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GROUND VEHICLE DRIVING AIDS: ASSESSING DRIVER WORKLOAD AND PERFORMANCE IN DEGRADED VISUAL ENVIRONMENTS

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GROUND VEHICLE DRIVING AIDS: ASSESSING DRIVER WORKLOAD AND PERFORMANCE IN DEGRADED VISUAL ENVIRONMENTS

By

Kayla L. Riegner

A DISSERTATION

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

In Mechanical Engineering-Engineering Mechanics

MICHIGAN TECHNOLOGICAL UNIVERSITY

2019

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This dissertation has been approved in partial fulfillment of the requirements for the Degree of DOCTOR OF PHILOSOPHY in Mechanical Engineering-Engineering Mechanics.

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Dedication

To my family, especially my loving and supportive parents, thank you for believing in me and pushing me to do more. Without you, I would not have learned to believe in myself and what I can accomplish.

To my husband, Bill. Thank you for never second-guessing this endeavor and for encouraging me to pursue my dreams.

To my three beautiful girls, Abigail, Liviana and Zemira, remember you can do anything you put your mind to as long as you want it enough. I'm so proud to be your mommy! I will always believe in you and will support you in pursuing your dreams. Dream BIG and then chase those dreams down!

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Preface

The work presented here was a collaborative effort, led by the gDVE team at the Ground Vehicle System Center in conjunction with various government agencies and contractors. This manuscript and all data analysis contained within are my original work. This dissertation is intended for publication.

Acknowledgements

The most difficult thing is the decision to act, the rest is merely tenacity. The fears are paper tigers. You can do anything you decide to do. You can act to change and control your life; and the procedure, the process is its own reward." -Amelia Earhart

I need to thank the many people for which made this dream of obtaining my Ph.D. possible.

I'd like to thank my advisor, my teacher, Dr. Kelly Steelman for all of her assistance, support and encouragement over the years it has taken me to complete this degree. Thank you for believing in me, teaching me and helping make this journey a reality. Not only do I feel fortunate to have been a student of yours, but also a friend now and into the future.

I would like to show my gratitude to my committee at Michigan Technological University. Dr. Ye Sun, thank you for taking an interest in my work and accepting a spot on my committee. Dr. Craig Friedrich, one my Co-Advisors, I cannot thank you enough for helping me connect with Dr. Kelly Steelman. Dr. Gregory Hudas, your presence in my life has been a blessing and I am forever thankful for your advice, guidance, and most of all your friendship!

I would like to acknowledge the Ground Vehicle Systems Center for their support of my efforts to complete this work. I want extend my gratitude to the gDVE team, especially Alex Marecki, my research would have been impossible without your support. A special thanks to Thomas Mikulski for teaching me to code and for your enthusiastic help.

I'd like to especially recognize Mr. Charles Coutteau, whom I have the highest respect for as a leader, for his support and belief in me. Dr. Paul Rogers, thank you for your mentorship throughout the years and encouraging me to pursue my PhD through Michigan Tech. A special thanks to June Cline for all the time she spent proofreading this manuscript to make sure it was ready for publication.

To my Ph.D. buddy, Dr. Christina Marsack -Topolewski, it's hard to believe we started this journey ten years ago together! Thank you for your endless encouragement, listening ear when I needed to vent and your helpful tips. Thank you for believing in me and reminding me that I WOULD finish!

Last but not least, thank you to the late Dr. Jim Overholt. Thank you for inspiring me!

Definitions

DVE: A degraded visual environment, or DVE, is a circumstance wherein weather, obscurants, or obstacles thwart the ability of a crew to see properly, or accurately know where they are in relation to surrounding terrain. There is no one standard for DVE, but sand, dust, fog, and smoke are common obscurants that create a degraded visual environment.

Operational Tempo: The pace of an operation or operations; includes all of the activities the unit is conducting; can be a single activity or series of operations.

List of abbreviations

AAR	After-Action Review
ANOVA	Analysis of Variance
BADSS	Blown Air Dust and Sand System
CCDC	Combat Capabilities Development Command
DA	Driving Aid
DGPS	Differential Global Positioning System
DTIC	Defense Technical Information Center
DVE	Degraded Visual Environment; Driver Vision Enhancer
gDVE	Ground Degraded Visual Environment
FHWA	Federal Highway Administration
GNG	Go/NoGo
GPS	Global Positioning System
GVSC	Ground Vehicle Systems Center
IE	Image Enhancement
IED	Improvised Explosive Device
ISEF	Integration Systems Engineering Framework
LRDWS	Lane/Road Departure Warning System
LZ	Landing Zone
MMWR	Millimeter Wave Radar
MOS	Military Occupational Specialty
ODCA	Obstacle Detection and Collision Avoidance System
POV	Personal Operating Vehicle

RH	Relative Humidity
RMS	Ride Motion Simulator
SSQ	Simulation Sickness Questionnaire
SUS	System Usability Scale
TLX	Task Load Index
WMI	Warfighter Machine Interface
YPG	Yuma Proving Ground
YTC	Yuma Test Center

Abstract

With degraded visual environments being a current priority to the Army, several research programs have been initiated to develop a complete sensor-to-soldier systems to allow operators to see through DVE conditions while conducting ground vehicle tactical operations. To enable indirect-driving maneuverability and threat detection in degraded visual environments (DVEs), CCDC's ground DVE program developed and tested a range of sensors and driver aid display systems. Six candidate driving aids were identified and tested in three simulator studies and two field tests to examine the effect of driving aids on driver workload and performance in different visibility conditions. The simulator-based testing revealed human factors issues such as the importance of the symbology of the aids used and how obstacles should be presented when designing individual displays. Soldiers were generally accepting of the overall gDVE system in field testing with no costs or benefits revealed using the driving aids. Before future development of the driving aids, a more human-centered design process must be pursued to optimize the human-system interaction to design driving aids that help performance and lower workload in degraded visual environments.

1 Introduction

Degraded visual environments (DVEs) – caused by sand, dust, smoke, fog, and precipitation – pose a major threat to Army personnel and property. Since 2002, DVEs contributed to a quarter of all Class A and B aviation accidents (those involving fatalities or property damage over $500,000), resulting in the loss of over 120 lives and more than $965 million in equipment (Director of Army Safety, 2017).

The costs of DVE-related motor vehicle crashes have received comparatively less attention. In general, motor vehicle crashes are a significant public health problem in the U.S. Army, resulting in more injuries among Army personnel then other causes (Rossen, Pollack, Canham-Chervak, Canada & Baker, 2011). DVEs, in particular, contributed to approximately 12% of Army motor vehicle crashes from 1999 to 2006 (Rossen, Pollack, Canham-Chervak, Canada & Baker, 2011). Approximately 98% of the military's equipment and supplies for operations in Iraq moves by ground transportation (Kincaid, 2006). Accordingly, ensuring continuous and uninterrupted distribution of supplies is important to military operations. Improving driving performance in DVEs is therefore critical.

DVEs contribute to crashes because they affect the driver's ability to see the world outside the vehicles, restricting the distance and time that a driver has to detect potential hazards and to respond in an appropriate manner. DVEs also mask the visual flow of objects in a physical environment – an important cue that helps the driver to accurately perceive speed and safely operate the vehicle.

Many researchers in the aviation sector have suggested solutions to the DVE problem. According to Eger (2012), technological solutions should help operators see hard-to-detect obstacles and overcome operators' physiological limitations. Addressing both of these issues requires integration of three categories of technology (Judge, 2006).

1. Displays – Provide aircraft state information adequate to control the aircraft at low speed without visual reference to the ground.

2. Sensors – Provide outside scene information to see through the brownout, the ability to detect obstacles including wires/cables, and the ability to choose the flight path for a successful landing.

3. Flight Controls – Augment aircraft stability and control so that constant reference to visual cues is not required to maintain the basic control and flight path.

Aligned with these suggestions, the Army has initiated several research programs dedicated to developing complete sensor-to-Soldier systems to allow operators to see through DVE conditions while conducting ground vehicle tactical operations. In 2014, Ground Vehicle Systems Center's Ground Degraded Visual Environment (gDVE) Program was tasked with leveraging aviation capabilities to enable indirect-driving maneuverability and threat detection in degraded visual environments (DVEs). To accomplish this, GVSC's gDVE program developed and tested a range of sensors and driver aid display systems.

The purpose of this effort was to develop driving aids to enable indirect vision driving maneuverability, reduce accidents, and improve threat detection. The goal was to allow operation in DVEs to maintain operating tempo (OPTEMPO), decrease occupant injury, and improve survivability. The final gDVE system should provide indirect vision driving performance that exceeds the current capability by integrating sensor technologies with Warfighter Machine Interface (WMI) and autonomy technologies.

Here, I present three simulator studies and two field tests that examined the effect of different driving aids on driver workload and performance in different visibility conditions. Each simulator experiment examined driver performance with two candidate driving aids, in three levels of degraded visual environment. The goal of these simulation experiments was to help down-select the driving aids for implementation and testing in an actual ground vehicle system and in a real DVE. With the selected driving aids, two field tests were conducted with a modified Stryker in a DVE of blown sand at Yuma Proving Grounds. The gDVE program goal was to understand the effect that visual degradation had on Soldiers' driving performance with the implementation of driving aids to decrease accidents/damage, improve driving performance, and decrease workload. My focus is on the human–machine interaction. Therefore, the current work focused on the driving aids, not sensor technology that enables these aids to function.

1.1 Initial Down-Select

The gDVE Program spent 10 months researching driving aids, down-selecting to the five candidate driving aids, and planning experimentation. This iterative process involved coordination with various team members on defining what was possible to test in simulation and in the field, as well as technical guidance.

1.1.1 Driving Aid Selection

Candidate driving aids were down-selected using the Integrated System Engineering Framework (ISEF; Umpfenbach, 2014). ISEF is a collection of government and commercial system engineering tools. The gDVE Program started by brainstorming currently available relevant driving aids, resulting in a list of 11 potential driving aids. The driving aids were evaluated using Decision Breakdown Structure (DBS), a decision tool that captured and traced decision criteria, alternatives, and consequences. This tool scored the alternatives with defined dimensions and scales as outlined in Table 1.1.

