The Costs and Benefits of Head-Up Displays (HUDs) in Motor Vehicles

Lisa Hagen, Matthew Brown, Chris M. Herdman, and Dan Bleichman
Centre for Applied Cognitive Research
Carleton University
Ottawa, Canada

Research in the aviation domain has shown that Head-Up Displays (HUDs) can facilitate performance in specific tasks such as controlling aircraft flight path and altitude (Fadden, Ververs, & Wickens, 2001; McCann & Foyle, 1995; Martin-Emerson & Wickens, 1997; Wickens & Long, 1995). However, there are a number of simulator-based studies suggesting that pilots may focus, or cognitively tunnel their attention on HUD symbology, resulting in performance decrements in tasks that require continuous monitoring of information from the outside scene (Foyle, Stanford, & McCann, 1991; McCann, Foyle, & Johnston, 1993), and in extreme cases, severe impairment or even failure to detect potentially critical discrete events in the external scene (Brickner, 1989; Fischer, Haines, & Price, 1980; Wickens & Long, 1995). In the present research, we extended our examination of aircraft HUDs to the domain of motor vehicles. Participants drove a high fidelity, fully configured driving simulator through a realistic scenario containing both urban and rural (highway) roads. Speed limit (and other) signs were posted. Two conditions were compared. In the no-HUD condition, a standard in-vehicle instrument panel was used. In the HUD condition, the instrument panel was augmented with a HUD showing digital speed on the windshield. The results showed a benefit of the HUD insofar as participants were better at maintaining their speed in the HUD than in the no-HUD condition. However, this benefit was accompanied by a cost in that participants showed significantly greater deviations in maintaining lane position when the vehicle’s speed was available on the HUD than when it was not. This finding suggests that HUD symbology distracts motor vehicle operators to the extent that they are less able to process information from the navigation environment.

Introduction

HUD technology, traditionally used in aircraft, has been implemented by various automobile manufacturers to project vehicle status information onto the windshield (e.g., speed, warning lights). Although there is thorough research on the efficacy of HUDs in aircraft, relatively little work has been done on the impact of HUDs in motor vehicles.

In the present research, the impact of a digital HUD speedometer on driving performance was assessed using a high-fidelity driving simulator. To quickly preview the results, the present study shows that although this particular HUD improved a driver’s ability to monitor speed, it impaired their ability to maintain lane position. This trade-off is explained in terms of cognitive tunneling.

Theoretical Benefits and Costs of HUDs

The benefit of HUDs, whether they are implemented in aircraft or in cars, is that they allow the user to monitor vehicle status without physically interfering with their ability to view the navigation environment. In theory, HUDs should provide the driver with more time to attend to events in the navigation environment. However, findings from studies testing the effects of HUDs in aircraft suggest otherwise (e.g., Herdman & LeFevre, 2003; McCann & Foyle, 1995). These studies showed that pilots have more difficulty detecting objects/events in the navigation environment when HUD information is available, relative to when it is not. One explanation for this counter-intuitive finding is that pilots are susceptible to a cognitive tunneling effect when a HUD is available. That is, the HUD symbology captures (and holds) the pilot’s attention, subsequently preventing them from attending to other events in the navigation environment.

Cognitive Tunneling and HUDs in Automobiles

It seems plausible that the inherent costs and benefits of HUD technology observed in aircraft operation would map directly onto the task of driving an automobile. However, the navigation environment faced by pilots is sparsely populated relative to that faced by a typical driver. As such, drivers are required to navigate in environments that require more precise control of their vehicle’s position both within lane markings and relative to other cars sharing the lane. It may therefore be the case that the cognitive tunneling effects observed in flight simulation studies (see Herdman & LeFevre, 2003; McCann & Foyle, 1995) are relatively minor both in terms of magnitude and in terms of consequence. The ever-increasing number of HUDs being installed in automobiles magnifies the importance of assessing the (a) extent to which HUDs render drivers...
susceptible to cognitive tunneling and (b) the subsequent impact on driving performance.

In order to determine whether cognitive tunneling occurs in automobile HUDs, a simulation experiment was conducted in which drivers’ performance in terms of their ability to monitor speed and lane position was assessed. The critical (within-subjects) manipulation had two conditions: (1) participants used the manufacturer-equipped analogue speedometer to ascertain speed (no-HUD condition) and (2) the analogue speedometer was augmented with a HUD of a digital speedometer (HUD condition). The participants’ driving performance in these two conditions was compared to determine whether HUD information yields costs and/or benefits.

Methods

Participants. Twenty-two Carleton University students participated and either received course credit or $20 remuneration. All participants were assumed to have normal or corrected-to-normal vision. Further, all participants held a valid Province of Ontario driver’s license and had at least two years of driving experience.

Design. One critical factor with two levels was manipulated (HUD condition: HUD vs. no-HUD). This factor was counterbalanced across participants such that half received the HUD condition first and the no-HUD condition second. This order was reversed for the other half of the participants.

