ARMY RESEARCH LABORATORY

Head-Up Display for Current Force Vehicles

by Jessie Y. C. Chen and Razia V. Nayeem

ARL-TR-5167 **May 2010**

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Human Research and Engineering Directorate, ARL

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14. ABSTRACT

The Scalable Embedded Training - Mission Rehearsal Army Technology Objective of the U.S. Army Research, Development, and Engineering Command Simulation and Training Technology Center is developing an innovative prototype visual imaging system, the switchable vision block, for embedded vehicle driver training, mission rehearsals, and mission operations. The effort will focus on current force combat vehicle vision blocks and night driving sensors. U.S. Army Research Laboratory researchers are designing a head-up display (HUD) that can overlay driving-related information (e.g., speed, fuel, engine feedback) on the vision blocks as well as provide situational awareness and C4 information to the driver. Drivers of Bradley and Stryker vehicles at Ft. Benning, GA, and U.S. Army Tank-automotive and Armaments Command were surveyed, and their recommended design features of the HUD were incorporated in the prototype HUD. HUDs have been found to be an effective means to enhance pilot situational awareness by making information more accessible to the pilot. However, past research has also shown that large amounts of information, while helpful in reducing the operator's scanning effort by providing more data in a centralized area, can create visual clutter and degrade the operator's information processing due to cognitive overload. Additionally, overlaying information on the vision blocks can potentially lead to attentional narrowing, as an operator's attention can be captured by the overlaid data while important elements/developments in the environment might be overlooked. Therefore, the display design tradeoffs between adding information to the vision blocks and the potential attentional narrowing effects need to be systematically evaluated. A study was conducted to evaluate differences in performance using a HUD vs. a traditional head-down display (HDD). Results showed that for objective driving performance, the HUD actually results in slightly worse performance and produces an attentional narrowing effect. However, on self-report measures, participants preferred the HUD to the HDD.

15. SUBJECT TERMS

head-up display, driving performance, user interface design, attention

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1. Introduction

1.1 Background

The Scalable Embedded Training - Mission Rehearsal (SET-MR) Army Technology Objective (ATO) of the U.S. Army Research, Development, and Engineering Command (RDECOM) Simulation and Training Technology Center (STTC) is developing a new prototype visual imaging system called a switchable vision block (SVB) to be used for embedded vehicle driver training, mission rehearsals, and mission operations (see figure 1 for the interior of a Stryker vehicle). A vision block is a solid, periscope-like apparatus that allows the crew inside a fighting vehicle to see the outside through a series of mirrors inside a box, one side of which is facing the outside environment and the other side of which the operator looks through. An SVB is a way to extend the capability of a regular vision block system with different operating modes—normal optical view, combined view (similar to a head-up display [HUD]), and a synthetic image for displaying additional information such as vehicle status (see figure 2 for a depiction of the SVB [Montoya et al., 2007]).

Figure 1. Stryker vehicle interior.

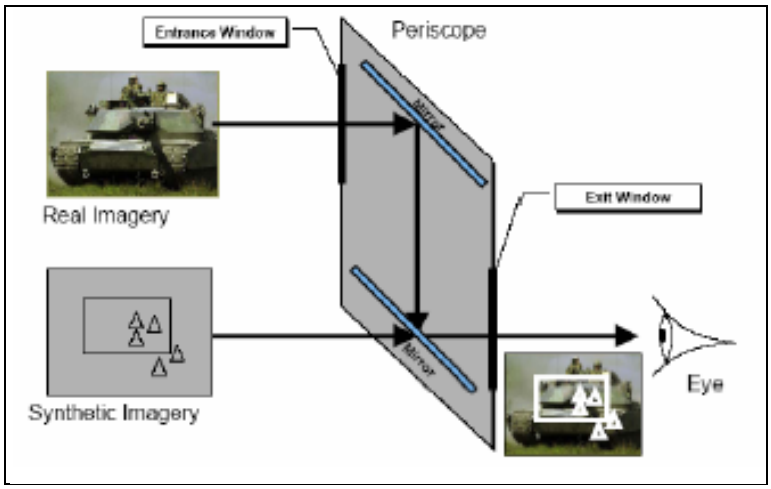

Figure 2. SVB concept (Montoya et al., 2007).

One of the key advantages to using an SVB is it gives the crew a common interface for both training and operating the vehicle. Additionally, extra elements can be displayed on the screen, such as maps, enemy/friendly information, or even relevant training elements, which can be helpful in training as well as operation. Added benefits include giving the crew the ability to maintain their vehicle position and orientation, giving the crew the ability to maintain position relative to friendly and enemy forces, giving the crew the ability to detect very close entities, and being easily compliant with several different vehicles. The SET-MR ATO of RDECOM-STTC is currently developing an SVB system that utilizes a collimated optical display, which is widely used in aircraft HUDs, for the overlayed symbology to appear to be at an optically infinite distance from the operator (Montoya et al., 2007). The advantage of such collimated displays is reduced visual misaccommodation for the operator since the overlayed images are displayed at the same optical depth as the outside world (Crawford and Neal, 2006). As part of the SVB effort, the U.S. Army Research Laboratory - Human Research and Engineering Directorate designed a HUD for the current force vehicles (see section 1.3 on the design process) that could be used in operational (i.e., driving) settings, in addition to its purposes for training and mission rehearsal. The following section briefly reviews the advantages and disadvantages associated with HUDs reported in the literature, followed by a summary of surveys of current-force vehicle drivers and the design process of our HUD. Section 2.5 reports a simulation experiment to investigate the effectiveness of the HUD and potential operator performance issues.