Table 1.1: Dimension, Definition, and Scale of Evaluation

Dimension	Definition	Scale
Technologies Required	# of the technologies that would be required if a particular driving aid was implemented. Examples include: IR sensors LADAR, RADAR, GPS	1 – the greatest number of technologies required 3 – less than most number 5 – less than predecessor in 3 7 – 2 technologies required 10 – 1 technology required
Expected Technological Risk	Level of risk from the technologies required to use the driving aid	1 – High risk 3 – Less high risk 5 – Medium risk 7 – Less medium risk 10 – Low risk
Environment(s) Application(s)	Evaluation of how many different environments a particular driving aid could operate in	1 – 1 environmental condition satisfied 3- 2-3 environmental conditions satisfied 5 – 4 environmental conditions satisfied 7 – 6 environmental conditions satisfied 10 – 7 or 8 environmental conditions satisfied
Mission Application(s)	How many different missions a particular driving aid could be operated in. The two different missions we defined are convoy and non-convoy missions.	5 – 1 mission met 10 – 2 missions met
Expected User Benefit	Rating of how high of an expected performance impact the driving aid has on the use.	1 – Very Poor 3 – Poor 5 – Average 7 – Very Good 10 – Great

The final results of the evaluation are show on the left side of Figure 1.1. The aids listed at the top (Optic Flow, Lane Departure, Lane Detection) scored the highest in this exercise. The final down-select was based upon the results from this exercise, with two additional considerations. First, for practical reasons, we considered the availability of the sensor systems required for each of the driving aids. Second, we considered which driving aids made the most sense to test in a simulation environment and which made more sense to test in the field on a live ground vehicle. For example, the lane detection and lane departure aids are not applicable on an unimproved road, which was the road type designated in field testing, so simulation testing was the best method of testing this aid.

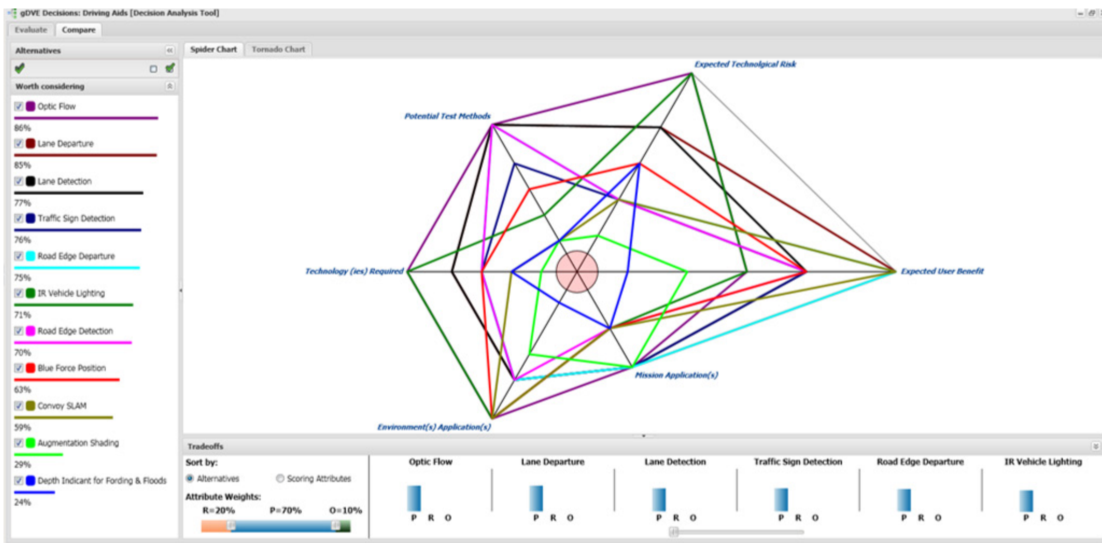

Figure 1.1 Spider Chart Results of Analysis in ISEF Tool

1.1.2 Driving Aids

The driving aids selected for the simulator and field testing included: Lane/Road Departure Warning Systems, Optic Flow Enhancer, Object Detection and Collisions Avoidance, Friendly Force Position, Go/No Go, and Image Enhancement.

1.1.2.1 Lane/Road Departure Warning System

Lane/Road Departure Warning System was selected as a candidate driving aid due its commercial availability and current use in civilian vehicles. In fact, the automobile industry has even implemented this type of technology in non-luxury cars such as the Honda Accord, Chevrolet Malibu, and Mazda CX-9. Using insurance collision claims data along with human factors research, it was determined that equipping all cars with a forward collision warning and lateral guidance system that was 100% effective could prevent up to 25% of all crashes (Kuehn, Hummel & Bende, 2009). Figure 1.2 illustrates a prototypical lane departure system in civilian vehicles.

Figure 1.2: Figure Lane/Road Departure Warning System

1.1.2.2 Optic Flow Enhancer

Optic flow is the perceived visual motion of objects relative to the observer. For instance, as a driver approached a sign on the side of the road, the sign would move from the middle of a driver's vision to the side, growing as the driver approached. This allows an operator to determine how close he is to certain objects and how quickly they approach (Ludwig et al., 2018). Researchers have found that the visual flow of objects in a physical environment impacts a driver's ability to operate the vehicle in the natural world. Drivers' gaze behaviors are highly correlated with road geometry because optical flow directs eye movements (Authie & Mestre, 2011). Additionally, optic flow is an important cue that drivers use to assess speed (Ludwig et al., 2018) The Optic Flow aid provides an overlay of dots, which is a cue for how quickly things are moving past in the periphery, to enable drivers to better judge speed and distance in DVEs. Figure 1.3 gives a feel visually of what the Optic Flow driving aid would look like.

Figure 1.3: Optic Flow Dot Pattern

1.1.2.3 Friendly Force Position (FFP)

The Friendly Force Position driving aid was designed for convoy scenarios. The location of a vehicle's own position and the location of others are identified within the convoy. In typical convoy situations, drivers are expected to maintain a prescribed distance between vehicles – neither straying too far away nor driving too close. The FFP aid provides visual information about the spacing of surrounding vehicles to help a driver maintain situational awareness. Figure 1.4 illustrates the FFP aid.

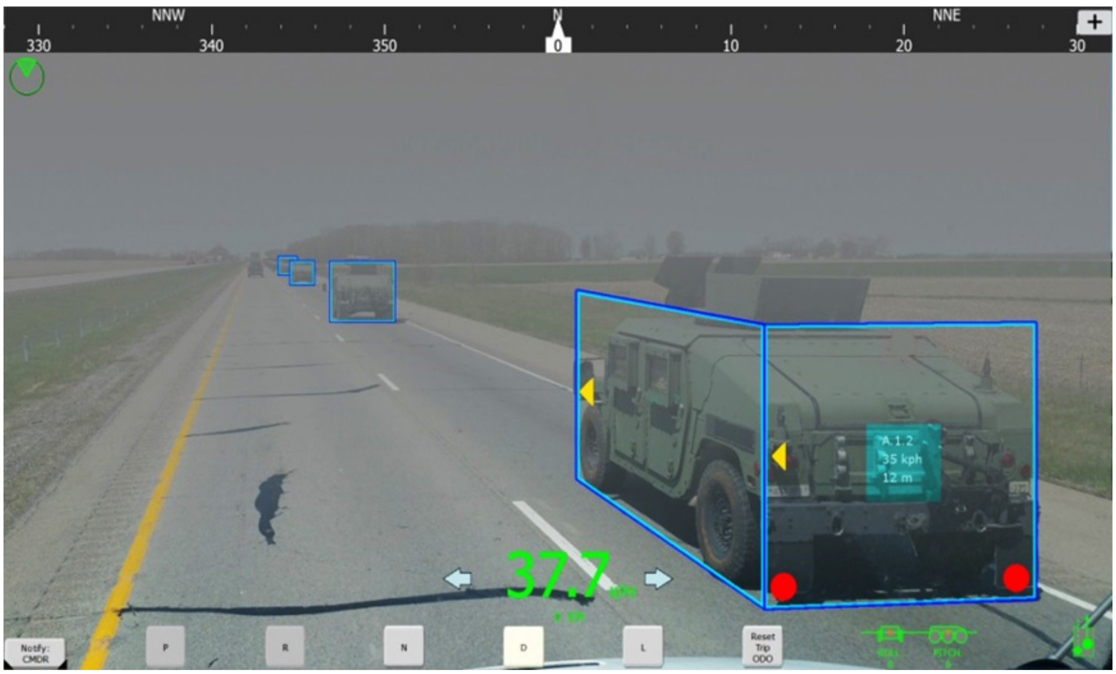

Figure 1.4: Friendly Force Position Aid in Convoy

1.1.2.4 Object Detection and Collision avoidance (ODCA)

The Object Detection and Collision avoidance (ODCA) (referred to in this document as the Radar driving aid) is used to detect objects in front of the vehicle. In the automotive world, this is called the Forward Collision Warning (FCW) system. As depicted below in

Figure 1.5, the Radar aid uses silhouette boxes to highlight potential hazards, such as pedestrians, other vehicles, animals, etc.

