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Motor vehicle manufacturers are installing Head-Up Displays (HUDs) in motor vehicles to provide drivers with a variety of vehicle information such as vehicle speed. In theory, HUDs should assist drivers in monitoring the status of their vehicle while allowing them to spend more time looking at the external scene. However, research in the aviation literature has shown that pilots tend to cognitively tunnel on HUDs to the extent that processing of the external scene is delayed. In the present research, a driving simulator was used to examine whether cognitive tunnelling occurs with analogue and digital HUDs. Participants were better at maintaining vehicle speed when either a digital or an analogue HUD was used as compared to a standard Head-Down Display (HDD) condition. However, the digital HUD resulted in cognitive tunnelling insofar as deviations in lane positioning were greater when speed was displayed in the digital HUD than analogue HUD or HDD conditions.

Introduction

Advances in technology have led to the installation of Head-Up Displays (HUDs) in aircraft and more recently, some automobiles. HUD technology allows the projection of instrumentation onto a transparent medium located at the same level of the windscreen and in the driver's forward field of view. Hypothetically, HUDs should allow the driver to monitor the status of the vehicle at the same time they are watching activities outside the vehicle. Research in the aviation literature, however, has shown that pilots tend to cognitively tunnel on a HUD at the expense of observing objects in the outside scene (see Fischer, Haines, & Price, 1980; McCann & Foyle, 1995; McCann, Foyle & Johnston, 1993; Herdman, LeFevre, Jarmasz, & Johannsdottir, Hagen, 2005). Jarmasz, Herdman & Johannsdottir (2005) showed that humans perceive the HUD and the external scene as two separate objects. This forces the user to switch attention between the HUD and the external scene. Consequently, when information on the HUD is being attended to and processed, processing of the external scene is delayed.

Compared to the body of research documenting the use of HUDs in aircraft, relatively little work has examined the use of HUDs in automobiles. On the surface, it seems plausible that the inherent costs and benefits of HUDs in aircraft would also occur when a HUD is used while driving. In fact, the potential negative impact of HUDs might be greater in automobiles than in aircraft: cognitive tunnelling on a HUD might prevent drivers from effectively using environmental cues to position their vehicle within a lane and relative to other vehicles.

Digital versus Analogue HUDs

The most common automobile HUD is a digital display of speed. Digital displays are simple in their presentation and are often assumed to be easier and more efficient to read than analogue displays (Miller & Penningroth, 1997). However, Paivo (1978) found that analogue displays are processed faster than digital displays under conditions that require spatial processing. Additionally, analogue displays are processed faster when rate-of-change information is required (see Helander, 1987; Kantowitz & Sorkin, 1983; Murrell, 1965). Given these findings, it may be that when drivers (and pilots) are attempting to process rate of change information using a digital HUD (e.g., change in motor vehicle speed or altitude change in an aircraft), they may spend more time attending to the HUD than if the information was presented in an analogue format.

Present Research

The present research examined the impact of presenting vehicle speed on a digital HUD versus an analogue HUD and a standard Head-Down Display (HDD). Two indices of driving behaviour were measured: (a) speed maintenance and (b) lane positioning.

Method

Participants. Twenty-four participants (16 male, 11 female) were paid $25.00 to complete the study. Participants all had valid driver's licenses and, on average, drove an estimated 18,290 km. per year. All participants had normal or corrected-to-normal vision. The average age of the 24 participants was 30 years.

Apparatus. The experiment was conducted using a high fidelity, fully configured, DriveSafetyTM 500c driving simulator. A cut-down passenger vehicle consisting of only the driver's seat and controls was located in front of the five projection screens providing 21.8° of vertical and 150° horizontal field of view. Imagery from the rear-view mirror and both side mirrors was superimposed on the projection screens in appropriate locations. The car simulator included computer-generated engine and external (passing traffic) noise. A single driving scenario was used. The driving scenario was constructed using Tool Command Language (TCL) scripting language that was executed under a PC-based Linux platform. The scenario simulated a two-lane highway passing through rural farming areas with incoming traffic.

