Human Factors in Accessibility and Assistive Technology, Vol. 37, 2022, 53–59
https://doi.org/10.54941/ahfe1001642

Head-Up Displays: Analysis of Automotive Use Considerations

Jenna Korentsides, Andi StClair, Meghana Dyapa, and Alex Chaparro

Department of Human Factors Embry-Riddle Aeronautical University Daytona Beach, FL 32114, USA

ABSTRACT

Head-Up Displays (HUDs) were developed to provide primary sensor data during flight at the pilot's customary view. The positioning of flight instrument data in the forward field of vision allows pilots to concurrently view this information and the external scene. The potential benefits of HUDs have also been recognized by the automotive industry with approximately 30 automobile brands offering HUDs as optional equipment in vehicles. By projecting driving information directly into the driver's line of view, the HUD reduces the number and length of the driver's eye movements away from the road, decreasing distraction and improving driver awareness. The purported benefits of automotive HUDs include decreasing cognitive workload, visual scanning, and by providing cues to guide their eyes to hazards or other pertinent information. The aim of this paper is to review how HUDs and their design properties affect pilot performance and attention in order to identify implementation issues relevant to the automotive industry.

Keywords: Human factors, Head-up display (HUD), Intelligent transportation systems, Assistive technology, Automotive

INTRODUCTION

The first head-up displays (HUDs) were developed in the late 1950's and were derived from aircraft gunsights (Newman, 1995). In its most basic form, a HUD consists of a display unit and semi-transparent mirror mounted rigidly in front of the pilot. The semi-transparent mirror positioned in the pilots' line of sight reflects an image from the display unit into the pilot's eyes. The optical components of the HUD produce a collimated image (light rays are parallel to one another) that appears in focus when the pilot looks out the cockpit. General Motors was the first automotive manufacturer to release a production vehicle with a HUD, a Cutlass Supreme, in 1988 (Weihrauch et al., 1989). While not widely available in automobiles, there is enduring interest from manufacturers in the applicability of HUDs as evidenced by the fact that 30 automobile brands offer HUDs as optional equipment in some vehicle models. Recent technological developments suggest that automotive applications might use the windscreen to display information to the driver instead of relying on the smaller optical displays positioned directly in users' line of sight (Stumpf, 2021).

© 2022. Published by AHFE Open Access. All rights reserved.

The information displayed on automobile HUDs varies by manufacturer and is user configurable, displaying information related to vehicle state, safety (e.g., collision warning, road signs notification), navigation, communication/infotainment, and environmental conditions (e.g., temperature) (Park & Park, 2019, Normile & Ulitskaya, 2021). Future applications might include augmented reality displays depicting crowdsourced data extracted from social media platforms or third-party providers. Drivers would be able to choose to display among a host of data including vehicle travel time, roadway conditions, accidents, or road obstructions (e.g., road debris, stalled vehicle, accident). This brief review summarizes the findings of the research literature on the effects of HUDs on pilot performance, how display symbology design characteristics (e.g., size, number, positioning etc.) affects user attention and vision, and differences in the two user populations (pilots versus drivers). Two databases were utilized to search for literature including Google Scholar and the University Reference Library Databases, as well as Google for demographic statistics. In addition, the reference section of each article was utilized in order to find additional relevant material.

OPERATIONAL AND USER DIFFERENCES

Unlike pilots, drivers receive little or no training on HUD use other than the information the dealer shares upon delivery of the vehicle or the information available in the owner's manual. In contrast, pilots receive rigorous training on the use of aircraft instruments, related Head-Down Displays (HDD), and Head-Up Displays. Aviation HUDs depict primary flight information sources that can vary by phase of flight. In comparison, there are fewer primary driving information sources (i.e., vehicle speed, fuel level, engine temperature, wayfinding, driving instructions, hazards, etc.) that might be displayed on a vehicle HUD, reducing potential clutter (Gabbard et al., 2014, Wood & Howells, 2000).

The characteristics of the pilot and driver populations also differ considerably. In the United States, pilots are predominantly male (86.2%) with a mean age of 46 years ("Airplane pilot demographics and statistics," 2022). Most pilots are required to submit to a yearly medical evaluation that assesses a range of functions including visual acuity, peripheral vision, and color vision. No such requirements exist for drivers. The population of drivers is significantly more heterogeneous in every relevant characteristic including age, visual acuity, contrast sensitivity, visual accommodative range, experience, and training, all of which affect an individual's ability to use a HUD.

