance after switching tasks, or shortly after being awakened. As it may be more difficult to establish situation awareness or to properly control the vehicle while in a drowsy state, transitions between mentally activating activities and driving may be safer than reacting when in a drowsy state, if transitions are properly structured, and human factors challenges are addressed.

DESIGN AND METHODS

Participants

Forty-eight licensed drivers, 20 women and 28 men, between the ages of 18 and 24 (M=20.85, SD=1.32), were recruited from the student population at Stanford University.

Experimental Design

This study employed a 3x3x2 mixed design (task x location of information x handoff stages). Study participants drove for 40 minutes, with three structured transitions from automated control to full driver control, shortly before encountering a potential hazard area such as a construction zone or school zone. This was intended to more realistically portray situations where a structured handoff would be likely to occur in a near-future automated vehicle scenario.

During the automated driving segments, participants performed one of three tasks: reading a selection from a book, watching an animated short movie, and supervising the ADAS (see Table 1). The non-driving activity preceding an event tested whether the engagement level of the activity had a bearing on drowsiness while disengaged from driving, and/or on post-transition accident avoidance ability. To address ordering effects, the order of the tasks was varied between participants using a Latin square design.

	Message on Instrument Panel	**Messages on Instrument Panel and Tablet**
Single Stage	**Nested Activities**	
Two-Stage	Reading - Video - Supervision	

Table 1. Experimental Conditions: the three activities are nested within the four between-participants conditions. The order of activities are rotated to compensate for order effects.

Independent Variables. The non-driving activities (supervising the ADAS, reading, and movie viewing) were selected to compare alertness during engagement in a visually and cognitively stimulating activity; during the supervision task, driver alertness was expected to flag. The environment of the simulation was designed with relatively low feature density in order to offer low stimulation, similar to a monotonous rural road.

Handoff staging varied as either as single stage or as a two-stage process. In the two-stage transition condition, participants were presented with a visual pre-alert message, 20 seconds ahead of transition, indicating a situation potentially requiring a transfer control was approaching. Twenty seconds was chosen as a reasonable upper bound for planned transitions, such as when one is approaching a marked construction site where it would be necessary for a driver to take control of the vehicle. Merat et al (2014) state that 15s is sufficient time to take control under reasonable conditions, and our experimental design specifically investigated well-planned and foreseeable transitions, not emergency unstructured takeovers of control. Gold et al. (2013) found that drivers given a shorter take-over time had faster reactions and made quicker decisions than drivers with a longer take-over time, but that the decisions and reactions were generally worse in quality. Locus of the hand-off message varied as well, being displayed on the instrument panel, or on both the instrument panel and the mobile tablet device. An audible alert, “please enable automation” or “please disable automation” was presented to all participants at the time of handoff message presentation, in addition to a visual alert.

Dependent Variables. Visual coding of driver behavior was used to assess driver drowsiness, defined as two or more yawns, and/or a single eye closure longer than 5s, based on research by Verwey and Zaidel (2000) and Senaratne et al. (2007). Eye closure was quantified by manual coding of the video by the researchers. Reaction time was quantified by measuring the time to acknowledge a mode switch by pressing a steering wheel-mounted button, and by measuring time to initiate an evasive maneuver in response to being cut-off by another vehicle or to a pedestrian incursion. Minimum headway distance to the leading car or pedestrian in the four critical event scenarios was used to assess whether drivers properly reacted to the situation presented.

Procedure

Participants were briefed before driving that each switch from driver control to computer control would be signaled by a voice command and visual indication on the instrument panel (or on the instrument panel and on the tablet), with the visual indicator counting up or down to indicate transition time remaining, and that automation state would be indicated by a visual indicator in the center of the instrument panel (see Figure 1). They were also instructed to press the “Mode” button on the steering wheel to take or relinquish control, within the five-second switch window. Irrespective of whether the participant pressed the button within the transition window, the computer would either take control or delegate control to the driver at the end of the 5s transition window, guaranteeing the timing between the transfer of control and the critical event (pedestrian incursion or car cut-off).