1.2 Head-Up Display (HUD)

HUDs are being increasingly used in aviation and have started being used in automobile driving and racing (BMW, 2009; Microvision, 2009; Sportvue, 2009). Some studies suggest that HUDs in automobiles are not that useful for things such as speed, tachometer, etc., but are mostly useful for directions and navigation (CNN, 2009). Most of the research in HUDs has been conducted in aviation, but there are studies conducted in ground vehicles, and many of the aviation findings can be extrapolated to ground vehicles. In aviation, HUDs are being used to increase situation

awareness (SA) for pilots in all segments of flight, including takeoff and landing, which are typically the most difficult times of a flight. While HUDs that project pathways have been shown to cause a slight decrement in vertical tracking, they also cause an improvement in event detection, horizontal tracking, and navigation on the ground (i.e., taxiing) (Crawford and Neal, 2006; Fadden et al., 2001; French et al., 2006; Hooey and Foyle, 2006). These findings would likely extend to automobiles since the environment is very similar to taxiing an aircraft (Crawford and Neal, 2006).

The main advantages of HUDs (as compared to head-down displays [HDDs]) include the following: (1) reduced scanning distance between instrumentation and the outside world, (2) increased SA of the external environment due to more visual attention to the outside world and less head-down time, and (3) the location gives a longer focal distance so the focal transition is easier for users (i.e., less visual misaccommodation) (Crawford and Neal, 2006; Martin-Emerson and Wickens, 1997; Tufano, 1997). Horrey and Wickens (2004a) found that HUDs are typically superior to HDDs because they utilize both the ambient visual system (peripheral vision) and the focal visual system. They showed that, while ambient vision can support some aspects of driving, such as vehicle control, this lessens as display separation increases, such as in HDDs. Additionally, they found that ambient vision cannot adequately support hazard awareness, so drivers are likely to miss obstructions in roadways when looking down at gauges in an HDD that they might otherwise notice in a HUD.

One area in which HUDs are particularly useful is when the outside environment is poor, such as rain or fog, because high-quality HUD images (typically collimated in the aviation domain) make the user focus further out which reduces visual accommodation problems (Crawford and Neal, 2006). However, very high-quality HUDs have been shown to capture attention too well and can divert attention away from other sources (Crawford and Neal, 2006). There is also some evidence that collimation does not always pull the operator's visual focus outward to optical infinity and, in some cases, visual misacommodation may become worse due to collimated displays (Crawford and Neal, 2006).

Although there are many advantages associated with HUDs, past research has shown various human performance issues that can be induced by HUDs. One study showed that HUDs resulted in a faster reaction time to obstructions in the roadway than with HDDs, but that was only true of expected objects—with unexpected objects, such as a pedestrian running into the roadway, the reaction time was slower with a HUD (Tufano, 1997). Another study showed that HUDs can cause users to completely miss targets, whereas HDDs did not, and the difference in missed targets was statistically significant (Crawford and Neal, 2006). However, the findings in the literature are not always consistent. For example, Horrey and Wickens (2004a) demonstrated that there was no increase in hazard detection time with a HUD vs. an HDD in a simulated driving task. Nevertheless, HUDs may create a false sense of awareness in users because, typically, users give HUDs a high rating and believe they are seeing all the pertinent information

because it is being presented in their visual fields, but they do not realize there could be other information they are neglecting to attend to (Crawford and Neal, 2006).

While some studies have found clutter to be an issue with overlayed HDDs, Horrey and Wickens (2004b) found no differences between superimposed HUDs and adjacent HUDs with respect to driving performance and secondary task performance. Additionally, vehicle control is largely achieved by the ambient visual system, which is less affected by clutter than the focal system. The success of HUDs in automobiles will largely depend on the usefulness of the information displayed to the driver by the HUD; therefore, the information displayed will have to provide a larger advantage to the driver than the disadvantages seen (Tufano, 1997).

The current research investigated the quantifiable performance differences in drivers using HUDs and HDDs to determine performance differences between the two displays for Bradley and Stryker fighting vehicles.

1.3 Driver Surveys

To understand how drivers use displays when performing various job tasks, 35 Bradley and Stryker drivers from Ft. Benning, GA, and from the Tank-automotive and Armaments Command completed surveys about using their current displays and potential HUDs. The most relevant data collected for designing a HUD are as follows and will be used for display recommendations in both platforms. The main categories are additions to the current HDD design, distractions to driving with the current HDD design, layout of the future HUD design, and the actual HUD design.

1.3.1 Additions to the Current HDD Design

Drivers were asked "Given any information in the vehicle (i.e., situation awareness, command, control, communication, and computer information), what would you like to see on the screen?" and "What information might other crew members have that you currently don't have convenient access to, which would you like to have?" Of the 35 respondents, 31 (88.6%) said they would add components to the current HDD design. The most popular answers to the question can be seen in table 1 as well as how many respondents reported each item.

As shown in table 1, most of the components drivers wanted to be added were indicators and gauges, with only four items related to other mission elements, such as situation awareness. These were outside camera views, inside camera views, weather, and wider range of view. As such, one might conclude that drivers have very little additional need for situation awareness aids but need more information about basic components of the vehicle so they can drive effectively.

Table 1. Additions to the current HDD design.

Item	No. Reported
Digital speedometer	15
Outside camera views	15
Grid position/map	14
Ammunition count/type	14
Compass/direction of travel	11
Fuel gauge	11
Turret position	10
Oil temperature	9
Battery life	9
Water temperature	8
Oil pressure	8
FBCB2	8

1.3.2 Distractions to Driving With the Current HDD Display

Drivers were asked "Which instruments must you look at a lot now that may briefly distract you from your driving?" Of the 35 respondents, 31 (88.6%) said there were components in the current HDD design that distracted them while they were driving. The most popular answers to the question can be seen in table 2 as well as how many respondents reported each item.