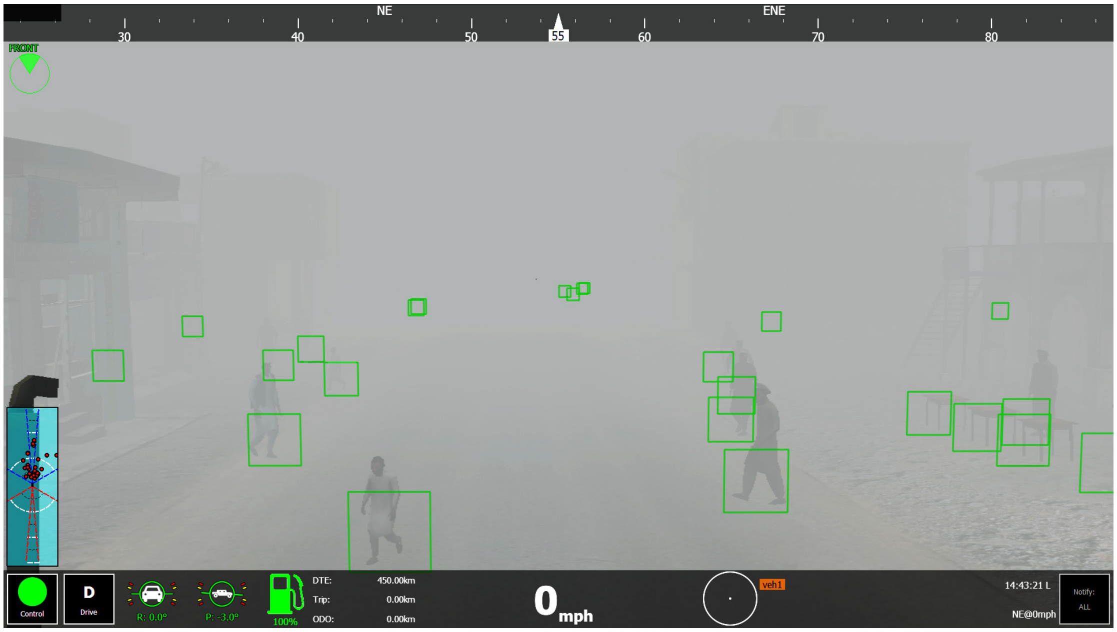

Figure 1.5: Radar Silhouette Highlighting Potential Obstacles

1.1.2.5 Go/NoGo

The Go/NoGo driving aid is a context warning system based on terrain slope. In contrast to other aids, it is not currently available (or relevant) in the commercial market. This technology comes from the mobile robotics world, and the underlying terrain parameter estimation was developed to enable robots to operate on rough terrain. The Go/NoGo is designed for use off road or on unimproved roads to help Soldiers identify and navigate uncertain terrain. Figure 1.6 displays a Go/NoGo driving aid showing terrain slope.

Figure 1.6: Go/NoGo Driving Aid showing terrain slope

1.1.2.6 Image Enhancement (IE)

The Image Enhancement (IE) driving aid improves video quality as it appears on the participants' screen. IE alleviates blurriness by applying a simple visual processing algorithm to the raw video feed. It functions by enhancing the edges of objects within the video feed; increasing the color contrast of the entire video feed, and reducing the noise within the entire video feed. IE driving aids have been researched for night driving as well as degraded visual environments. The benefits of IE are especially pronounced when driving in foggy conditions, with drivers seeing further to allow earlier detection of potential obstacles/hazards. Figure 1.7 illustrates the capabilities of IE.

Figure 1.7: Example of Image Enhancement

1.1.3 Research Questions

The current research examined performance with each of the six driving aids and addressed the following research questions:

1. To what extent did the driving aids provide performance improvement in DVEs?
    a. Which of the driving aids best supported maintaining desired speeds and distance while in convoy formation in DVEs?
    b. Which of the driving aids best supported object avoidance in DVEs?
    c. Which of the driving aids best supported faster driving in DVEs?
2. Which aids best support workload reduction in DVEs?
3. To what extent did the Soldiers find the driving aids to be usable and useful in DVEs?
4. Do any performance benefits observed in the driving simulator scale up to the field test experiments?

1.1.4 Organization of the Dissertation

This dissertation presents three completed simulator experiments and two field experiments that tested operator performance with driving aids. Chapter 2 presents the literature review. Chapter 3 presents Simulator Experiment 1, which tested the

Lane/Road Departure Warning System (LRDWS) and Optic Flow Enhancer (OFE) driving aid in three degraded visual environments. Chapter 4 presents Simulator Experiment 2, which tested operator performance with a refined Lane/Road Departure Warning System and a new aid Friendly Force Position (FFP). This experiment focused on a convoy scenario. Chapter 5 presents Simulator Experiment 3, which tested the Radar and Go/NoGo driving aids in three more heavily degraded visual environments. This experiment assessed both driving performance and threat detection and avoidance. Chapter 6 presents the first field test experiment, which tested the Friendly Force Position driving aid and Millimeter Wave Radar (MMWR) with image augmentation overlays. This experiment focused on performance with convoy operations.

Chapter 7 presents the second field test, which evaluated two candidate driving aids: Obstacle Detection & Collision Avoidance System (ODCA) and Image Enhancement (IE). Trained drivers used the driving aids while driving a modified Stryker vehicle to complete an obstacle course under both clear and dense airborne dust conditions. Chapter 8 synthesizes the results across all experiments and discusses the implications for application and future work.

2 Literature Review

Introduction

This chapter reviews degraded visual environments in aviation, degraded visual environments in ground vehicles, indirect driving, driving aid design, augmented reality, and workload in driving. Each section addresses the problems and work in that area and highlights the gap that will be filled through my research.

Degraded Visual Environments in Aviation

Degraded visual environments are important in the Aviation sector. Military helicopters are expected to be able to operate 24-hours a day, 7-days a week due to the time sensitive tasks given to their crews, including medical services. Helicopters specifically rely on visual cues to land, with brownouts/whiteouts (as shown in Figure 2.1) preventing feedback needed for a safe landing. Loss of situational awareness in degraded visual environments (DVEs) is one of the largest threats to rotary wing aircrafts. A widely accepted model developed by Endsley, Bolte, and Jones (2003) described situational awareness in three levels:

- Level 1: Perception of the elements in the environment
- Level 2: Comprehension of the current situation
- Level 3: Projection of future status

Figure 2.1: Helicopter Landing with Brownout. Image source: https://www.arl.army.mil/www/default.cfm?article=2837.

DVE in aviation directly restricts Level 1 Situational Awareness (SA), which is perception of the elements in the environment. This restriction in turn restricts higher levels of SA. Loss of situational awareness and other human factors accounted for more than 79% of airframe losses and fatalities (Couch, 2010). With the loss of life and significant costs associated with these accidents, a large body of research has been completed in the Rotorcraft sector in regard to DVE (Viertler & Hajek, 2017; Viertler, Krammer, & Hajek, 2015; Völschow, Münsterer, Strobel, & Kuhn, 2016). One potential solution is to combine additional tactical and auditory cues with dust-penetrating visual displays to improve situational awareness (Rupert, 2014).

Another technology solution that has been tested and examined with regards to the situational awareness sector is Heads-Up Displays (HUD). Use of HUDS supports more accurate flight path guidance and detection of expected incidents or warnings (Wickens & Long, 1995). In one simulation experiment, use of HUD supported early detection of obstacles, allowed pilots more time to decide how to avoid collisions, and increased perceived safety (Viertler & Hajek, 2017). HUD also reduced reported workload.

Figure 2.2: Example of Heads Up Display (HUD). Image source: https://www.dyess.af.mil/News/Article-Display/Article/269558/a-new-hercules-for-the-21st-century/.

With human-machine interfaces, display clutter is a concern because it can increase the search time needed to gather the required information, instead of enabling the pilot to accomplish the required task successfully and safely (Viertler, Krammer, & Hajek, 2015). Methods for analyzing visual clutter have been explored: using different frames of reference and colors, fundamentals of depth perception, and information blending (Viertler et al., 2015). The researchers concluded that pseudo-photorealistic display must be shut off by the pilot and returned to the symbology screen only to avoid cluttering the Head Mounted Display (HMD) vision.

Under particularly high workload conditions, HUD induces a narrowing of attention to processing the routine information on the symbology that can lead to detection errors (Larish & Wickens, 1991). For example, in one study, pilots flying with HUDs failed to notice or reacted slower to obstacles on the active runway during an approach (Fischer, Haines, & Price, 1980). Fadden, Ververs, and Wickens (1998) did a meta-analysis on other Aviation HUD studies. Although HUDs offer performance benefits during normal and routine flight operations, they can be detrimental during exceptional situations (a runway incursion by another aircraft), which is when pilots have the greatest need for help (Fadden, Ververs, and Wickens (1998). These findings pointed to the importance of evaluating HUD technology and potential outcomes, good or bad, of using additional technology.

Degraded Visual Environments in Ground Vehicles

The same degraded visual environments (DVEs) that pose a problem in the aviation sector extend to ground vehicles. Fog and heavy rainfall, as well as wind-blown snow, dust, and smoke, minimize visibility distance. Visibility conditions are known to affect drivers' eye movements and increase processing time, negatively affecting drivers' visual search. In one simulator study, drivers had lower sampling rates and longer fixations when driving a route with decreased visibility in comparison to day driving (Konstantopoulos, Chapman, & Crundall, 2010).

DVEs in driving pose a threat due to the complex environment that drivers encounter. DVEs prevent drivers from seeing the road, other vehicles, and potential obstacles in or near the roadway. Drivers are not the best estimators of risk and sometimes do not adjust their driving behavior accordingly to the external environment (Kilpeläinen & Summala, 2007). Degraded Visual Environments only exacerbate the problem. Though optical effects of many atmospheric obscurants on light transmission are well quantified and generally understood (Malm, 1999), the resultant consequences to human visual perception cannot be easily predicted. According to Snowden, Stimpson, and Ruddle (1998), many accidents result from a perception error, with drivers thinking they are driving far slower than they actually are in foggy conditions and therefore increasing their speed. For example, Edwards (1999) completed a study that found a reduction in mean speed among drivers during wet, rainy weather, although the reduction did not compensate for the hazards present. Bresciani, Pretto, Rainer, and Bülthoff (2012) noted that the reduced luminance contrast in gDVE results in speed underestimation and sometimes could lead to inadvertent excessive speed.

Low visibility affects not only speed but also vehicle spacing. Hawkins (1988), for example, embedded loop sensors to assess speed and gap distance in fog. The data suggested that driver in foggy conditions reduced speed by approximately 25-30% when visibility was reduced to 100 m, which was safer. However, there was an increase to 25% of drivers who maintained gaps less than 60 m between vehicles (Hawkins, 1988). The drivers failed to maintain a safe distance from the car in front of them in decreased visibility. To fully understand driving behavior in DVE, behavioral changes from foggy conditions and speed perceptions must be investigated (Brooks et al., 2011).

