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In-Vehicle Drowsy Driving Detection and Alerting

Drowsy driving is a common phenomenon that contributes to fatal and injurious crashes in the United States. The Fatality Analysis Reporting System (FARS) attributed 633 fatalities (1.6% of total crash fatalities) in 2020 to drowsy driving (Stewart, 2022), but these figures likely underrepresent the prevalence of drowsy driving. Research from the AAA Foundation for Traffic Safety suggests the number of crashes and fatal crashes attributed to drowsiness is underreported (Tefft, 2012, 2014), and it estimates that 6% of all crashes and 21% of fatal crashes involve a drowsy driver. A survey by the Foundation found that 17% of drivers reported having driven drowsy in the last month (2021). Despite being aware of their level of impairment when drowsy, many drivers report feeling that they can "push through" their drowsiness to reach their destinations (Alvaro et al., 2018). In-vehicle countermeasures, in the form of driver monitoring systems, may have the potential to reduce drowsy-driving crashes.

Some vehicle systems have two components: a state detection system (or driver monitoring system) and a countermeasure. Considerable research and development efforts in the last 10 years focused on detecting and classifying driver state using different measures. Limited research, however, has focused on understanding the efficacy of driver notification countermeasures. Driver notification countermeasures can be classified as state-based or performance-based. State-based strategies focus on altering the physiological state of the driver, with the goal of keeping the driver alert and engaged or waking the driver up once drowsiness is detected. Performance-based strategies target improving behavior and performance without considering whether or how the driver is impaired. This study compared the effectiveness of a representative state-based[1] drowsiness alerting countermeasure and a lane departure warning (LDW) system (performance-based countermeasure) with a baseline condition of no countermeasure.

Method

The study design involved three conditions: a baseline condition with no drowsiness notification; an LDW condition that triggered an auditory/visual alert when the vehicle came within 12 inches of a lane line without signaling; and a drowsiness notification (DN)/LDW condition. For the DN part of the DN/LDW condition, an algorithm used temporal steering information and eye tracking to classify driver state and presented the driver with a continuous "attention" scale, indicating the driver's level of drowsiness. In addition, when the attention scale reached a low (high drowsy) level, the instrument panel gave the driver a drowsiness warning consisting of a coffee cup icon, an auditory alert, and text prompting the driver to consider taking a break. The instrument cluster displayed the coffee cup icon above the attention level display, and the visual and auditory alerts persisted until cleared via a button the driver pressed, regardless of whether the driver stopped to rest. Seventy-two male drivers 21 to 30 years old completed the study, with 24 randomly assigned to each of the three conditions. The researchers limited participation to younger male drivers to reduce variability in driving performance that may be due to age and sex differences, thus increasing statistical power, and because research suggests that those who are younger and male are more likely to engage in drowsy driving (Wheaton et al., 2013, 2014). Caution should be applied when generalizing results to the larger U.S. population. The study used the high-fidelity, full-motion National Advanced Driving Simulator at the University of Iowa. The study drive contained a 40-mile Interstate loop repeated five and a half times for a total of 220 miles with two rest areas approximately 40 miles apart, where participants could stop to rest.

Participants were intentionally given false information about a system of monetary incentives for the study drive to replicate the motivational tradeoffs of a drowsy driving situation—that is, the desire to reach a destination versus preserving one's own safety. Prior to the study drive the research team told participants their possible compensation started at $85 but they would lose the $85 if they departed the road or collided with another vehicle during their drive. At 65 mph, the drive took approximately 3.5 hours without stopping. The research team told participants they would each earn bonus compensation for reaching the destination in less than 4 hours, prorated at $1 per minute under the time limit, up to a total bonus of $50. This incentive structure forced participants to consider a tradeoff between continuing to drive—"pushing through"—if they experienced drowsiness and risking their compensation, or stopping at rest areas to avoid road departures and crashes but potentially losing the time bonus. (Participants were actually paid $150 regardless of performance on the test.)

[1] "State" meaning condition, not a U.S. State.

To ensure participants were sufficiently drowsy, they had to be awake by 8 a.m. the day of the visit, did not sleep during the day, and did not consume caffeine after 1 p.m. At 11 p.m. they took a short screening drive, then waited (without sleeping) until beginning the potentially 4-hour drive at 2 a.m. Thus, the participants had been awake for a minimum of 18 hours when they began their drive on the simulator.