Table 2. Distractions to driving with the current HDD design.

Item	No. Reported
Speedometer	17
Oil/engine temperature	17
Fuel	7

As shown in table 2, all the components that distracted drivers in the current HDD display are functional components. Also, there is overlap between what some drivers want to add to the current display and what distracted some. This could be from varying display components between the Bradley and Stryker, but could also be from driver preference. Implications of this overlap will be discussed later.

1.3.3 Layout of the Future HUD Design

Drivers were asked "If we could display the information you would like to see in the new vision block, how do you think it should be displayed? For example, which area of the screen, colors used, audible alerts, etc.?" Of the 35 respondents, 30 (85.7%) gave suggestions about the layout of the display. The most popular answers to the question can be seen in table 3 as well as how many respondents reported each item.

Table 3. Layout of the future HUD design.

Item	No. Reported
Lower part of the screen	15
Red/flashes for alert	14
Green for good/ample	13
Amber	13

As table 3 shows, most of the responses were in relation to placement of components on the screen and color. Also, with respect to color, drivers wanted a traditional color scheme where green indicates something good, red indicates something bad, and amber or yellow indicates something that could become bad in the near future.

1.3.4 HUD Design

Using the information from the surveys, a HUD was developed (see figure 3). Each component of the HUD was suggested by drivers. Across the top of the display is a heading indicator with turret direction indicated by an arrow. A small map of the surrounding area is displayed in the upper left corner, and six gauges are displayed in the upper-right corner, which are fuel, battery, ammunition count, oil temperature, oil pressure, and water temperature. An analog speedometer is in the bottom middle and has the speed digitally shown at the bottom of the speedometer. Additionally, a gear indicator is just right of the speedometer. The bottom corners were left open due to comments about the need to search for improvised explosive devises (IEDs) in those areas. The HUD was used in the current experiment comparing the HUD to an HDD. With respect to the overlapping components, it was decided that since the three most overlapping components were critical gauges with mission-relevant information, the risk of not having that information when needed was greater than the distraction they might provide, so they were all included in the HUD design.

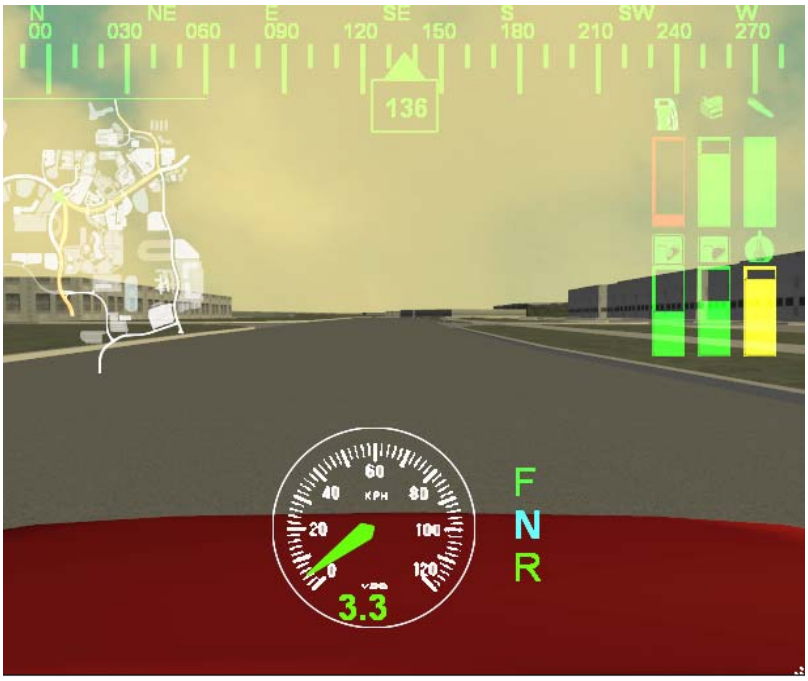

Figure 3. HUD projected onto background.

1.4 Current Study

In this experiment, we compared driving performance on a simulator using a collimated HUD (see section 2.2, Apparatus) vs. a traditional HDD. The primary task was driving a predetermined route, and the secondary tasks were monitoring the roadways and adjacent areas for IEDs and monitoring gauges for anomalies. It was hypothesized that the HUD would result in better overall driving performance, as well as subjective self-report measures, than the HDD because studies have shown that participants are more successful at driving when information is displayed in an integrated fashion rather than in separate displays (Horrey and Wickens, 2004a, 2004b). Driving performance was comprised of number of collisions, number of stop signs run, number of times vehicle left the roadway, and average speed. Subjective workload and performance were also measured, as well as subjective sickness symptoms. Secondary task performance was comprised of number of IEDs missed, distance to IED when IED was identified, number of gauge anomalies cleared, and response time to clear gauge anomalies.

2. Method

2.1 Participants

Twenty participants from the University of Central Florida area were recruited to participate in the study. The age range was between 18 and 36, and a valid driver's license was required for participation. Individuals were informed that participation was voluntary and that they could withdraw at any time without penalty. Participants were paid $15/h for their participation.

2.2 Apparatus

2.2.1 Simulator

The game engine used in this experiment was ManiaDrive.* This engine is software that can be run on any standard computer and is the environment in which participants navigated in the simulated driving routes. The driving scene was displayed using a collimated display, which is viewed by looking into a display box and appears to be at an optically infinite distance from the viewer (Montoya et al., 2007). A Logitech steering wheel and gas and brake pedals were used for participants to navigate through the game engine (see figure 4 for the experimental setup)

Figure 4. Collimated display viewing box and simulated driving equipment.

*ManiaDrive by Raydium is a free clone of the game TrackMania, a registered trademark of Nadeo Studios.