Indirect Driving

Indirect driving is driving a vehicle without a direct view to the outside. Other research has found that indirect driving performance in gDVE can be adversely affected by both decreased accessibility of visual data and presentation of data to the driver. It can be tricky, with the forward view misleading because it provides less information than what would be available if looking directly outside. Indirect vision driving increases both mental workload and demand on situational awareness (Smyth, 2001). Display screens are flat, which makes it more difficult to judge depth and distance. Motion on the screen is different from how it looks when seen directly. With indirect driving, the driver sees less and sees it differently; because of this situation, it can be difficult to control speed and position. Driving becomes even more difficult if the environment is degraded by dust, smoke, or fog because less visual information is available on which to rely. The environment is especially important to indirect driving because imagery from sources other than natural-light cameras may have contrast characteristics that are different from images in natural daylight, whether or not the source information is coming from a gDVE. With indirect driving in the natural world, additional effects of display compression adversely influence cognitive workload and situational awareness due to misperceptions of speed (Smyth, 2002).

Driving Aid Design

With newly emerging sensor technologies that can provide visual information where the human system is deficient, driving aids have the potential to enable human operators to drive safer, faster, and more efficiently. The biggest challenge with designing driving aids is to encourage positive behavior in drivers while avoiding negative effects of driver distraction that a new interface could produce. Brookhuis and Brown (1992) argued that behavioral change with engineering measures, in the form of electronic driving aids, needs to be adopted to improve road safety and transportation efficiency.

Within the commercial sector, driving aids are being presented to drivers as a comfort item as well as a safety feature. Driving aids such as smart parking assistance system (SPAS), lane keeping assistance system (LKAS), and adaptive cruise control (ACC) already exist in the private sector, with consumers using them on modern cars. The availability of Forward Collision Warning (FCW), Lane Departure Warning (LDW), and Blind Spot Monitoring (BSM) technologies could reach 95% of the registered vehicle fleet anywhere between the years 2032 and 2048 (HLDI, 2014). These driving aids help drivers stay within their lanes, park their vehicles, and detect objects with which they may collide when changing lanes. Military vehicles have some of the same driving tasks as civilian vehicles, so it is a natural fit to extend benefits of driving aids to military ground vehicles.

To design driving aids for military vehicles, many products being considered exist in civilian or commercial vehicles (Barickman et al., 2007; Campbell et al., 2007; Hoover et al., 2014; Houser et al., 2005; Kozak et al., 2006; LeBlanc et al., 2006; Lee, Park, & Yoo, 2011; Mehler et al., 2014; Olsen, 2004; Scanlon et al., 2015).

The driving aid design was a major part of the gDVE experiments, and the proper implementation and integration were well thought out and executed. In the future, it is not a question of wherher driving aids will be implemented in POVs; it is a matter of when. Knowing that, military applications must be pursued.

Augmented Reality

Many aviation-based DVE displays systems and commercial driving aids rely on augmented reality in which sensor data is overlaid upon the operator's view of the outside world to mark roadways and hazards or to provide cues to help the operator interpret speed and distance. Augmented Reality (AR) is a way to engage humans with machines. Although Augmented Reality (AR) can benefit operators, there are risks and challenges associated with its use.

Augmented reality can benefit drivers/pilots by cueing objects that they may have missed otherwise. Schall et al., (2013) did a study that evaluated the effectiveness of AR cues in improving driving safety of elderly drivers. The participants responded to 25% more pedestrians and 5% more warning signs in cued conditions than in uncued conditions (Schall et al., 2013). This finding was consistent with reports of Rusch et al. (2013) and Yeh and Wickens (2001) who noted that benefits of cueing were greatest for objects of low visibility.

Despite these benefits, additional information displayed on a screen may have unintended consequences. First, attentional bias or "tunneling" may occur when users become focused on the cue, to the extent that other important things or activities are not attended. Second, the cue might be unreliable, failing to emphasize an event, object, or target that it was designed to emphasize or falsely emphasizing a nontarget (Yeh & Wickens, 2001). The reliability of augmented reality may affect its use or disuse by the operator and cues are only as good as quality of the sensor systems. At times a system may commit an error: miss a cue or a false alarm. Both have consequences for how the operator interacts with the system. Sullivan, Tsimhoni, and Bogard (2008) studied how driver behavior was influenced by the reliability of an in-vehicle warning system under naturalistic driving conditions. The drivers appeared to respond faster if prior warnings were perceived to be reliable. Accordingly, AR must be designed and implemented with caution (Rizov, KJosevski, & Tashevski, 2017).

Workload in Driving

Driving in DVE is a stressful and attentionally-demanding task – one that is likely to exert a large workload on the operator. Hu, Li, and Wang (2011) tested drivers' mental workload on a freeway under different weather conditions through simulation experiments. These authors found a positive correlation between the drivers' mental workload and the severity of bad weather.

Mental workload alters the strategies of visual information acquisition while driving (Recarte & Nunes, 2000). Workload can also affect processing capacities in terms of detection, discrimination, and response selection (Recarte & Nunes (2003). This research found mental workload during stimulated driving resulted in reduced detection and discrimination of critical targets, implying a risk of reduced hazard perception during high task demand conditions (Recarte & Nunes, 2003). Not only does workload change the way the driver looks at their environment, but it also creates potential hazards to the driver.

Understanding the workload of humans during operator tasks is extremely useful for designing technologies that could alert the drivers or pilots about their combined state. Mental workload is not an inherent property of the operator's brain but rather emerges from the interaction between the driving task, circumstances performing the task, and the skills, behaviors, and perceptions of the driver/pilot (Hart & Staveland, 1988). One of the greatest challenges for any type of technology used for DVE activities is to provide intuitive displays with enough information to support safe and effective performance in a way that potentially decreases operator workload rather than increases it (Egar, 2012). The introduction of new in-vehicle technologies (IVTs), however often creates additional activities that drivers may have to perform concurrently with their primary driving task (Ashley, 2001). To complete these tasks, information needs to be accessed and processed from multiple sources all while maintaining safe vehicle control. Methods of assessing differential mental workload requirements of differing driving situations (e.g., visibility, road type, and traffic density) are imperative to maintaining the safe implementation of advanced IVT systems (Baldwin, Freeman, & Coyne, 2004). One commonly used method for assessing workload is the NASA Task Load Index (NASA TLX), which is also the method used in this dissertation.

How driving aids are implemented is as important as their implementation. Whether it is a personal automobile, fighter jet, or military ground vehicle doesn't matter. The operator is limited by the human processing information and can experience higher workloads with increased environmental situations and/or tasks. It is important to understand that devices used to help drivers must do just that and not put too much demand on the driver, compromising safety.

3 Simulation Experiment 1

The first Simulator Experiment (Riegner, Ammori, O'Hearn, & Steelman, 2018) tested two of the indirect driving aids selected in the Integrated System Engineering Framework (ISEF): the Lane/Road Departure Warning System (LRDWS) and Optic Flow Enhancer (OFE). Participants drove simulated routes with each of the two aids and without either aid in three DVE conditions. Driving performance and driver workload were assessed. This research examined (a) effects of levels of visibility on indirect-vision driving performance, (b) the effect of prototype driving aids on mitigating the effects of gDVE during indirect driving, and (c) the effect of visibility and driving aids on usability and workload. I hypothesized that the LRDWS's visual guides, auditory alerts, and seat vibrations would be beneficial in helping drivers maintain their position on the roadway and avoid lane and road departures. I hypothesized that the OFE would help drivers maintain an appropriate speed while driving in DVEs.

3.1 Methods

3.1.1 Participants

Fourteen men, all military or department of defense civilians with over 5,000 miles per year of driving experience, participated in the study. Of the 14 participants, 11 successfully completed the experiment. Three experimental sessions were terminated due to simulator sickness or technical problems.

3.1.2 Apparatus and Materials

3.1.2.1 Ride Motion Simulator (RMS)

The experiment was conducted on the Ride Motion Simulator (RMS), a 6 degree of freedom (DF) motion-based simulator capable of reproducing the dynamics of military ground vehicles over the vast array of terrains seen by current force vehicles. The simulator was comprised of a platform mounted on a hexapod designed to produce motions in the longitudinal, lateral, vertical, roll, pitch, and yaw directions.

3.1.2.2 Crewstation Configuration

The simulator cab was configured to simulate a wheeled vehicle crewstation similar to one found in a Stryker. Figure 3.1 shows the cab, which included a vehicle seat, a seat belt, and a driving station with steering wheel and pedals. Bokam manufactured the yoke and pedals. Three ASUS 15.6" laptops were used as the displays. Mean viewing distance to the center screen was 488 mm (*SD* = 56 mm), mean line of sight angle was 8.5° (*SD* = 5.2°), and mean vertical visual angle was 22.2° (*SD* = 3.4°).

Figure 3.1: Crewstation Configuration

3.1.2.3 Simulated terrain

The simulated terrain included three route types. The Urban Route contained a four-lane road with intersections and bends. The Rural Route contained a two-lane road with intersections and numerous right-angle bends. The Highway Route contained a divided four-lane road with 425 m radius bends that were banked at five degrees. As illustrated in Figure 3.2, the routes were non-contiguous; after completing seven minutes in one route, the driver stopped and was "teleported" to the beginning of the next route. The experimental routes were populated with ambient traffic vehicles driving in opposing lanes and pedestrian entities walking alongside the roads. The scenario was specifically scripted so that ambient traffic vehicles would not be allowed to drive in the same lanes that the subject vehicle was occupying.

