**Editorial**　　　　　　　　　　　　　　　　　　　　　　　　　　**Open Access**

# Head-Up Display for Pilots and Drivers

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Head-Up Display (HUD) was first used in the aviation industry as a synthetic information display for pilots and then it was applied to the automobile industry because of its commonly agreed benefits for pilots. With the booming of smart wearable and mobile devices, such as Google Glass and Garmin HUD, HUD is likely to become increasingly popular for pilots and drivers because of its reduced cost and flexibility in developing new applications with different interfaces and interactions. However, despite the benefits of HUD in the aviation industry, more human factors, ergonomics and psychological factors need to be considered and investigated before the implementation of HUD in vehicles and aircrafts [1]. How will these new infotainment or informatics devices influence piloting and driving performance? Will the HUD produce the claimed benefits for drivers as it benefits pilots, or actually create more sources of operator distractions?

HUDs present superimposed visual information onto a medium usually located at the same level of the windscreen and beyond the standard instrument panel. The visual information in HUD appears to be displayed in operator's forward field of view [2,3]. HUDs include wearable devices, in-vehicle projectors and displays, such as Google Glass, Garmin HUD and MicroVision's PicoP® HUD. According to the Proximity Compatibility Principle [4], information relevant to a common task should be displayed close together in perceptual space. For example, vehicle speed and driving road, or the aircraft height and forward scene in the sky are critical information for driving and piloting, thus these types of information should better be displayed in close proximity. The HUD meets the recommendation of the Proximity Compatibility Principle by showing task-critical information in perceptual neighborhood [5]. As a result, it reduces eye scanning compared to a Head Down Display (HDD) or the vehicle instrument panel. HUD can make the increasing amount of information easily accessible and can potentially minimize operators' mental workload [6].

Another display design that is often compared with HUD is the Head-Down Displays. HDD is often positioned in the middle of the vehicle's control panel. To read information displayed in a HDD, users often need to move attention from the forward view and look down at the display, causing visual distractions. If the visual information in the HDD is hard to process or not well formatted, users may move attention away from the road for a long time. Gaze-off-the-road longer than 2s greatly increases traffic accident, which is one of the major causes of traffic accident [7]. Pilots using HDD had poorer flight path control [8]. In contrast, HUD can reduce the amount of visual distractions that HDD causes and let operators focus on the important forward view [9].

The performance benefits of HUD are frequently reported and have led to widely adoption of HUD in aircrafts and automobiles. The major advantage of HUD over HDD is the reduction of eye scanning. Visual information access cost increased as display separation increased [10,11]. The reading time on a HUD and the transition time between speedometer shown in a HUD and the roadway were both significantly shorter than that of a HDD [9,12], which thereby reduced the amount of visual distraction. For example, drivers using HUD produced better lane-keeping [13-15], better speed maintenance and quicker response time for speed limit sign changes and urgent events [16-18], and lower subjective workload than users of HDD [14]. Older drivers using a HUD was able to detect pedestrians quicker and more accurately, and produced less navigation errors, which demonstrated an improvement of older drivers' ability to see forward scene events [9]. Attracted by the benefits of HUD, researchers are trying to design innovative HUD interface to reduce operator distraction and to improve performance [19,20]. For example, compared to the center-console-mounted phone, drivers using a HUD-based phone produced much quicker response time and fewer line crossings [20]. In aviation, pilots using a HUD produced smaller path tracking errors than pilots using a HDD [21] and helicopter pilots were able to detect and avoid obstructions earlier when using a head mounted display than flying without it [22].

However, despite the commonly accepted benefits of HUD, HUD comes with potential concomitant performance costs too. For example, pilots using HUD instrumentation produced longer detection response time to unexpected events [23,24]. Compared to symbology displayed in HDD, HUD produced faster transition from instrument to visual flight reference. However, HUD also resulted in slower responses to the unexpected events in the far domain and greater tracking error of digital airspeed [8]. When vehicle speed was displayed in the digital HUD, the deviation of lane position was much larger than when speed was shown in the analogue HUD or HDD [3].

The performance benefits and costs of HUD are modulated by several factors, such as task workload, visual clutters, and fixation tunneling. First, the benefits of HUD may be limited to the low workload condition. Driving behaviors and hazard response time deteriorated as workload increased [16]. When operators' workload is high, the performance using HUD may be similar to HDD, or even poorer than HDD. For example, the reaction time of HUD users under high workload condition was even longer than users of HDD [25,26]. The response time to and detection of changes in the HUD and the outside world got worse as cognitive demand and age increased [27]. Second, HUD can potentially increase visual clutter by superimposing imagery into the visual world, which thereby increases the perceptual workload [28]. Third, HUD could capture operator's attention such that attention was seldom directed elsewhere, causing a fixation tunneling effect [15]. HUD can reduce eye scanning to objects at far visual angles, causing a narrowing of gaze distribution. Thus, objects located at far visual angles are less likely to be detected. For example, pilots using a HUD produced a slower response to unexpected events at far visual angles [29]. For the overlaid images in the HUD and the real world, if

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operators' attention was paid to the HUD rather than the real world, they may not be able to perceive the object in the real world even if their fixations were right on that object, a phenomenon often called as "inattentional blindness" [30]. Thus, HUD could cause difficulties in detecting unexpected events and switching attention between HUD and the real world [31].

Considering the potential benefits and costs of HUD, aircraft and automobile designers should be cautious when designing and implementing HUD. The introduction of novel in-vehicle devices, such as a HUD or a HDD, may introduce new distraction and increase workload of operators. Hardware and interface designers of HUD and HDD are recommended to consider existing human factors guidelines for visual displays [32,33]. New HUD and HDD should be tested before they are implemented in actual aircraft or vehicles to make sure the devices do not create visual clutter and induce overwhelming operator workload. Operators of HUD and HDD should be offered sufficient training before actual operation. Future academic research may consider how to minimize visual distraction and reduce operator workload for HUD and HDD.

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