2.2.2 Head-Up Display

The HUD information unit was placed at the top of the viewing box (see figure 4), and its imageries were projected onto the driving scene via mirrors in the box (see figure 3). Figure 5 shows a sample route used in an experimental scenario.

2.2.3 Head-Down Display

For this condition, participants still viewed the driving environment through the box as shown in figure 4 (using the collimated display), but the imageries were presented in a separate computer screen placed below the box (to the left of the steering wheel, see figure 4), simulating how one would view the instrument panel in an automobile by looking from the windshield down to the panel (i.e., HDD).

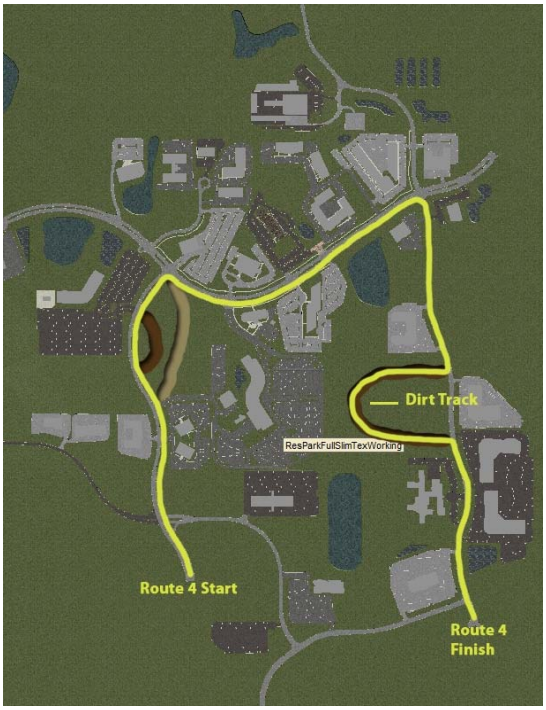

Figure 5. Sample route used in an experimental scenario.

2.3 Surveys and Tests

Participants first completed an informed consent and a demographics questionnaire (appendix A). Participants completed "The Map Reading Test" (appendix B) (Money and Alexander, 1966), which required them to follow a route on a map and indicate the direction (i.e., right or left) at each turn. The participant's score was the number of correct responses within the time limit of 20 s.

Participants' perceived workload was evaluated using the National Aeronautics and Space Administration Task Load Index (NASA-TLX) questionnaire (Hart and Staveland, 1988; see appendix C). The NASA-TLX is a self-reported questionnaire of perceived demands in the following six areas: mental, physical, temporal, effort (mental and physical), frustration, and performance. Participants used this questionnaire to evaluate their perceived workload level in these areas on 10-point scales as well as completing pairwise comparisons for each subscale. The subscale of performance was also analyzed on its own.

The Simulator Sickness Questionnaire (SSQ) was used to evaluate participants' simulator sickness symptoms (Kennedy et al., 1993; see appendix D). The SSQ consists of a checklist of 16 symptoms. Each symptom is related in terms of degrees of severity (none, slight, moderate, and severe). A total severity score was derived by a weighted scoring procedure and reflects overall discomfort level.

2.4 Experimental Design

The overall design of the study was a repeated measures design, with each participant completing all routes. The independent variable was Display Type, and it had two levels—HUD and HDD. The order of presentation for the experimental conditions was determined by a Williams Square.

2.5 Procedure

Upon arrival to the study, participants were briefed on the purpose of the study, and they signed the informed consent form, completed the demographics questionnaire, and had their questions answered. Participants then received practice on the driving tasks and familiarized themselves with images of IEDs (images were not present when participants completed driving trials) and with the gauges that showed anomalies.

For the experimental trials, participants were asked to drive a predefined route while following certain guidelines, such as speed limits, lane-keeping behavior, and stop sign behavior. Participants were also asked to monitor the roadway and adjacent areas for IEDs. Participants were instructed that if an IED was spotted, they should press a button to acknowledge the IED. Additionally, while driving, participants were asked to monitor the gauges on the displays and press a button when a gauge had an anomaly to acknowledge it. Participants completed four trials using four different, but comparable, driving routes—two trials with the HUD and two with the HDD. Trials were counterbalanced using a Williams Square to avoid order effects. After each trial, participants assessed their workload and sickness symptoms by using the NASA-TLX and SSQ, respectively. There was a 5-min break between trials. After all trials were completed, participants were compensated and fully debriefed, having all their questions answered. Each trial took ~5 min, and the experiment took ~1 h.

2.6 Measures

Driving performance was comprised of number of collisions, number of stop signs run, number of times vehicle left the roadway, and average speed. Subjective workload and performance were also measured as well as subjective sickness symptoms. Secondary task performance was comprised of number of IEDs missed, distance to IED when IED was identified, number of gauge anomalies cleared, and response time to clear gauge anomalies.

3. Results

Table 4 lists several measures relating to operator driving performance, secondary task performance, SSQ, subjective workload, and performance assessments. All tests were performed using a statistical program SPSS 16 with an alpha level of 0.05. There were no outliers or abnormal data unless otherwise noted. Paired samples t-tests were performed on each variable between the HUD condition and HDD condition. Additionally, Pearson's correlations were run between the map reading test and driving performance variables.

Table 4. Operator task performance and subjective assessments.