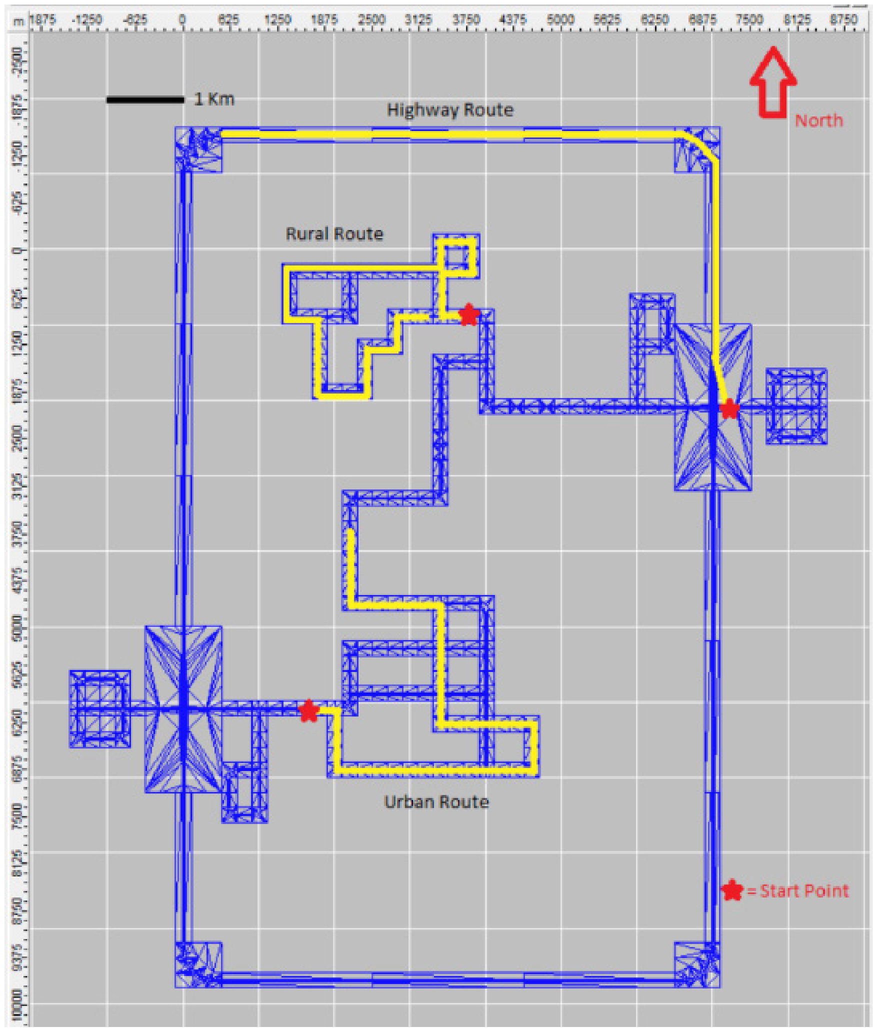

Figure 3.2: Route is highlighted in yellow

3.1.2.4 Simulated DVE

Three DVE levels were tested. The *no* DVE condition featured a cloudy sky and slight environmental fog, with a density of .001 and a visibility of 2000 meters. The *moderate* and *severe* DVE conditions presented denser simulated fog. The *moderate* DVE condition had an obscurant density of .02 and visibility of 100 meters. The *severe* DVE condition (shown in Figure 3.3) presented *severe* fog with an obscurant density of .04 and a visibility of 50 meters. The simulated fog was only a visual effect and had no influence on either the road surface or vehicle response.

3.1.2.5 Driving Aids

Lane/Road Departure Warning System (LRDWS).

Two driving aid conditions were tested. As illustrated in Figure 3.3, the Lane/Road Departure Warning System (LRDWS) provided visual guides, alert sounds, and vibrations corresponding to lane position. Yellow/white virtual pavement markings show lane/road stripes as they would appear if seen directly. The road edge was indicated in orange, representing the limit of the road shoulder. The driver seat included a vibrating unit that simulated a rumble strip effect when driving across lane markings, with audio alerts instructing the driver to move in the correct direction. The alert included three beeps followed by a voice saying "*Drifting: move [right/left]*".

Figure 3.3: *Severe* fog with Lane/Road Departure Warning System (LRDWS)

Optic Flow Enhancer (OFE).

The second aid, Optic Flow Enhancer (OFE), provided a visual indication of speed and movement through the environment. The OFE overlay was presented on the center driving screen with dots spread on the landscape ahead at ground level, as illustrated in Figure 3.4. As the vehicle advances, the dots appear closer and move underneath the vehicle as it is driven over them. The dots indicated only the vehicle's forward movement and speed; they did not provide any data about the road itself.

Figure 3.4: Urban route with Optic Flow Driving aid presented as dots at ground level

3.1.2.6 Questionnaires

The NASA Task Load Index. The TLX is a measure of subjective workload (Hart 2006; Hart & Staveland, 1988). The index includes questions about perceived mental demand, physical demand, temporal demand, performance, effort, and frustration that are rated on a scale of 0 to 100. The TLX was administered electronically on a tablet after each trial.

Simulator Sickness Questionnaire (SSQ). The SSQ is a standard instrument used to assess whether a participant is experiencing motion sickness or other adverse effects (Kennedy, Lane, Berbaum & Lilienthal, 1993). The experimenter verbally administered the SSQ after each trial.

System Usability Scale (SUS). SUS is a reliable, low-cost usability scale that is commonly used for global assessments of system usability (Brooke, 1996). The SUS includes questions related to several aspects of usability, including one's desire to use the system, perceived system complexity, the time and knowledge required to learn the system, and the need for training or support to use the system. This scale also was administered electronically on the tablet.

Demographics Data Sheet. A demographics data sheet was used to record general information about the participants and their background. A copy of this is located in Appendix A.

3.1.3 Design

This study employed a 3 (driving aid) x 3 (visibility) within-subject design. The three driving aid conditions included *no* driving aid, LRDWS, and OFE. Each participant completed nine trials, driving with *no aid* and with each of the two driving aids in each of the three DVE conditions (no DVE [cloudy daylight], *moderate* DVE, and *severe* DVE). The order of the nine trials was counterbalanced across subjects according to a digram-balanced Latin-square design.

Dependent variables included the NASA TLX score, SUS score, forward velocity, number of collisions, lane departures, and lane position.

3.1.4 Procedure

Upon entering the laboratory, participants were briefed on the objectives of the experiment, and then they reviewed and completed the informed consent form, the Simulator Sickness Questionnaire (SSQ), and the demographics data sheet. Next, the experimenter briefed participants on the TLX scales, driving aids, and general functionality, safety features, and safety stops of the simulator.

Following the briefing, each participant completed a 15 to 20 minute practice drive on urban roadways to familiarize himself with the RMS, driver's station, driving aids, and all safety controls. Next, the participant completed nine trials, one in each of the experimental conditions.

After each trial, participants were unloaded from the RMS to complete the SSQ and the NASA TLX. The session was terminated if the SSQ indicated that the participant was experiencing motion sickness or other adverse effects.

After the final trial, the participant completed the SUS for each driving aid and then was debriefed and released.

3.2 Results

Data were analyzed using IBM-SPSS version 25. Unless otherwise reported, each dependent variable was analyzed using repeated-measures ANOVA with the three visibility conditions and three driving aid conditions as factors.

3.2.1 Workload and System Usability Scale

The analysis revealed a significant main effect of driving aid on workload, F (2, 20) = 3.98, MSE = 22.33, p = .04. As shown in the left side of Figure 3.5, the LRDWS driving aid elicited lower workload ratings than either driving with no technology, t (11) = -2.82, p = .02, or driving with the OFE, t (11) = -2.46, p = .03. There was no effect of visibility on workload ratings, F (2, 20) = 2.74, MSE = 164.69, p = .09, nor a significant interaction between driver aid and visibility, F (4, 40) = 1.88, MSE = 34.03, p = .13.

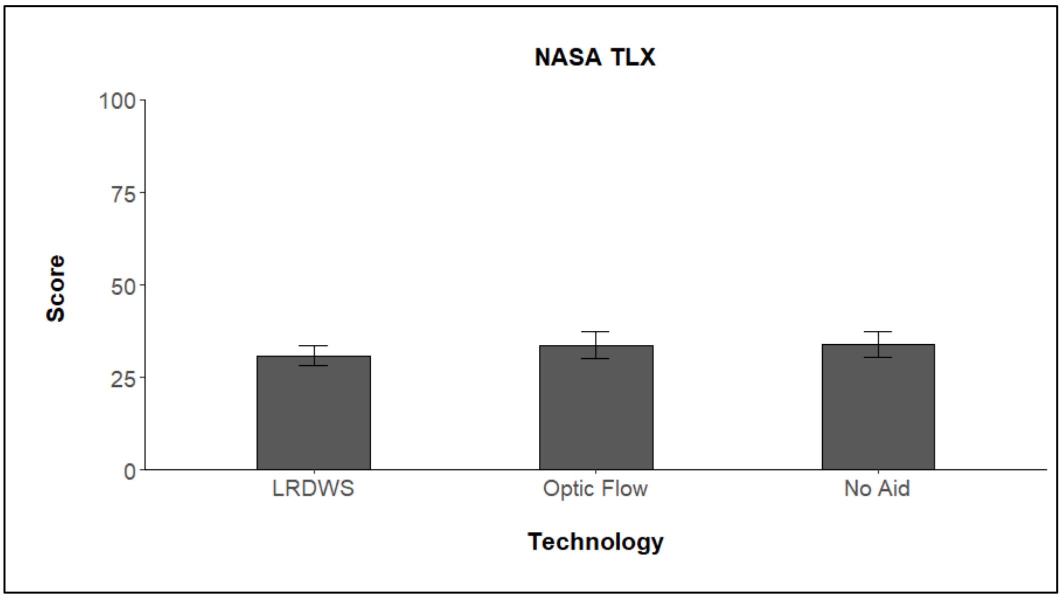

Figure 3.5: NASA TLX ratings for each driving aid.
Error bars represent within-subject 95% confidence intervals (Cousineau, 2005)

SUS ratings were collected at the conclusion of the experiment for each of the two driving aids. As illustrated in figure 3.6, participants rated the LRDWS as significantly more useable than the OFE, t (11) = -1.47, p = .03.