HUD ISSUES

HUDs are standard equipment in a wide range of military and civilian aircraft, and research has confirmed some of the hypothesized benefits on pilot performance over HDDs (Fadden et al., 2000, Wickens et al., 2004). Because the HUD displays flight instrument information proximal to the pilots' out-the-cockpit (OTC) view, it lessens visual scanning and related head and eye movements when scrutinizing flight relevant information

(Martin-Emerson & Wickens, 1997). The proximal position of flight information to the pilot's line of sight may increase the probability of detecting events in the external scene compared to HDDs (Wickens et al., 2013). Finally, HUDs reduce accommodative visual responses associated with shifts in attention between the OTC view and HDDs in the cockpit (Fadden et al., 2000, Wickens et al., 2004). On road and simulator studies of automotive HUD applications have reported similar benefits compared to HDDs including reduced response times to urgent events (Liu & Wen, 2004, Srinivasan, 1997, Horrey et al., 2003, Horrey & Wickens, 2004), reduced mental stress (Liu & Wen, 2004), fewer and shorter fixations away from the road (Kaptein, 1994), greater adherence to posted speed limits (Sojourner & Antin, 1990), and better longitudinal and lateral vehicle control (Smith et al., 2015, Topliss et al., 2019).

Attention and Cognition

Research has also demonstrated that HUDs can reduce a pilot's ability to detect unexpected events in the external scene (Haines et al., 1980). This phenomenon, termed cognitive or attentional tunneling, arises when pilots attend to the display symbology on the HUD instead of jointly processing the HUD symbology and external environment. Visual display clutter, the use of non-conformal symbology, and the location of symbology on the HUD appear to increase the susceptibility to cognitive tunneling (Pullukat et al., 2020). Similarly, a driver's attention might be captured by the overlaid HUD symbology and graphics rather than processing the external scene and symbology simultaneously. In fact, the use of a digital HUD displaying vehicle speed has been reported to slow responses to a braking lead vehicle (Wolffsohn et al., 1998) and to impair lane keeping performance while improving the maintenance of vehicle speed (Hagen et al., 2005). The findings offer evidence that when a driver's focus is directed toward the display, other primary tasks are unintentionally abandoned, thus compromising the driver and their passengers' safety (de Oliveira Faria, 2020). The risks are perhaps greater in driving given the number and diversity of potential hazards a driver must detect, evaluate, and avoid (Maroto et al., 2018). Topliss et al. (2019) found that in higher mental workload situations, such as when the HUD displays an alert when a lead car brakes, the driver's performance suffers. Whenever the driver was interrupted with an alert while also performing another cognitively demanding task, driving performance was impaired leading to longer reaction times and heavy, abrupt braking (Topliss et al., 2019). Moreover, when using a full windscreen display, they reported that lane keeping was poorer when the HUD imagery was presented peripherally. This was likely due to rapidly switching ambient and focal visual scenes (i.e., focal - from reading a message on a display to reading a road sign, or ambient - from viewing the display screen and then switching to the road view).

Image Optical Distance

A primary design concern is the optical distance of symbology displayed on the HUD. Aviation HUD images are collimated and thus appear at optical infinity whereas automotive HUDs are focused at a distance of 2 to 2.5 meters or 6.5 to 8.2 ft (Tufano, 1997, Gish & Staplin, 1995). Shorter optical distance may be problematic for older drivers due to presbyopia which reduces their accommodative range particularly for near distances. For accurate depth perception, the driver needs to infer the correct depth of the symbology and object when displayed in order to react accordingly to the hazard in the real world (Singh et al., 2018). Matching the perceived depth of HUD symbols and graphics to the external scene is challenging due to differences in the effectiveness of the cues depending on visual characteristics, such as scene content and the distance of the display from the driver's eyes.

Vision

A central purpose of a HUD is for the vehicle operator to recognize symbology and graphics in order to evaluate vehicle states and detect alerts concerning road conditions or hazards. The ability of a driver to detect and read HUD symbology may be affected by changes in visual acuity and contrast sensitivity that worsen with age, due to normal aging processes and an increase in prevalence of medical conditions affecting vision (McGwin et al., 2000, Owsley et al., 1999). Older adults have a higher risk of eye diseases like cataracts and age-related macular degeneration (ARMD). Cataracts increase light scatter inside the eye reducing visual acuity and image contrast including that of HUD text and symbology, which would in turn affect symbol detection and recognition (Ortiz et al., 2013). ARMD is a retinal disease process that often damages the central foveal region of the retina reducing visual acuity and the readability of small text or icons. Other eye diseases such as Glaucoma affect peripheral vision resulting in increased detection thresholds or loss of peripheral vision. Individuals experiencing these eye conditions may be licensed to drive with or without restrictions. The designers of automotive HUDs must be cognizant of these conditions so they can make informed design choices to accommodate the largest range of users.