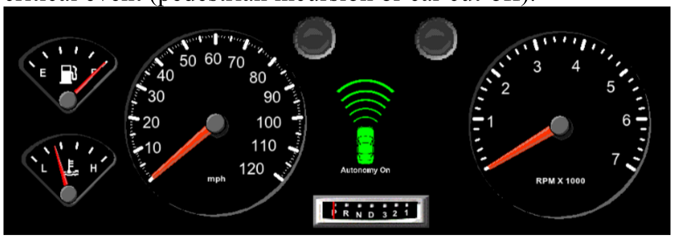

Figure 1. The automated driving system state is indicated by the icon in the center; state changes are depicted by an increasing or decreasing number of arcs above the car icon.

For participants in the two-stage handoff conditions, a pre-cue message was displayed on the instrument panel 20 seconds before the start of the handoff, (see Figure 2); and for participants in the conditions where information was presented on both tablet and instrument panel, messages were shown on the tablet and instrument panel simultaneously (see Figure 3).

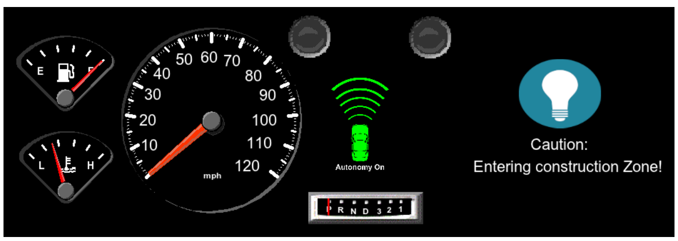

Figure 2. Pre-alert is shown on the right, indicating the driver is approaching a construction area, which may require the driver to take control of the vehicle.

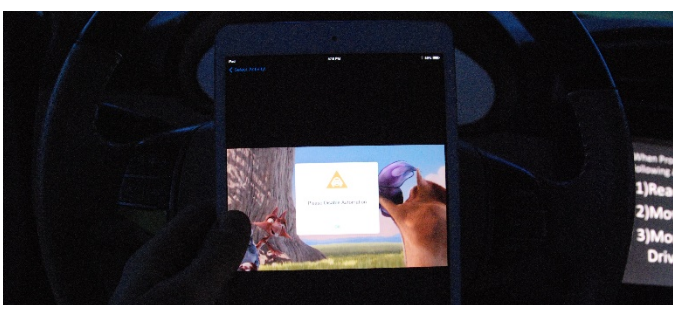

Figure 3. Handoff message presented on the tablet, overlaid over the movie to break visual attention from the media experience.

Distraction/Engagement Tasks

Each participant experienced three tasks: supervising the car's driving, watching a short animated movie, *Big Buck Bunny* (Sacha Goedegebure, 2008), and reading an excerpt from *Little Brother* (Doctorow, 2008) on a tablet. The movie and book were selected as they were considered engaging to the audience of students, and are Creative-Commons licensed for non-commercial use.

Each automated driving section was 8.5 minutes long, intended to provide enough time for the driver to become less engaged in overseeing the automated driving system, or to fully engage in reading or watching the movie, before being presented with an alert to take control of the vehicle ahead of a potentially hazardous area. The post-drive questionnaire inquired about the video and reading to assess engagement with these tasks, as part of the manipulation checks.

RESULTS

Transition to Driver Control

The activity engaging the driver immediately before a mode switch had a significant influence on the time drivers took to reclaim control of the vehicle, but this relationship was only found after the third activity block: drivers supervising the ADAS took control in an average of 3.74s (SD=.849), significantly faster than the other two conditions, $F(2, 45) = 13.205$, $p<.01$ (see Figure 4). Post-hoc comparison using the Tukey HSD showed highly significant differences between supervision and movie watching ($p<.001$), and supervision and reading ($p<.001$).