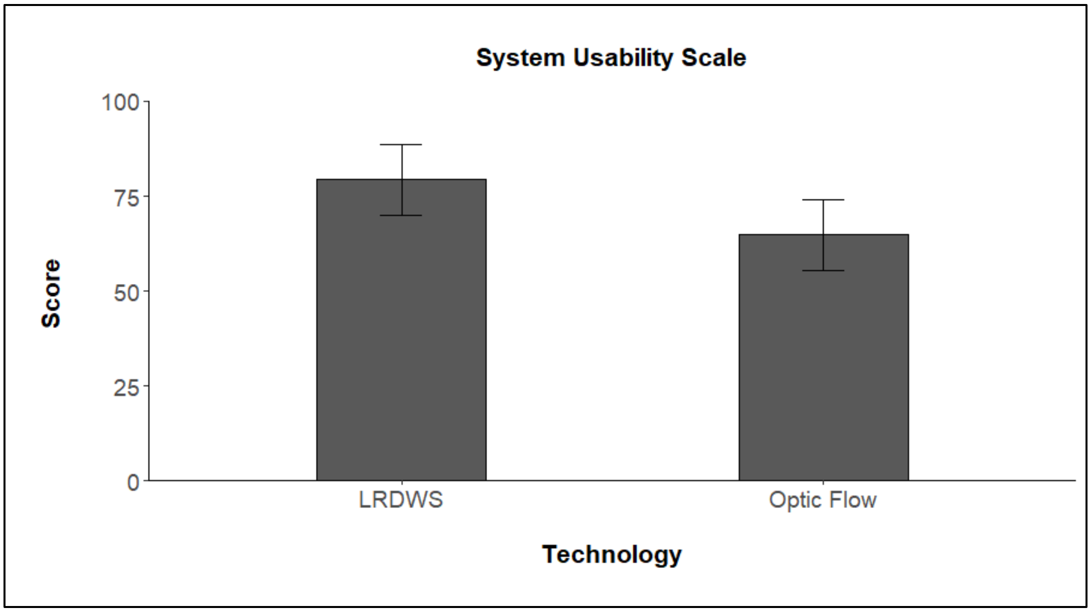

Figure 3.6: SUS ratings for each driving aid.

3.2.2 Average Forward Velocity

The analysis revealed a significant main effect of visibility on average forward velocity, *F* (2, 20) = 7.78, *MSE* = 4.21, *p* = .003. Participants drove faster in clear conditions (*M* = 16.38 *SD* = 2.63) than in the *moderate* DVE (*M* = 15.42 *SD* = 1.93), *t* (11) = 2.24, *p* = .05, and *severe* DVE conditions (*M* = 14.35 *SD* = 2.68), *t* (11) = 3.85. Participants also drove faster in the *moderate* DVE condition than in the *severe* DVE condition, *t* (11) = 2.49, *p* = .03.

Although the effect of driving aid on forward velocity was not significant, *F* (2, 20) = 2.84, *MSE* = 1.68, *p* = .08, the analysis revealed a significant interaction between driving aid and DVE, *F* (4, 40) = 3.05, *MSE* = 1.08, *p* = .03. In the *no* and *moderate* DVE conditions, there was no difference in speed among any of the technology conditions (all p-values were > .09). In the *severe* DVE, the LRDWS supported a higher average velocity than the OFE, t (11) = 2.93, p = .01, or driving without an aid, t (11) = -2.73, p = .02).

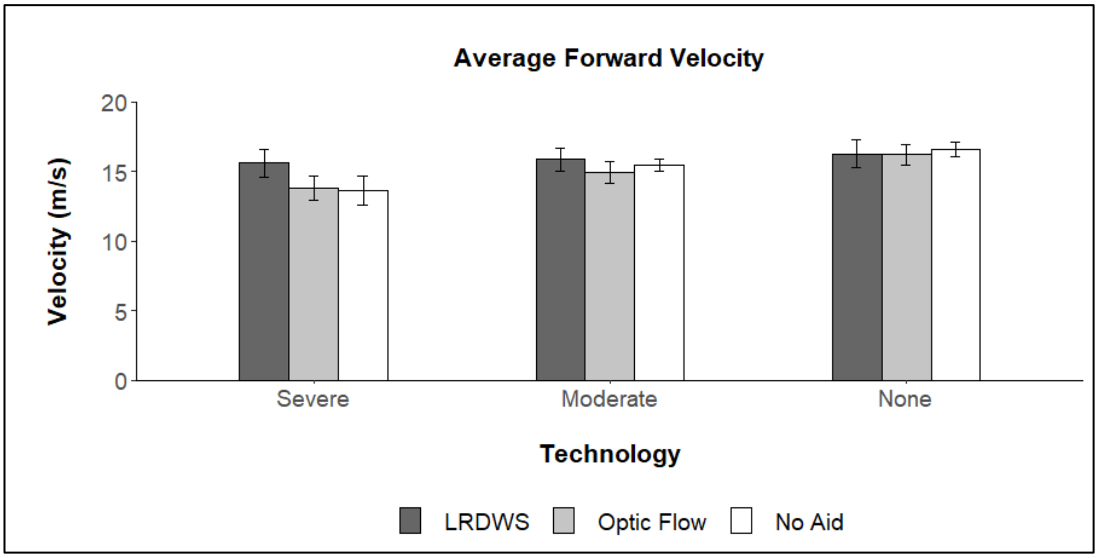

Figure 3.7: Average Forward Velocity for each driving aid in each DVE condition.

3.2.3 Standard Deviation of Forward Velocity

Analyses revealed a significant main effect of driving aid on standard deviation of forward velocity, F (2, 20) = 20.75, MSE = 0.18, p < .001. Drivers maintained a more consistent speed when driving without an aid, t (11) = -5.86, p = < .001; M = 6.28 SD = 0.96, or with the OFE, t (11) = 4.57, p < .001, M = 6.36 SD = 1.08, than when driving with the LRDWS, M = 6.95 SD = 1.03.

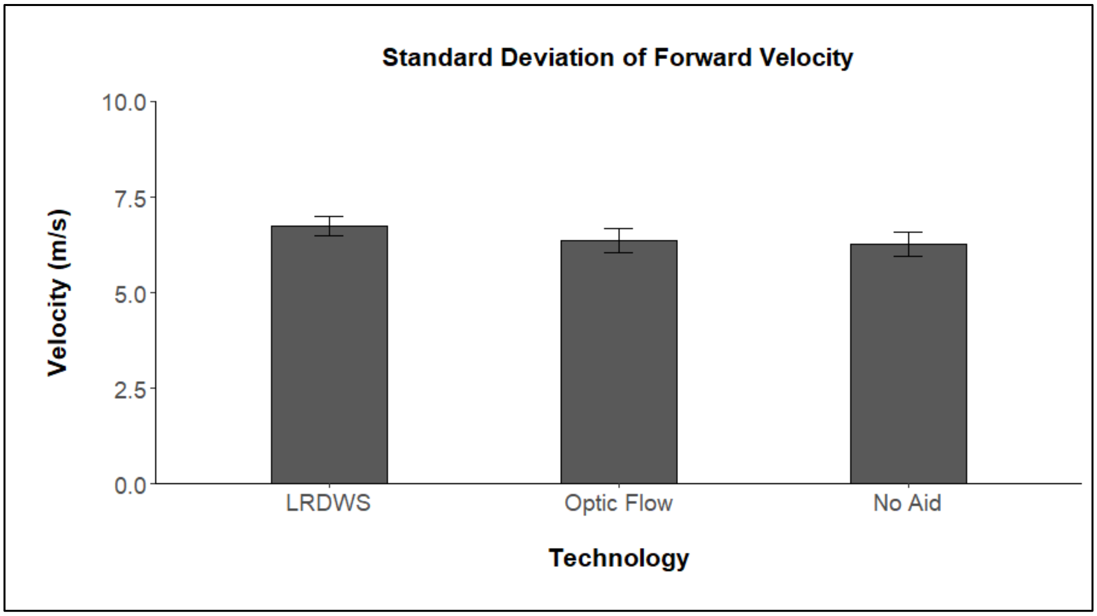

Figure 3.8: Standard deviation of forward velocity for each driving aid.

The main effect of DVE was also significant on standard deviation of forward velocity, *F* (2, 20) = 13.02, *MSE* = 0.65, *p* < .001. Drivers maintained a less consistent speed in the *no* DVE condition (*M* = 5.28 *SD* =0.78) than in the *moderate*, *t* (11) = -7.61, *p* = < .001, and *severe* DVE conditions, *t* (11) = -3.33, *p* = .007. The *severe* DVE elicited a lower variance than *moderate* DVE ((*t* (11) = -3.30, *p* = .007). The interaction between driver aid and visibility was not significant, *F* (4, 40) = 1.81, *MSE* = 0.26, *p* = .15.