NTE and HMD Technology

Near-to-Eye (NTE) and Head-Mounted Displays (HMD) are two forms of assistive technology that display information in the user's front field of view. Due to the visual and accommodative issues of potential HUD users, the closer the display is placed to the eye, the more significant these concerns become. Additionally, in a study on the use of Google Smart Glass, results showed weaker visual attention when using wearable technology in dual-task scenarios; this poses a significant issue in the use of NTE/HMD technology during potentially dangerous situations such as driving (Lewis & Neider, 2018). Users of consumer HMDs such as Microsoft HoloLens also report motion sickness, eyestrain, headaches, and general discomfort following use (Vovk et al., 2018). These symptoms may diminish with training and fitting of the HMDs to address individual differences such as interpupillary distance and facial features (e.g., the shape of the nose). Windshield HUDs may be preferred over NTE/HMDs given they cannot be lost, broken, or misplaced and do not interfere with the driver's eyeglasses. Further, Head-Mounted

Display devices have also been found to negatively impact visual search due to the promotion of movement of both the eyes and the head (Grudin, 2002).

Clutter and Distraction

HUD symbology, text, or associated pictograms can cause visual clutter, thus, slowing search for relevant driving information. This may be exacerbated under higher workload conditions. Windshield HUDs enable wider implementation of augmented reality. Information displayed on the windshield is tightly registered to an object appearing in the environment to alert the driver of a hazard or to present identifying information related to road features. However, the visual saliency of the information will vary depending on the visual scene (Gabbard et al., Pauzie, 2015). Thus, the superimposed information may compete for attention when the driver is focused on demanding driving conditions, like inclement weather, or it may obscure important road features (e.g., road debris). Under these situations, a HUD might be more of a distraction than a safety aid.

CONCLUSION

Drivers are managing the operation of vehicles equipped with many automated safety features that share and receive information from the transportation infrastructure and other road users. Drivers have access to an extensive range of information sources and apps (e.g., navigation, traffic reports, weather, food stops, fuel stations) to make driving related decisions. These advances offer a compelling case motivating the development of automotive HUDs (or new Windshield HUDs). Automotive HUDs and related technology hold promise of positively impacting driver performance, situational awareness, and safety. However, lessons from aviation also demonstrate that this is not always true. Future applications must carefully consider what, where, when, and how to present information to maximize safety while minimizing driver workload and distraction. This review highlights some of the unique challenges that designing HUDs for the consumer population poses for engineers and human factors experts.

ACKNOWLEDGMENT

The authors would like to acknowledge Rebecca DeMarco's (ERAU) insight, comments, and advice during the course of this project.

REFERENCES

Airplane pilot demographics and statistics [2022]: Number of airplane pilots in the US. (2021). Retrieved January 14, 2022, from https://www.zippia.com/airplane-pilot-jobs/demographics/

Crowdsourcing for Operations (2021). U.S. Department of Transportation/Federal Highway Administration. Available from: https://www.fhwa.dot.gov/innovation/everydaycounts/edc_5/crowdsourcing.cfm (accessed 25 January 2022).

de Oliveira Faria, N. (2020). Evaluating automotive augmented reality head-up display effects on driver performance and distraction. In 2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW) (pp. 553–554). IEEE.

Fadden, S., Ververs, P. M., & Wickens, C. D. (1998, October). Costs and benefits of head-up display use: A meta-analytic approach. In Proceedings of the human factors and ergonomics society annual meeting (Vol. 42, No. 1, pp. 16–20). Sage CA: Los Angeles, CA: Sage Publications.

Gabbard, J.L., Fitch, G.M. and Kim, H. (2014). Behind the glass: driver challenges and opportunities for AR automotive applications. Proceedings of the IEEE, 102(2), pp. 124–136.

Gabbard, J. L., Mehra, D. G., & Swan, J. E. (2018). Effects of AR display context switching and focal distance switching on human performance. IEEE Transactions on Visualization and Computer Graphics, 25(6), 2228–2241.

Grudin, J. ed. (2002). Rivalry and interference with a head-mounted display. ACM Transactions on Computer-Human Interaction (TOCHI), 9(3), pp. 238–251.

Hagen, L., Brown, M., Herdman, C.M. and Bleichman, D. (2005). The costs and benefits of head-up displays (HUDss) in motor vehicles. In Proceedings of the 13th International Symposium on Aviation Psychology.

Haines, R. F., Fischer. E .. and Price, T. A. (1980). Head-up transition behavior of pilots with and without head-up displays in simulated low-visibility approaches (NASA TP-I720).

Horrey, W.J., Alexander, A.L. and Wickens, C.D. (2003). Does workload modulate the effects of in-vehicle display location on concurrent driving and side task performance. In Driving Simulation Conference North America, Dearborn, Michigan (pp. 1–20).

Horrey, W.J. and Wickens, C.D. (2004). Driving and side task performance: the effects of display clutter, separation, and modality. Human Factors, 46(4), 611–624.