Measures	Display	
	HUD	HDD
Primary (Driving) Task Performance		
Number of collisions[a]	0.35 (0.5)	0.05 (0.22)
Number of stop signs run[b]	1.05 (0.65)	1.98 (0.51)
Number of times vehicle leaves roadway	2.28 (1.66)	1.5 (1.84)
Average speed in kph[b]	26.76 (3.91)	29.8 (3.35)
Secondary Task Performance		
Number of IEDs missed[a]	4.05 (0.76)	3.6 (0.84)
Distance to IED when identified IED in world units	4.46 (4.42)	5.90 (3.22)
Number of gauge anomalies cleared	0.95 (0.22)	0.93 (0.24)
Response time to clear gauge anomalies in seconds	8.2 (13.91)	13.39 (10.11)
Subjective Assessments		
NASA-TLX overall score	30.85 (6.8)	29.5 (7.1)
Performance score—subscale of NASA-TLX	3.78 (1.45)	4.4 (1.76)
SSQ score	8.41 (9.39)	6.26 (5.95)

Note: Standard deviations are presented in parentheses.
[a] $p < .05$.
[b] $p < .01$.

3.1 Driving Performance

Analysis on the number of collisions showed that participants had significantly more collisions in the HUD condition than when in the HDD condition, $t(19) = 2.26$, $p = 0.036$. The t-test on running stop signs showed that participants ran significantly more stop signs in the HDD condition than in the HUD condition, $t(19) = -8.37$, $p < 0.000$. Analysis on average speed

showed that participants drove significantly faster in the HDD condition than in the HUD condition, $t(19) = -4.79$, $p < 0.000$. However, the t-test on number of times the vehicle left the roadway did not show a significant difference between the HUD condition and the HDD condition, $t(19) = 1.88$, $p = 0.076$. It is important to note that the difference in average speed might be attributed to the increased number of collisions in the HUD condition and the increased number of stop signs run in the HDD condition; thus, participants were stopping more in the HUD condition, so that could be why their average speed was higher in the HDD condition. Figure 6 shows the four driving-related performance measures.

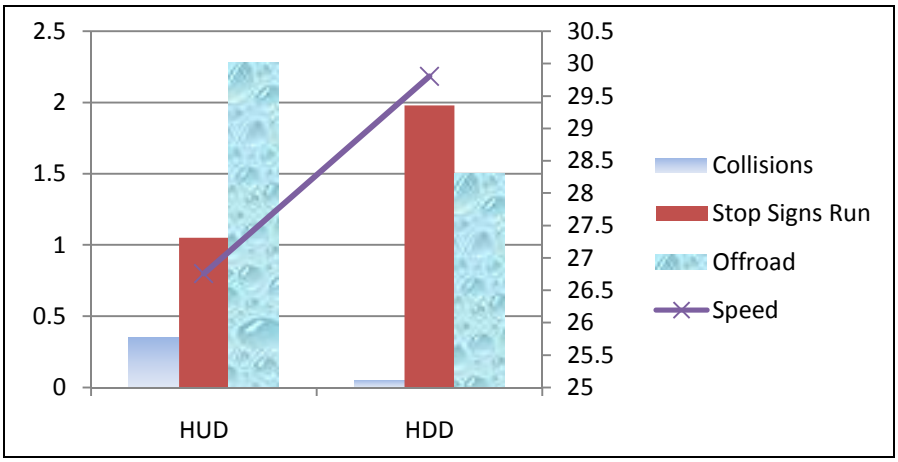

Figure 6. Number of vehicle collisions, stop signs run, number of times the vehicle driving off road, and speed by condition.

3.2 IED Identification

With respect to IED detection, route 2 was taken out of the final analyses. In this route, only two participants out of 20 detected any IED, so this condition was treated like an outlier for this variable, and the data were removed prior to analysis. For number of IEDs missed, the t-test showed that participants missed significantly more IEDs when in the HUD condition than when in the HDD condition, $t(19) = 2.49$, $p = 0.022$. For distance to IED when IED was identified, the analysis also showed there was not a significant difference, $t(19) = -0.13$, $p = 0.209$. The overall IED behavior can be seen in figure 7.

3.3 Gauge Anomaly Clearing

The first analysis of number of gauge anomalies showed there was no significant difference between the HUD condition and the HDD condition, $t(19) = 1.00$, $p = 0.33$. For the analysis of response time to clear gauge anomalies, there was one outlier for both conditions that was removed from the data, so the analysis was done on 19 participants rather than 20. The t-test showed there was no significant difference in response time to clear gauge anomalies between the HUD condition and the HDD condition, $t(18) = -1.18$, $p = 0.255$ (figure 7).

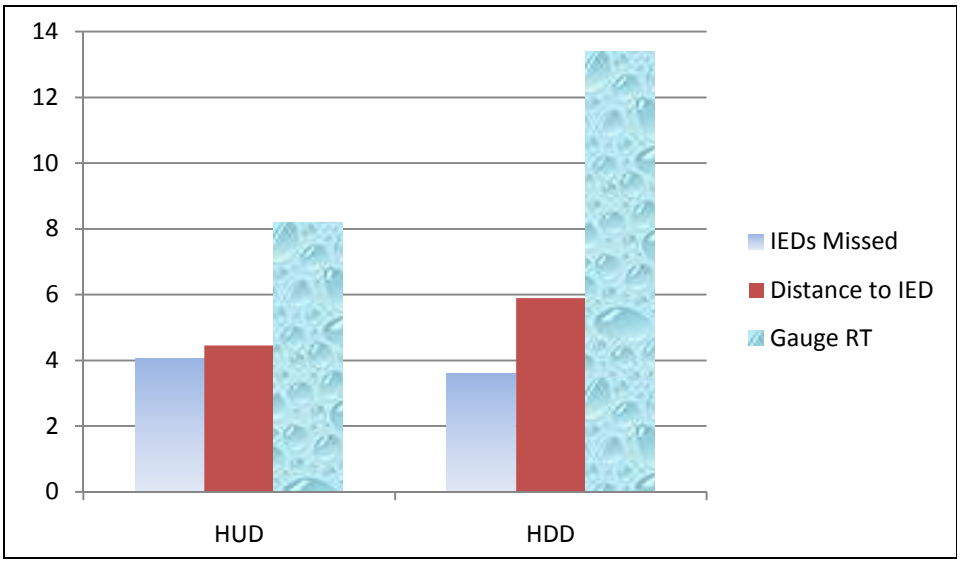

Figure 7. Number of IEDs missed, distance to IED identification, and response times for gauge anomalies clearing by condition.