Apparatus. The experiment was conducted on a high-fidelity, fully configured DriveSafetyTM 500c driving simulator consisting of a (partial) cabin of a Saturn passenger car mounted in front of five flat-screen projectors subtending approximately 22° of vertical visual angle and 150° of horizontal visual angle. The HUD information (i.e., a digital display of the vehicle’s current speed) was located 5° of visual angle below the horizon and 10° of visual angle to the left of the center of the driver’s field of view. The HUD was light green in color and subtended 4° of visual angle vertically and 2° of visual angle horizontally. Computer-generated engine noise, which changed accordingly with engine speed, and external noise (e.g., passing traffic) were presented on speakers mounted in the cabin or on the cabin platform. The driving scenario was scripted using TCL scripting language that was executed on a PC-based Linux platform and simulated a two-lane highway passing through small towns, mountain passes, and rural farming areas. The scenario was updated at a rate of 30 to 60 Hz and the data were collected at a rate of 5 Hz.

Procedure. Participants familiarized themselves with the controls and operation of the driving simulator during a ten-minute practice session. The HUD was displayed during practice to minimize potential novelty effects associated with its presence during the experimental session. The experimental session consisted of two identical 25-minute trials, except that participants used the HUD to monitor their speed (HUD condition) on one trial, whereas they used the analogue speedometer on the other (no-HUD condition). Participants were instructed to (a) obey all posted speed limits and general rules of the road and (b) keep the vehicle centered in their lane. Participants were debriefed and received appropriate compensation following completion of the second experimental trial.

Results

Two participants were removed from the analyses: one was unable to complete the experiment due to illness and the other misunderstood task instructions. The data from the remaining 20 participants were trimmed such that data at both the beginning and at the end of the experiment (accelerating to the posted speed limit and decelerating to a full stop) were eliminated. Outlier data were eliminated based on the criteria that the participant’s lane position deviated 1.8 m (or more) from the center of their lane.

Speed Monitoring Data

Participants’ ability to monitor speed was measured by comparing actual speed to the posted speed limits. This measure was calculated by taking the absolute value of the difference between their actual speed and the speed limit. Speed monitoring was significantly better in the HUD condition than in the no-HUD condition \( t(19) = 9.0, p < .001 \). On average, speed in the no-HUD condition deviated from the speed limit by 3.98 MPH, whereas it only deviated by 2.48 MPH in the HUD condition.

Lane Position Data

The ability to monitor lane position is a critical aspect of safe driving, given that the consequences of failing to do so (e.g., crossing into oncoming traffic) are so dire. Indeed, it could be argued that lane position monitoring is more important that speed monitoring in terms of road safety. For this reason, participants’ lane position data were logged and subsequently
analyzed. The center-most position of the lane was assigned a value of zero and any deviation left of center was recorded as a negative value, whereas deviations right of center were assigned a positive value. Although knowing about possible systematic tendencies to drift in one direction relative to the other could be of some interest, it is beyond the scope of the present research. As such, lane position monitoring performance was calculated by taking the absolute value of their current lane position (which represents the distance from the center of the lane given that the center of the lane was assigned a lane position value of zero). The interesting result here is that lane position monitoring was significantly worse in the HUD condition than in the no-HUD condition \( t(19) = 4.3, p < .001 \). On average, participants in the HUD condition drifted .33 m from the center of their lane, whereas participants in the no-HUD condition only drifted .29 m from the center of their lane. This difference of .04 m could represent the difference between a “close call” and a head-on collision.

**Discussion and Conclusion**

The results from this driving simulation experiment show that when a manufacturer-equipped analogue speedometer is augmented with a digital speed HUD, drivers are better at monitoring their speed, but worse at maintaining their lane position, relative to when no HUD is available. These results are consistent with the claim that digital speed HUDs (typical of HUDs used in automobiles) render participants susceptible to cognitive tunneling effects, whereby attention is captured and held by the HUD symbology such that it is difficult (or impossible) to concurrently attend to information in the navigation environment (e.g., lane position).

Although monitoring vehicle speed is important, the consequences of failing to do so pale in comparison to the potentially disastrous outcomes of neglecting one’s lane position or not being able to detect objects and/or events in the navigation environment (e.g., a child running into the roadway). As such, the present research suggests that the limited benefits of a digital speed HUD are outweighed by the potential costs associated with not adequately processing information in the navigation environment. It is therefore essential to refine and empirically assess how and what information (if any) should be presented on a HUD so as to maximize driver awareness of vehicle status while minimizing potential cognitive tunneling effects.

**References**


Acknowledgements

We are grateful to Transport Canada for providing access to a driving simulator for this research.

Correspondence should be directed to:
Dr. Chris M. Herdman, Centre for Applied Cognitive Research, Carleton University, Ottawa, ON. Canada, K1S 5B6.

Direct email correspondence to:
chris_herdman@carleton.ca