If the driver was reading, the average switch time increased to 4.72s (SD=.434), and the video-watching drivers took an average of 4.77s (SD=.547). The majority of participants took at least 3s to acknowledge the transfer of control (within the 5s switch window). Failure to acknowledge the handoff (not pressing the mode button) during the switch window was coded as 5s, the time when the ADAS would release control. The time required for the different groups to initiate evasive actions did not vary significantly between groups, and most participants did initiate evasive actions in time to avoid collisions.

For the first post-transition car cut-off event, all but four participants used exclusively braking to attempt to avoid a collision, two employed a braking and steering evasion, and two did not engage in any evasive action at all. Two participants did strike the pedestrians which walked into the roadway at a speed to require a panic braking or steering evasion action, the remaining 46 successfully avoided striking the pedestrian, using either a steering evasion (1), braking and steering (5), and one did not respond. The lack of variance between groups may have been due to a ceiling effect relative to response times: a five-second transition period provides sufficient time to switch tasks mentally and to put aside the tablet before resuming driving.

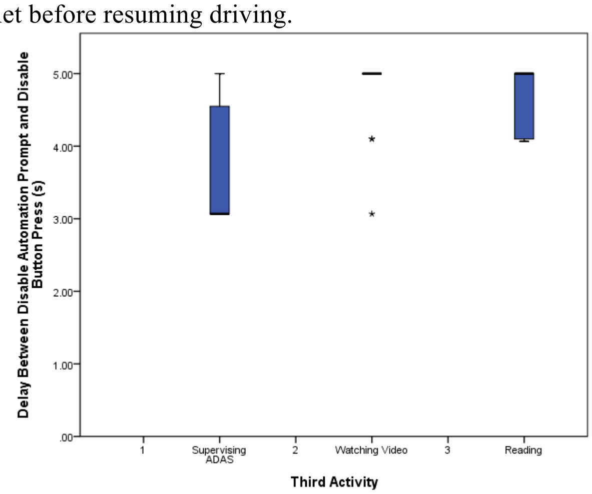

Figure 4. Time between mode switch prompt and mode switch in the third activity block, collapsing one and two-stage transitions.

Drowsiness During Non-Driving Segments

As drowsiness is a factor in many accidents, video recorded during the study was analyzed for markers of drowsiness, specifically eye closure longer than 5s, and incidence of yawning. During the first automated driving segment, there was not a significant occurrence of drowsiness among participants supervising the ADAS. There was a significantly greater incidence of drowsiness among participants supervising the ADAS, during both the second $\chi^2(2, N=48) = 15.71$, $p<.001$ and third $\chi^2(2, N=48) = 24.94$, $p<.001$ segments, compared with participants reading or watching the video (see Figure 5). There was not a significant incidence of drowsy behavior during the first automated driving period for any of the activities.

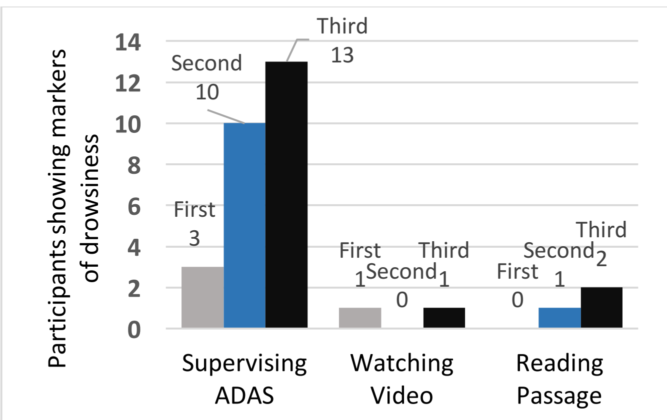

Figure 5. Identified episodes of prolonged eye closure, or multiple yawns, during the 8-minute activity blocks, indicative of drowsiness.

DISCUSSION

As noted by Hancock, "If we build systems where people are rarely required to respond, they will rarely respond when required." (Smith, 2014). Our results indicate that the introduction of part-time fully automated driving may place drivers in an underloaded state if not alternately engaged, possibly leading to drowsiness which may impair post-transition performance.