3.4 Perceived Workload and Performance

The overall NASA-TLX score was analyzed by condition. The analysis showed no significant difference between the two conditions, $t(19) = 1.86$, $p = 0.079$. In addition to the overall NASA-TLX workload score, the subscale of performance was analyzed. The analysis showed no significant difference between the two conditions, $t(19)$, $p = 0.059$.

3.5 Sickness Symptoms

The analysis showed no significant difference between the HUD condition and the HDD condition, $t(19) = 1.48$, $p = 0.156$.

3.6 Map Reading Test Correlations

There was a negative correlation between participants' map reading test (MRT) scores and the number of times their vehicle was driving off road in the HDD condition, $r = -0.438$, $p = 0.027$. Those with lower MRT scores tended to drive off road more frequently than did those with higher MRT scores. There was also a significant correlation between the MRT scores and self-assessed performance in the HUD condition, $r = 0.457$, $p = 0.043$. Those with higher MRT scores tended to assess their own driving performance as better than did those with lower MRT scores.

3.7 Participant Preference

At the end of the experiment, the researcher asked participants which display they preferred. Sixteen participants (80%) said they preferred the HUD to the HDD. Though they were not asked to elaborate on why, several participants said they preferred not having to scan back and forth so much between displays. Interestingly, participants' preferences mostly were not in accordance with their performance.

4. Discussion

As the results indicate, the HUD produced slightly worse driving performance (i.e., more collisions and slower driving speed) than the HDD (i.e., more stop signs violations), although many of the secondary tasks had no significant differences between the two conditions. One significant finding is participants missed more IEDs in the HUD condition than in the HDD condition. This result suggests that, when using the HUD, participants tended to pay less visual attention to the driving environment than when using the HDD. In other words, the results indicate that participants neglected the driving environment and experienced some cognitive tunneling of attention, also known as attentional narrowing, when using the HUD, as has shown in past research (Crawford and Neal, 2006; Tufano, 1997; Wickens, 2005). The term cognitive tunneling most often refers to a broad, overarching concept, including things such as attentional narrowing, visual narrowing, spatial narrowing, etc., whereas attentional narrowing specifically refers to the tunneling of attention, without any other narrowing factors. Much as Crawford and Neal (2006) found, it appears participants had a false sense of security when using the HUD, as they rated their performance the same with the HUD and the HDD, although their actual performance was sometimes worse with the HUD. This could be from differences in metacognitive abilities. It has been shown that people who have lower metacognition often rate themselves as performing better than they actually do, but as metacognition increases, people rate their performance closer to what it actually is. Thus, if participants had better metacognition, such as experts do, they might rate their performance on the displays to be more in line with their actual performance (Kruger and Dunning, 1999). One way to potentially mitigate this effect would be to measure metacognition and use this as a covariate in future studies.

According to our surveys, Bradley and Stryker drivers are in favor of replacing their current displays with a HUD-like display. It is anticipated that the HUD could provide advantages over the traditional HDD (e.g., easy access to the map or global positioning system information and other driving-related information); however, the attentional narrowing effect of the HUD, as demonstrated in the current study and numerous previous studies, needs to be further investigated. More research needs to be conducted to mitigate the attentional narrowing effect, so HUDs can be more effective.

It is important to note that the routes used in this experiment were fairly simple and straightforward. Had more difficult routes been used, participants likely would have had to divert their attention from the driving environment down to the information needed in the HDD condition, and the performance for that condition might have been worse. Additionally, the routes were not randomized between conditions, so the same two routes were used for every participant for the HUD condition, and the same two routes were used for every participant for

the HDD condition. The routes were organized this way to ensure that each route would be completed an equal number of times; however, this could have been a confound in the experiment, especially with respect to IED detection, so for future studies, each route should have the same chance of being used in the HUD or the HDD condition. Finally, those participants with lower map reading test scores drove off road significantly more times than did those with higher test scores when the display was HDD. It is reasonable to expect that those individuals with poorer map reading skills may have significantly degraded driving performance if the routes are more complicated and they need to consult the map more frequently.

5. Conclusions

This study supports the notion that using a HUD while driving may lead to attentional narrowing and an overall lack of situation awareness, leading to worse driving performance than when using a traditional HDD. However, participants thought they did equally well in both conditions, which shows they are not aware of their objective performance and might have negative implications for driving in the real world. If drivers believe they are performing at a higher level than they really are, they may not take necessary precautions and corrective actions, which could result in accidents and injury.

Additionally, participants preferred the HUD to the HDD. This becomes problematic because if drivers are in support of using HUDs, they may be implemented without fully investigating the driving performance effects associated with the displays.

Furthermore, performance for detecting unexpected objects along the roadway was poorer when using the HUD than when using the HDD, which has implications for using these displays in the real world. If drivers do not detect an obstacle, they may not be able to avoid hitting the object, which can result in injury and fatalities. However, the caveat to this research is that the routes used in the current experiment were fairly simple.

Future studies should focus on finding ways to mitigate the attentional narrowing effect of the HUD. Future studies should also employ routes with various levels of difficulties to determine the point at which driving performance associated with HDD becomes significantly worse than that with HUD.

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Appendix A. Demographic Questionnaire

This appendix appears in its original form, without editorial change.