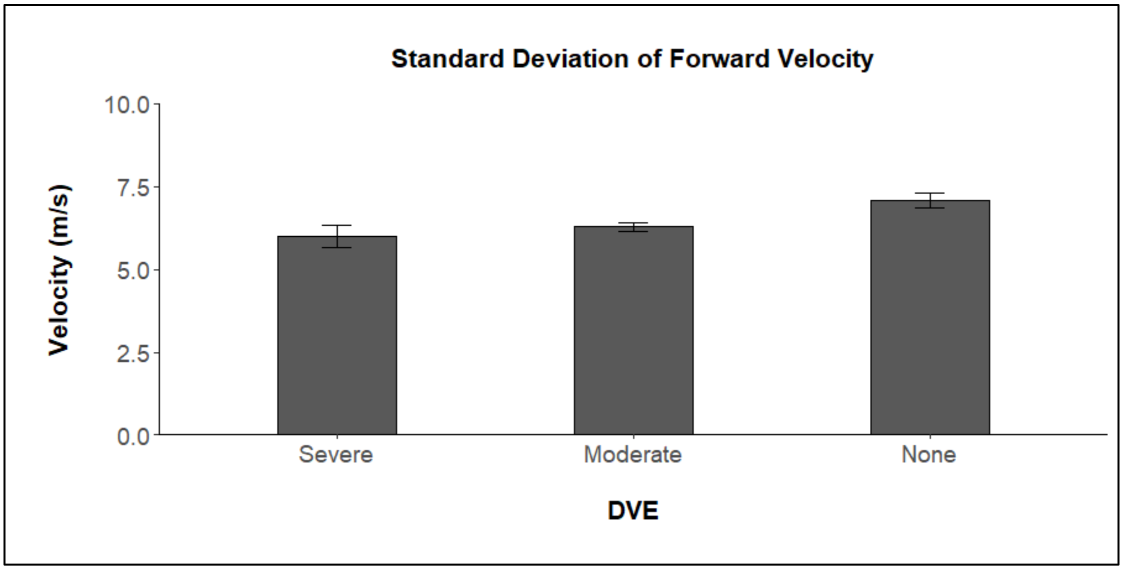

Figure 3.9: Standard deviation of forward velocity for each degraded visual environment.

3.2.4 Road Departures and Collisions

Within the highway portion of the drive, participants averaged 0.3 lane departures per condition (*SD* = 0.3). Analysis indicated no significant effects for either driving aid or DVE on the number of road departures (all *p*s > 0.3). A coding error in the output files precluded analysis of road departures and lane position within urban and rural routes.

3.2.5 Lane Position

While driving on the highway route, participants spent an average of 96% of their driving time in the right-hand lane, maintaining a position just left of lane center (*M* = -0.15, *SD* = 0.11). Analyses of average lane position and standard deviation of lane position revealed no statistically significant effects of driving aid (all *p*s > 0.12) or DVE (all *p*s > 0.16).

3.3 Discussion

The results suggested that drivers preferred the LRDWS technology and that it best supported driving performance. Drivers reported lower workload while driving with the LRDWS and rated the system as more usable. When driving without an aid or with the OFE aid, drivers reduced their speed in the *severe* DVE condition. In contrast, with the LRDWS, drivers were able to maintain similar speeds across visibility conditions.

I hypothesized that LRDWS's visual guides, auditory alerts, and seat vibrations would be particularly beneficial in helping drivers maintain their position on the roadway and avoid lane and road departures. The data, however, did not support this hypothesis. In the *severe* DVE condition, lane-keeping performance was similar across conditions, but operators drove more slowly when they did not have the LRDWS technology available. This finding was consistent with a strategy that prioritized lane keeping over driving speed and experimental instructions to drive as safely as possible, given the conditions.

Interpretation of the data is limited in some ways. First, a coding error in the output files prevented a more complete analysis of lane-keeping behavior across conditions. It was possible that lane-keeping behavior on the highway route did not reflect drivers' lane-keeping behavior in the rural and urban routes.

Second, no collisions and very few lane departures occurred during the experiment, and drivers reported only *moderate* levels of workload. Even in the *severe* DVE, drivers were able to stay on the road and maintain a reasonable speed. In real operational settings, a driver must also monitor the roadway and surrounding terrain for hazards or other potential threats (e.g., Improvised Explosive Devices) and may also need to maintain his or her vehicle's position within a convoy—two tasks that were not required in this simulation. Experiments 2 and 3 address these issues.

4 Simulation Experiment 2

The second simulator experiment built on Experiment 1 by testing two driving aids, a refined Lane/Road Departure Warning System and the Friendly Force Position (FFP) aid. FFP provided a visual indication of friendly vehicle locations and a gap indicator that depicted own-vehicle position with respect to adjacent convoy vehicles. Both aids were tested in a simulated convoy task in which the subject's vehicle was the third vehicle in a march unit of five Strykers on patrol. Convoys are important to the military because aerial resupply cannot deliver all the supplies needed to maintain continuous operations.

4.1 Methods

4.1.1 Participants

Fourteen men, all military with over 5,000 miles per year of driving experience individually, participated and successfully completed the experiment. All the participants were recruited at Ft. Benning and were enlisted (E4-E9) non-commissioned officers with heavy combat or tactical vehicle driving experience.

4.1.2 Apparatus and Materials

4.1.2.1 Ride Motion Simulator (RMS)

This experiment, like Experiment 1, was conducted on the Ride Motion Simulator (RMS). See Chapter 3 for additional details.

4.1.2.2 Crewstation Configuration

The simulator cab was configured to simulate a wheeled vehicle crewstation similar to the one found in a Stryker, just as in Experiment 1. There was a slight change of viewing distance. Mean viewing distance to the center screen was 474 mm, (*SD* = 51 mm), mean line of sight angle was 6.5° (*SD* = 4.8°), and mean vertical visual angle was 23.2° (*SD* = 3.1°).

Figure 4.1: Crewstation Configuration

4.1.2.3 Simulated terrain

The simulated terrain was identical to Experiment 1.

4.1.2.4 Simulated DVE

The same three levels of DVE were applied as in Experiment 1.

4.1.2.5 Driving Aids

Lane/Road Departure Warning System (LRDWS). Two driving aid conditions were tested. The first aid was a refined Lane/Road Departure Warning System (LRDWS). In the first experiment, the LRDWS was configured to respond to lateral excursion distances of 0.3 meters for the Caution alert and 0.7 meters for the Warning alert. In Experiment 2, these values were increased to 0.5 and 1.0 respectively, which had the effect of permitting more variation in lane keeping. This change was implemented primarily to accommodate the second experiment's tactical mission scenario, which included the potential need for rapid lane-change maneuvers, and to reduce the frequency of nuisance alarms occurring on curves.

Friendly Force Position (FFP). The second aid, FFP, is intended for use in convoy operations to help the driver maintain prescribed vehicle spacing when the lead vehicle is visually obscured. This aid also indicates the identity, location, and movements of other vehicles. Nearby friendly vehicles are highlighted for visibility, and a gap indicator provides real-time depiction of the position with respect to adjacent convoy vehicles. Friendly-force vehicles are highlighted with a blue box on the driving screen. The vehicle's current speed, turn signals, and state of the brake are displayed on the bottom of the driving screen. The right-hand side of Figure 4.2 shows the gap indicator, a vertical line with a moving pointer that indicates the vehicle's current position with respect to the two closest same-lane vehicles directly ahead and to the rear of the vehicle.

Figure 4.2: Urban route with Friendly Force Position (FFP).

4.1.2.6 Questionnaires

Experiment 2 employed the same questionnaires as Experiment 1, all presented on a tablet.

4.1.3 Design

This study employed a 3 (driving aid) x 3 (visibility) within-subject design. The three driving aid conditions included no driving aid, LRDWS, and FFP. Each participant completed nine trials, driving with no aid and with each of the two driving aids in each of the three DVE conditions (no DVE [cloudy daylight], *moderate* DVE, and *severe* DVE). The order of the nine trials was counterbalanced across subjects according to a digram-balanced Latin-square design.

Dependent variables included the NASA TLX score, SUS score, forward velocity, number of collisions, lane departures, lane position, average following distance from lead vehicle, and standard deviation of following distance.

4.1.4 Procedure

Upon entering the laboratory, participants underwent the same procedures as in Experiment 1, with the exception of the change in the task of the experiment. The task required the participant to drive the third vehicle in a convoy of five Strykers on patrol. At the start of each road type, the Strykers were arranged into a stationary column formation with a 50-meter gap. Once the participant started moving, the Strykers tried to maintain the predetermined speed and gap distance for the current road type. Table 4.1 below indicates the target speed and gap for the different road types. Once the participant started, the lead Stryker accelerated forward along an acceleration curve that was slower than that of the participant's vehicle's dynamics model. The other Strykers maintained a headway distance equal to the current gap distance. The other Strykers would stop and wait if they travelled greater than 200 meters ahead of the subject vehicle, but aside from this, the simulated vehicles in the convoy behaved independently from the participant's vehicle.

Table 4.1: Speed and Gap Distance

	Highway	**Rural**	**Urban**
Speed (mph)	45	35	25
Gap (m)	50	35	25

4.2 Results

Data were analyzed using IBM-SPSS version 25. Each dependent variable was analyzed using repeated-measures ANOVA with the three visibility conditions and three driving aid conditions as factors. Data is very limited in this experiment. First, a coding error in the output files prevented a complete average forward velocity, standard deviation of forward velocity, road departures, collisions, and lane position, average following distance from lead vehicle, and standard deviation of following distance. Here, I present an analysis of the workload and System Usability Scale.

4.2.1 Workload and System Usability Scale

Figure 4.3 presents the workload data. The analysis revealed no effect of driving aid on workload, F (2, 26) = 0.14, MSE = 2.22, p = .87. There was no effect of visibility on workload ratings, F (2, 26) = 2.07, MSE = 55.53, p = .15, nor a significant interaction between driver aid and visibility, F (4, 52) = 0.07, MSE = 1.85, p = .99.