Results

There was a statistically significant main effect of condition on lane departure frequency ($F(2, 69) = 4.532$, p = 0.015) (Table 1). Dunnett's post-hoc tests revealed that the DN/LDW condition had statistically fewer lane departures per minute compared to the baseline condition ($t(47) = 2.290$, $p = 0.049$). The LDW condition had similar lane departures per minute compared to baseline ($t(47) = 2.190$, $p = 0.061$). These results suggest that the DN/LDW condition, but not the LDW condition, was effective in reducing the frequency of lane departures compared to the baseline condition.

Table 1. Descriptive Statistics for Lane Departures per Minute

Condition	Mean	Median	SD
Baseline	0.266	0.181	0.241
DN/LDW	0.104	0.048	0.108
LDW	0.115	0.051	0.138

There was a statistically significant main effect of condition on time to stabilization ($F(2, 69) = 45.628$, $p < 0.001$). Dunnett's post-hoc test found that both the DN/LDW and LDW conditions had statistically faster time to stabilization compared to the baseline condition ($t(47) = 4.872$, $p < 0.001$ and $t(47) = 2.788$, $p = 0.011$, respectively), such that participants had faster responses to lane departures compared to the baseline condition. There was a statistically significant main effect of condition on PERCLOS (percentage of eyelid closure) prior to lane departures ($F(2, 69) = 55.912$, $p < 0.001$). Dunnett's post-hoc test showed that the DN/LDW condition, but not the LDW condition, had statistically lower PERCLOS prior to lane departures compared to the baseline condition ($t(47) = 5.301$, $p < 0.001$ and $t(47) = 0.483$, $p = 0.832$, respectively). These results indicate that the DN/LDW condition, but not the LDW condition, reduced PERCLOS (a potential proxy for drowsy driving) prior to lane departure events compared to baseline. There were no differences between conditions for lane departure severity, drowsiness before rest areas, frequency of breaks taken, length of time for breaks taken, or subjective drowsiness at the start of breaks.

Discussion

This project evaluated the effectiveness and effect of drowsiness countermeasures on drivers' driving ability and rest-taking behavior in long drowsy-driving situations. It implemented a novel incentive method to replicate the motivational tradeoffs of a drowsy-driving situation in 4-hour drives on the high-fidelity National Advanced Driving Simulator. The results indicate that notification was effective at reducing lane departures in the context of a long drowsy driving situation. The DN/LDW reduced the frequency of lane departures and displays of drowsiness prior to lane departures—as measured by PERCLOS—compared to the baseline condition. There was no difference between the notification conditions and baseline in the severity of lane departures when they did occur as all conditions showed similar lane departure magnitudes. This finding suggests that the key benefit of the DN/LDW countermeasure was preventive in nature. It appears that the DN/LDW condition reduced PERCLOS in lane departure situations, improving lane keeping performance, and decreasing the probability of lane departures. Increased alertness in the DN/LDW condition also appears to have speeded responses to lane departures when they did occur, as evidenced by shorter time-to-stabilization in the DN/LDW condition compared to baseline.

There were no differences in stopping behavior for either notification condition compared to baseline. Participants with the DN/LDW and LDW did not take more frequent breaks, earlier breaks, or increase the duration of their breaks compared to the baseline condition. These results suggest that although notification improved driving performance, it did not influence decisions about whether and when to stop to rest.

Several possible limitations exist in this study. First, it was conducted in a driving simulator and, although the simulator was high-fidelity and included motion feedback, the results may not generalize to different, more complex driving situations. Second, this study focused on young male drivers, as this group is particularly at high risk for drowsiness-related crashes, which may limit generalizability. Finally, there are significant differences in how production DN technologies detect and respond to drowsiness, from the data used for state classification to the human-machine interfaces to interact with the driver, which should be considered.

A previous study by Gaspar and colleagues (2017) found that DN is effective in reducing lane departures over relatively short drives. This study extends previous research by demonstrating the potential safety benefit of DN/LDW for drowsy drivers in longer driving situations. It is important to remember, however, that participants still departed the lane and showed evidence of drowsiness with both the DN/LDW and LDW conditions. The results of this study suggest that neither DN/LDW nor LDW conditions increased the frequency or timing of break taking, suggesting that these countermeasures may best be considered as short-term solutions that improve but do not eliminate the consequences of drowsiness.

Full Report

Gaspar, J. G., Schwarz, C. W., Marshall, D., Jenness, J., De Leonardis, D., & Blenner, J. A. (in press). *In-vehicle drowsy driving detection and alerting* (Report No. DOT HS 813 438). National Highway Traffic Safety Administration.

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