Participant # _____ Age _____ Major _____ Date _____ Gender ___

1. What is the highest level of education you have had?
Less than 4 yrs of college ____ Completed 4 yrs of college ____ Other ____

2. When did you use computers in your education? (*Circle all that apply*)

Grade School	Jr. High	High School
Technical School	College	Did Not Use

3. Where do you currently use a computer? (*Circle all that apply*)

Home Work Library Other_____ Do Not Use

4. For each of the following questions, circle the response that best describes you.

How often do you:

Drive a car?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Play computer/video games?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use a driving simulator/game?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Operate a radio controlled vehicle (car, boat, or plane)?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Play ManiaDrive/TrackMania?	Daily, Weekly, Monthly, Once every few months, Rarely, Never

5. Which type(s) of computer/video games do you most often play if you play at least once every few months?

6. Which of the following best describes your expertise with computer games and/or driving simulators/games? (check √ one)

_____ Never played any type of driving simulator/game
_____ Novice
_____ Good with one type of simulator/game
_____ Good with several simulators/games
_____ Expert

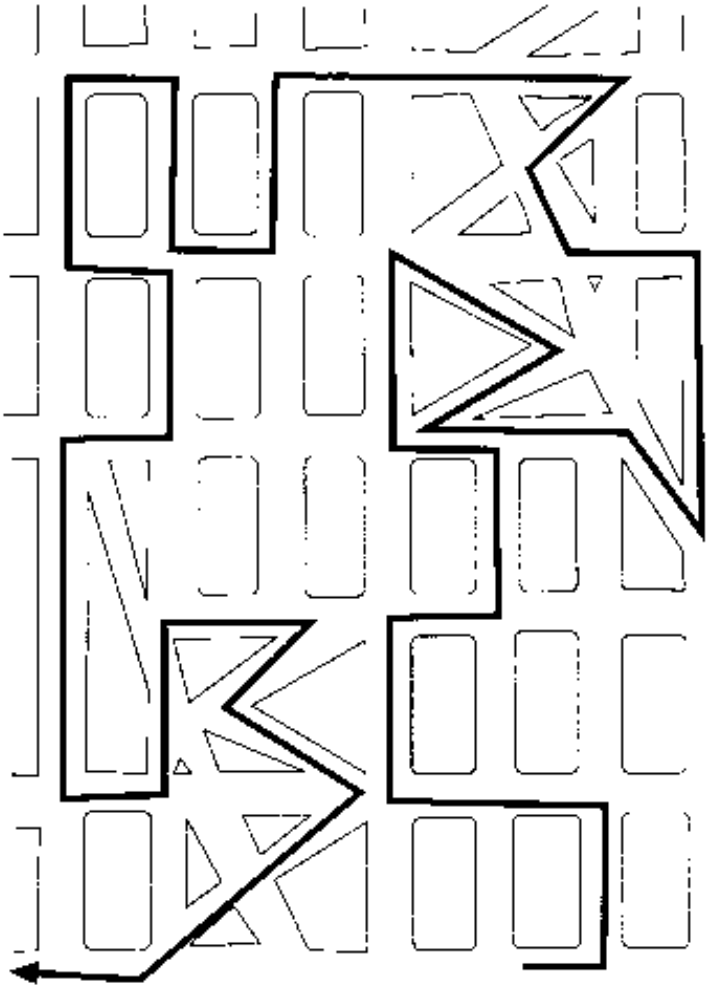
7. Are you in your usual state of health physically? YES NO
If NO, please briefly explain:

8. How many hours of sleep did you get last night? _____ hours

9. Do you have normal/corrected-to-normal vision? YES NO

Appendix B. Map Reading Test

This appendix appears in its original form, without editorial change.



Appendix C. NASA-TLX Questionnaire

This appendix appears in its original form, without editorial change.

NASA-TLX (Part 1)

Please rate your overall impression of demands imposed on you during the exercise.

1. Mental Demand: How much mental and perceptual activity was required (e.g., thinking, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

2. Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

3. Temporal Demand: How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

4. Level of Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

5. Level of Frustration: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

6. Performance: How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

NASA-TLX (Part 2)

Select the member of each pair that provided the most significant source of workload variation in these tasks.

Physical Demand vs. Mental Demand

Temporal Demand vs. Mental Demand

Performance vs. Mental Demand

Frustration vs. Mental Demand

Effort vs. Mental Demand

Temporal Demand vs. Physical Demand

Performance vs. Physical Demand

Frustration vs. Physical Demand

Effort vs. Physical Demand

Temporal Demand vs. Performance

Temporal Demand vs. Frustration

Temporal Demand vs. Effort

Performance vs. Frustration

Performance vs. Effort

Effort vs. Frustration

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Appendix D. Simulator Sickness Questionnaire

The text in this appendix appears in its original form, without editorial change.

Developed by Robert S. Kennedy & colleagues under various projects. For additional information contact:
Robert S. Kennedy, RSK Assessments, Inc., 1040 Woodcock Road, Suite 227, Orlando, FL 32803 (407) 894-5090

Subject Number: **Date:**

PRE-EXPOSURE BACKGROUND INFORMATION

1. How long has it been since your last exposure in a simulator? days
   How long has it been since your last flight in an aircraft? days
   How long has it been since your last voyage at sea? days
   How long has it been since your last exposure in a virtual environment? days

2. What other experience have you had recently in a device with unusual motion?

PRE-EXPOSURE PHYSIOLOGICAL STATUS INFORMATION

3. Are you in your usual state of fitness? (Circle one) YES NO
If not, please indicate the reason:

4. Have you been ill in the past week? (Circle one) YES NO
If "Yes", please indicate:
a) The nature of the illness (flu, cold, etc.):
b) Severity of the illness: Very Mild ----------Very Severe
c) Length of illness: Hours / Days
d) Major symptoms:
e) Are you fully recovered? YES NO

5. How much alcohol have you consumed during the past 24 hours?
_____12 oz. cans/bottles of beer _____ounces wine _____ounces hard liquor

6. Please indicate all medication you have used in the past 24 hours. If none, check the first line:
a) NONE
b) Sedatives or tranquilizers
c) Aspirin, Tylenol, other analgesics
d) Anti-histamines
e) Decongestants
f) Other (specify):

7. a) How many hours of sleep did you get last night? _____hours
b) Was this amount sufficient? (Circle one) YES NO

8. Please list any other comments regarding your present physical state which might affect your performance on our test battery.