Allowing drivers to engage in alternate activities may forestall drowsiness, but then the challenge will be in transitioning mentally from an alternate media activity to driving, with the possible added complexity of managing a handheld device. In the case of a planned transition from computer control to driver control, the challenges are relatively easily managed by drivers, as shown in this study. Even a potential accident situation occurring shortly after a transition to full manual control can often be managed by an alert driver. As a result, the design challenge will be to design systems that can aid drivers in transitions of control, both when the transition can be forecast ahead of time (e.g. exit from a highway, a construction site), and when unexpected but where there is some ability for the ADAS to manage the transition, combining human and machine actions.

Although drowsiness was forestalled by engagement with visual media, there may be a cost to media engagement, especially on a brought-in device, in the case of an unanticipated transition that gives the driver little advance warning. In the case of an unstructured or rapid handoff where the computer will need to quickly transfer control of the vehicle to a driver, workload will dramatically and rapidly increase from a low to a very high level, potentially raising the risk of accident beyond that seen by a driver who was not disengaged from the environment. As stated by Solovey et al. (2014), "It has been shown that operators perform better at intermediate levels of workload compared to extreme levels (i.e. too low or too high workload)." This follows the Yerkes-Dodson (1908) principle of there being an optimal arousal level, especially in the frame of arousal varying over time during a task. As a result we consider the design of media engagement in the vehicle environment to be an area of great interest

Design Considerations

Considering that in cases where the ADAS cannot manage situations presented by the ambient environment, the driver will need to be engaged quickly in order to ensure safety, several design challenges arise. Design for vehicles has so far been centered around direct control, and shifting to design for supervisory control will be difficult (Sheridan & Verplank, 1978). If the driver is to serve in a supervisory capacity, an awake (if to some degree less situation-aware) driver may be better able to rapidly acquire sufficient situation awareness to address a hazardous situation than one who needs to be awakened from sleep, and drivers are likely to engage in media use, even if officially prohibited. Managing visual media so to make transitions safer may be a solution, if mechanisms are in place to help the driver switch back to driving, both physically and mentally, from non-driving activities

Due to the diversity of activities a driver could attend to, varied ambient conditions, and possible driver states, the vehicle may need to monitor the driver, assess her or his readiness and ability to control the vehicle safely (Hancock, 2013), and adjust the behavior of the ADAS' accordingly. Sensing systems that can detect driver focus are already a technological reality, and are available in current vehicles (Diamler A.G., 2014). As these systems improve and proliferate, they will be an essential part of the solution space for addressing the variance in engagement possible with partially-automated vehicles.

CONCLUSIONS

Both drowsiness and distraction are potential hazards present in highly automated driving which may make transitions to driver control more difficult. While the participants in this study did not sleep for any protracted period, but in the case of future automated vehicles, drivers may sleep for significant periods on long journeys, increasing the difficulty of rousing them and having immediate engagement. This presents a significant design challenge, which will have to be dealt with by both design and policy. A potential design solution is to manage the use of media in the vehicle, allowing structured transitions to be optimally designed so drivers can be best able to respond to potential hazards.

Future work must investigate the optimal time at which a driver's attention must be diverted from a distraction and back to the driving task, when structured handoffs are possible, and specifically how to design safe transitions and mechanisms for collaborative vehicle control in challenging situations.

Limitations of this Study

This study was conducted with a limited population of university students, who represent only a small part of the spectrum of drivers. Studying new drivers and older drivers whose faculties have begun to decline will provide important information on the design challenges of partially automated driving. The time blocks in this study, 8.5 minutes per activity, are relatively short—if drowsiness is present in such a short time, longer periods of inactivity are likely to cause a higher incidence of drowsiness and greater impairment. The controls on the distractions in this laboratory study separate it from the natural behaviors of drivers who can choose their media and engage/disengage at will. This study attempted to survey the space with a relatively controlled design, and future research will can explore more natural scenarios. The limitations of the simulation environment, with straight roads with low visual interest represent only one type of driving environment—more challenging environments may have different effects on drivers, yielding different behaviors in response.

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