Vehicle speed was displayed using either: (1) a digital HUD, (2) an analogue HUD, (3) a standard vehicle HDD instrument panel. The digital HUD was located 5° below the horizon and 10° to the left of centre on the front screen. HUD digits were green and subtended a viewing angle of 4° vertically and 2° horizontally. The analogue HUD was centred relative to the location of the digital HUD and subtended 10° both vertically and horizontally. The analogue HUD was the same green colour as the digital HUD. The HDD was located in the dash of the car. The visual displays of the scenario and date collection were updated at 60 Hz.

Procedure. Each participant familiarized themselves with the controls and operation of the driving simulator during a ten-minute practice session. The digital HUD was displayed during this practice session to minimize novelty effects associated with the presence of a HUD that could occur during the experimental trials. Participants were instructed to (a) obey all posted speed limits and general rules of the road, and (b) keep the vehicle centred in the traffic lane. Participants were told that their primary task was safe operation of the vehicle.

Results

RMSE Speed. Speed monitoring performance was calculated using Root Mean Square Error (RMSE). $RMSE_{speed}$ indexed participants' ability to keep the vehicle speed steady and close to the posted speed limits.

A (Display: HDD vs. analogue HUD vs. digital HUD) one-way within-subjects ANOVA revealed a main effect of Display, $F(2, 46) = 20.35$, MSE = .23, $p < .001$. There was a general HUD advantage over the HDD where deviations from the posted speed limit were significantly better (lower) in the digital HUD (2.2 MPH) and the analogue HUD (2.27 MPH) conditions than in the HDD (3.00 MPH) condition.

RMSE Lane Position: Participants were instructed to maintain a centre lane position. Lane position performance was calculated using RMSE.

A one-way within-subjects ANOVA (Display: HDD vs. analogue HUD vs. digital HUD) showed a significant main effect of Display, $F(2, 46) = 4.438$, MSE = .002, $p < .05$. Deviations in lane position were worse (largest) in the digital HUD condition (0.46 m.) than in the analogue HUD (0.42 m.) and HDD conditions (0.42 m.).

General Discussion

The results from this driving simulation experiment are straightforward in showing both benefits and costs of HUDs. The digital and analogue HUDs both resulted in better monitoring of vehicle speed. However, when a digital HUD was used participants were worse at maintaining their lane position compared to the analogue HUD or HDD conditions. The lane position results are consistent with the claim that digital HUDs (typical of most HUDs currently used in passenger automobiles) render participants susceptible to cognitive tunnelling. On this view, driver's attention is focused on the digital HUD to the extent that information in the environment that is required for lane positioning is not processed adequately.

Although monitoring vehicle speed is important, the consequences of failing to do so pale in comparison to the potentially disastrous outcomes of neglecting lane position. As such, the present research suggests that the limited benefits of a digital speed HUD are outweighed by the potential costs.

References

Fischer, E., Haines, R. F., & Price, T. A. (1980). Cognitive issues in head-up displays. *NASA Technical Paper 1711*, NASA Ames Research Center, Moffett Field, CA.

Helander, M. G. (1987). Design of visual displays. In G. Salvendy (Ed.), *Handbook of Human Factors* (pp. 507-548). New York: Wiley.

Herdman, C. M., LeFevre, J., Jarmasz, J., Johannsdottir, K. R., & Hagen, L. (2005). Situation awareness, performance and workload in simulated flight: Head-Up Display (HDD) versus Head-Down Display (HDD). *Report Number 007SV-W7714-010547*.

Kantowitz, B. H., & Sorkin, R. D. (1983). *Human factors: Understanding people-system relationships*. New York: Reinhold.

McCann, R. S., & Foyle, D. C. (1995) Scene-linked symbology to improve situation awareness. *AGARD Conference Proceedings CP 575* (pp. 16-1 – 16-11). Brussels, Belgium.

McCann, R. S., Foyle, D. C., & Johnston, J. C. (1993). Attentional limitations with head-up displays. In R. S. Jensen (Ed.), *Proceedings of the Human Factor Society* (1345-1349). Columbus, OH: The Ohio State University.

Miller, R. J., & Penningroth, S. (1997). The effects of response format and other variables on comparisons of digital and dial displays. *Human Factors, 39(3)*, 417-424.

Murrell, K. F. H (1965). *Human Performance in Industry.* New York: Reinhold.

Paivo, A. (1978). Comparisons of mental clocks. *Journal of Experimental Psychology: Human Perception and Performance, 4*, 61-71.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3-25.

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