Kaptein, N.A., 1994. Benefits of in-car head-up displays. TNO Report TNO-TM 1994 B-20, TNO Human Factors Research Institute, The Netherlands.

Liu, Y.C. and Wen, M.H. (2004). Comparison of head-up display (HUD) vs. head-down display (HDD): driving performance of commercial vehicle operators in Taiwan. International Journal of Human-Computer Studies, 61(5), pp. 679–697.

Lewis, J.E. and Neider, M.B. (2016). Through the google glass: the impact of heads-up displays on visual attention. Cognitive research: principles and implications, 1(1), pp. 1–10.

Maroto, M., Caño, E., González, P., & Villegas, D. (2018). Head-up displays (hud) in driving. ArXiv preprint arXiv:1803.08383.

Martin-Emerson, R. and Wickens, C.D. (1997). Superimposition, symbology, visual attention, and the head-up display. Human Factors, 39(4), pp. 581–601.

McGwin Jr, Gerald, Victoria Chapman, and Cynthia Owsley. (2000). Visual risk factors for driving difficulty among older drivers. Accident Analysis & Prevention 32, (6), 735–744.

Normile, B., and Ulitskaya, J. (2021). Which cars have head-up displays? Cars.com, Cars.com. Available from: https://www.cars.com/articles/which-cars-have-head-up-displays-434824/ (accessed 25 January 2022).

Owsley, C., Stalvey, B. T., Wells, J., Sloane, M. E., & McGwin, G. (2001). Visual risk factors for crash involvement in older drivers with cataract. Archives of Ophthalmology, 119(6), 881–887.

Ortiz, C., Castro, J. J., Alarcón, A., Soler, M., & Anera, R. G. (2013). Quantifying age-related differences in visual-discrimination capacity: drivers with and without visual impairment. Applied Ergonomics, 44(4), 523–531.

Park, J. and Park, W. (2019). Functional requirements of automotive head-up displays: a systematic review of literature from 1994 to present. Applied Ergonomics, 76, pp. 130–146.

Pauzie, A. (2015). Head up display in automotive: a new reality for the driver. In International Conference of Design, User Experience, and Usability (pp. 505–516). Springer, Cham.

Pullukat, J., Tanaka, S. and Jiang, J. (2020). P-25: Effects of image distance on cognitive tunneling with augmented reality head up displays. In SID Symposium Digest of Technical Papers (Vol. 51, No. 1, pp. 1427-1430).

Singh, G., Ellis, S. R., & Swan, J. E. (2018). The effect of focal distance, age, and brightness on near-field augmented reality depth matching. IEEE Transactions on Visualization and Computer Graphics, 26(2), 1385–1398.

Smith, M., Streeter, J., Burnett, G. and Gabbard, J.L. (2015). Visual search tasks: the effects of head-up displays on driving and task performance. In roceedings of the 7th international conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 80-87).

Sojourner, R.J. and Antin, J.F. (1990). The effects of a simulated head-up display speedometer on perceptual task performance. Human Factors, 32(3), pp. 329–339.

Srinivasan, R. (1999). Overview of some human factors design issues for in-vehicle navigation and route guidance systems. Transportation research record, 1694(1), pp. 20–29.

Stumpf, R. (2021). Volvo wants to turn your entire windshield into a heads-up display. Popular Science. Retrieved December 27, 2021, from
https://www.popsci.com/technology/volvo-spectralics-windshield-hud-display/

Topliss, B. H., Pampel, S. M., Burnett, G., & Gabbard, J. L. (2019). Evaluating head-up displays across windshield locations. In Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 244–253).

Vovk, A., Wild, F., Guest, W. and Kuula, T. (2018). Simulator sickness in augmented reality training using the Microsoft HoloLens. In Proceedings of the 2018 CHI conference on human factors in computing systems (pp. 1–9).

Weihrauch, M., Meloeny, G.G. and Goesch, T.C. (1989). The first head up display introduced by general motors (No. 890288). SAE Technical Paper.

Wickens, C.D., Helton, W.S., Hollands, J.G. and Banbury, S. (2021). Engineering psychology and human performance. Routledge.

Wickens, C.D., Ververs, P.M. and Fadden, S.F. (2004). Head up displays. Human factors for civil aviation.In D. Harris (Ed.), Human Factors for civil flight deck design (pp. 103–140). UK: Ashgate.

Wolffsohn, J.S., McBrien, N.A., Edgar, G.K. and Stout, T. (1998). The influence of cognition and age on accommodation, detection rate and response times when using a car headâŁłup display (HUD). Ophthalmic and Physiological Optics, 18(3), pp. 243–253.

Wood, R.B. and Howells, P.J. (2000). Head-up displays. CRC Prss LLC, URL: http://www. Davi.ws/avionics/TheAvionicsHandbook_Cap_4. pdf [cited 14 July 2014].