Table D-1. Baseline (pre) exposure symptom checklist.

Instructions: Please fill this out BEFORE you go into the virtual environment. Circle how much each symptom below is affecting you right now. #					
	Symptom	**Severity**			
1.	General discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Boredom	None	Slight	Moderate	Severe
4.	Drowsiness	None	Slight	Moderate	Severe
5.	Headache	None	Slight	Moderate	Severe
6.	Eye strain	None	Slight	Moderate	Severe
7.	Difficulty focusing	None	Slight	Moderate	Severe
8a.	Salivation increased	None	Slight	Moderate	Severe
8b.	Salivation decreased	None	Slight	Moderate	Severe
9.	Sweating	None	Slight	Moderate	Severe
10.	Nausea	None	Slight	Moderate	Severe
11.	Difficulty concentrating	None	Slight	Moderate	Severe
12.	Mental depression	None	Slight	Moderate	Severe
13.	"Fullness of the head"	None	Slight	Moderate	Severe
14.	Blurred vision	None	Slight	Moderate	Severe
15a.	Dizziness with eyes open	None	Slight	Moderate	Severe
15b.	Dizziness with eyes closed	None	Slight	Moderate	Severe
16.	Vertigo[a]	None	Slight	Moderate	Severe
17.	Visual flashbacks[b]	None	Slight	Moderate	Severe
18.	Faintness	None	Slight	Moderate	Severe
19.	Aware of breathing	None	Slight	Moderate	Severe
20.	Stomach awareness[c]	None	Slight	Moderate	Severe
21.	Loss of appetite	None	Slight	Moderate	Severe
22.	Increased appetite	None	Slight	Moderate	Severe
23.	Desire to move bowels	None	Slight	Moderate	Severe
24.	Confusion	None	Slight	Moderate	Severe
25.	Burping	None	Slight	Moderate	Severe
26.	Vomiting	None	Slight	Moderate	Severe
27. Other:					

[a]Vertigo is experienced as loss of orientation with respect to vertical upright.
[b]Visual illusion of movement or false sensations of movement, when not in the simulator, car or aircraft.
[c]Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Table D-2. Post 00 minutes exposure symptom checklist.

Instructions: Please fill this out BEFORE you go into the virtual environment. Circle how much each symptom below is affecting you right now. #					
	Symptom	**Severity**			
1.	General discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Boredom	None	Slight	Moderate	Severe
4.	Drowsiness	None	Slight	Moderate	Severe
5.	Headache	None	Slight	Moderate	Severe
6.	Eye strain	None	Slight	Moderate	Severe
7.	Difficulty focusing	None	Slight	Moderate	Severe
8a.	Salivation increased	None	Slight	Moderate	Severe
8b.	Salivation decreased	None	Slight	Moderate	Severe
9.	Sweating	None	Slight	Moderate	Severe
10.	Nausea	None	Slight	Moderate	Severe
11.	Difficulty concentrating	None	Slight	Moderate	Severe
12.	Mental depression	None	Slight	Moderate	Severe
13.	"Fullness of the head"	None	Slight	Moderate	Severe
14.	Blurred vision	None	Slight	Moderate	Severe
15a.	Dizziness with eyes open	None	Slight	Moderate	Severe
15b.	Dizziness with eyes closed	None	Slight	Moderate	Severe
16.	Vertigo[a]	None	Slight	Moderate	Severe
17.	Visual flashbacks[b]	None	Slight	Moderate	Severe
18.	Faintness	None	Slight	Moderate	Severe
19.	Aware of breathing	None	Slight	Moderate	Severe
20.	Stomach awareness[c]	None	Slight	Moderate	Severe
21.	Loss of appetite	None	Slight	Moderate	Severe
22.	Increased appetite	None	Slight	Moderate	Severe
23.	Desire to move bowels	None	Slight	Moderate	Severe
24.	Confusion	None	Slight	Moderate	Severe
25.	Burping	None	Slight	Moderate	Severe
26.	Vomiting	None	Slight	Moderate	Severe
27. Other:					

[a]Vertigo is experienced as loss of orientation with respect to vertical upright.
[b]Visual illusion of movement or false sensations of movement, when not in the simulator, car or aircraft.
[c]Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

POST-EXPOSURE INFORMATION

1. While in the virtual environment, did you get the feeling of motion (i.e., did you experience a compelling sensation of self motion as though you were actually moving)? (Circle one) YES NO SOMEWHAT

2. On a scale of 1 (POOR) to 10 (EXCELLENT) rate your performance in the virtual environment:

3. a. Did any unusual events occur during your exposure? (Circle one) YES NO
b. If YES, please describe

List of Symbols, Abbreviations, and Acronyms

HDD	Head-down display
HUD	Head-up display
IED	Improvised explosive device
SA	Situation awareness
SET-MR	Scalable Embedded Training - Mission Rehearsal
SSQ	Simulator Sickness Questionnaire
SVB	Switchable vision block

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