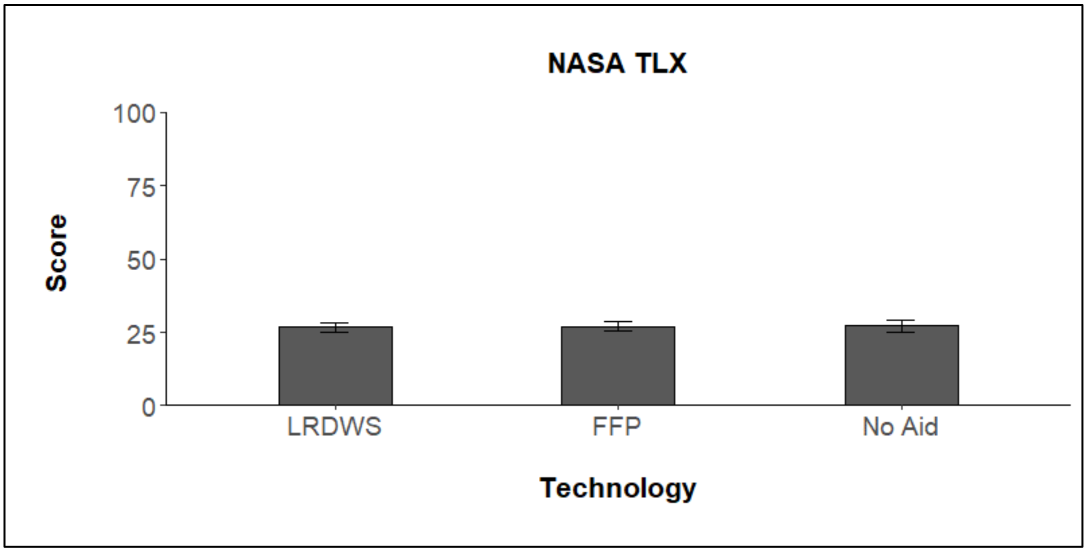

Figure 4.3: NASA TLX ratings for each driving aid.
Error bars represent within-subject 95% confidence intervals (Cousineau, 2005)

SUS ratings were collected at the conclusion of the experiment for each of the two driving aids. The analysis did not reveal any significance, t (13) = .178, p = .68. As illustrated in Figure 4.4, participants rated the LRDWS driving aid and FFP as having similar usability levels.

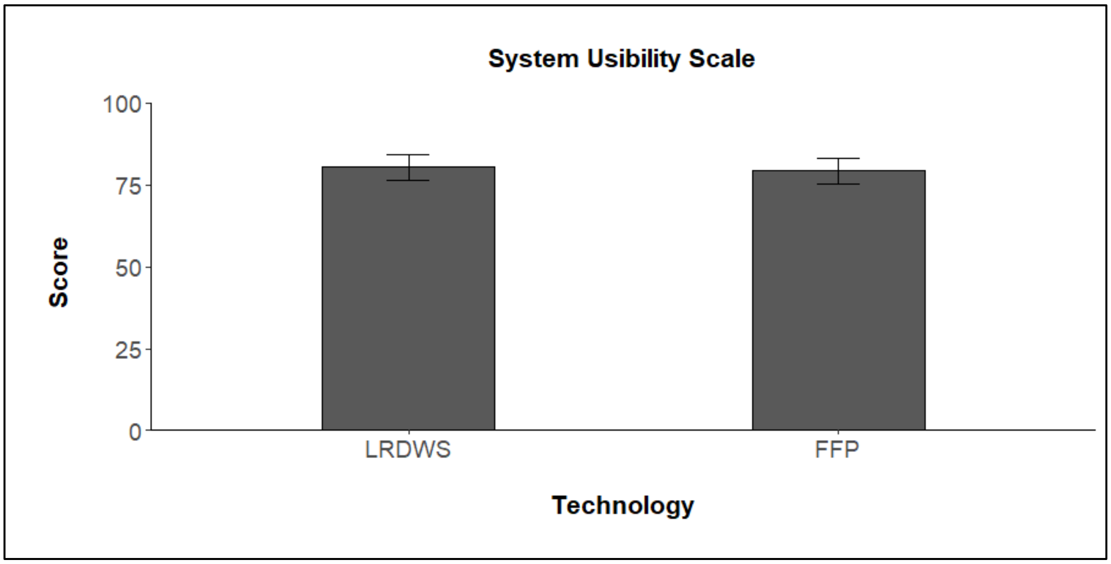

Figure 4.4: SUS ratings for each driving aid.

4.3 Discussion

Drivers reported only moderate levels of workload and rated the two driving aids similarly in usability. Despite the lack of significant differences in these measures, drivers did make comments on the after-action review that suggests a preference of the LRDWS. The LRDWS driving aid received numerous comments on the helpfulness of this aid in DVEs. The Friendly Force driving aid elicited numerous comments on the helpfulness of this aid, but many Soldiers indicated that it was a distraction at times, and drivers felt they had information overload, suggesting that that the FFP indicators may produce too much on-screen clutter. Although the workload data does not reflect out, future work is necessary to examine human performance variables.

5 Simulation Experiment 3

The third simulator experiment built upon Experiments 1 and 2 and tested two additional candidate driving aids that the gDVE team wanted to test in a simulated environment before making a decision on what to implement in the live field test. The two new driving aids were the Radar and Go/NoGo driving aid. The Radar driving aid highlights potential obstacles. It presents data from commercial, off-the-shelf LiDAR and Radar sensors that are easily accessible and a good fit for integration into the Stryker vehicle. The Go/NoGo driving aid provided a visual indication of boundaries beyond which it is not safe to drive and was predicted to help keep participants on the roadway. The experimental task required participants to drive along an unimproved road, with a route and terrain that is more representative of northern Afghanistan and similar to real environments that Soldiers may experience in combat. Also, instead of having static objects, dynamic objects were introduced into the roadway. I anticipated that average cumulative road distance traveled would be increased due to the help of the Go/NoGo driving aid. I also anticipated that the Radar driving aid would reduce the number of collisions.

5.1 Methods

5.1.1 Participants

Fourteen volunteers participated in the experiment. All were Department of Defense civilians or contractors. Five did not complete the study due to technical problems. All had over 5,000 miles per year of driving experience. Participants were pre-screened to make sure they were in good health, free of any medical conditions that prohibit vibration, and not prone to motion sickness.

5.1.2 Apparatus and Materials

5.1.2.1 Ride Motion Simulator (RMS)

The experiment was conducted on the Ride Motion Simulator (RMS), described in Chapter 1.

5.1.2.2 Crewstation Configuration

The simulator cab was configured the same way as in Experiment 1 and 2, except the Ultra MSI Driver Gunner yoke replaced the Bokam manufactured yoke. The new yoke is illustrated in Figure 5.1.

Figure 5.1: Crewstation Configuration with Ultra MSI Driving Gunner Yoke

5.1.2.3 Simulated terrain

The simulated terrain used in Virtual Battlespace 3 (VBS3) was Takistan, which is a rural road measuring 5 miles long that is representative of roads in northern Afghanistan. As shown in Figure 5.2, there were a variety of elevations on the route with villages, curves, and steep hills. Dynamic obstacles were presented frequently on the roadways. In total, 169 simulated obstacles were included: civilian pedestrians, goats, dogs, and rabbits.

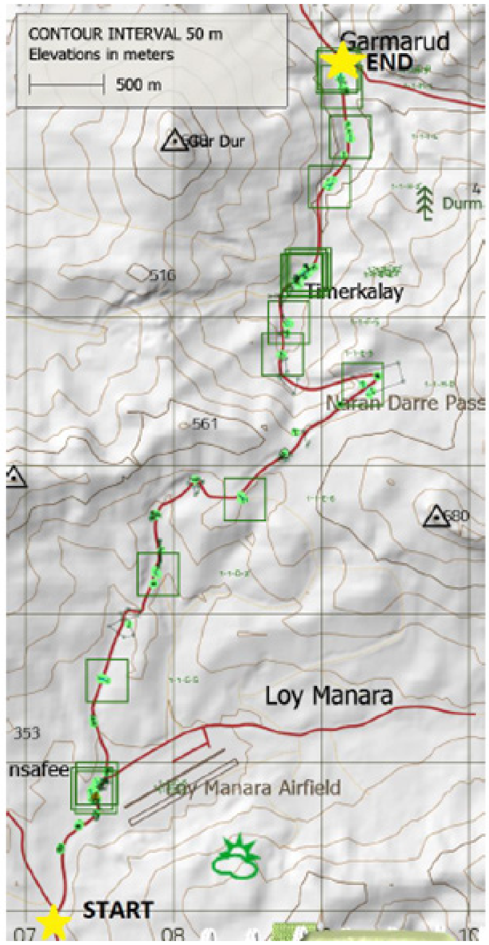

Figure 5.2: Driving Route: The green dots show where dynamic entities were placed on the route, and the boxes highlight the areas with the most entities

5.1.2.4 Simulated DVE

Three levels of DVE were tested, with higher levels of obscurant density than the previous two experiments. In the previous two experiments the most *extreme* conditions were substantially less degraded than is commonly encountered in battlespace environments. For the present study it was decided to eliminate the baseline and replace it with the *moderate* DVE condition, which had an obscurant density of .03 and a visibility of 60 meters. The *severe* and *extreme* DVE conditions presented denser simulated fog.

The *severe* DVE condition had an obscurant density of .05 and a visibility of 40 meters. The *extreme* DVE condition had an obscurant density of .2 and presented fog with a visibility of 10 meters. The simulated fog was only a visual effect and had no effect on either the road surface or vehicle response.

5.1.2.5 Driving Aids

Radar Driving Aid. Three DVE conditions were tested with two driving aids. The Radar aid detected and highlighted objects near the vehicle (people, vehicles, trees, and buildings). If an object was detected, a green box overlay outlined the object. If an object was in the collision path, it was dual-coded with color and blink rate. If the vehicle's path was predicted to collide with the object in 5 to10 seconds, the box would blink yellow. For collisions within 5-seconds, the box would flash red, with increasing blink rate as time to collision drew near. Figure 5.3 illustrates the Radar driving aid.

Figure 5.3: Radar driving aid highlighting obstacles with *moderate* DVE.

Go/NoGo Driving Aid. The second aid, the Go/NoGo driving aid, provided a visual indication of boundaries beyond which it was not safe to drive, based upon the terrain slope. The yellow boundary indicated it was unsafe or difficult to drive with a slope ≥30% (≈17°) but <60% (≈31°) (see Figure 5.4 below). Red indicated it was very dangerous or impossible to drive with a slope of ≥60%.

Figure 5.4: Go/NoGo driving aid showing boundary markers in *moderate* DVE.

5.1.2.6 Site Map

A map was provided to the drivers that showed the driving route and its main features, distance markers, and locations of villages, hills, and treacherous curves. A printed copy of this map was provided in the cab of the Ride Motion Simulator. The site map is pictured below in Figure 5.5.

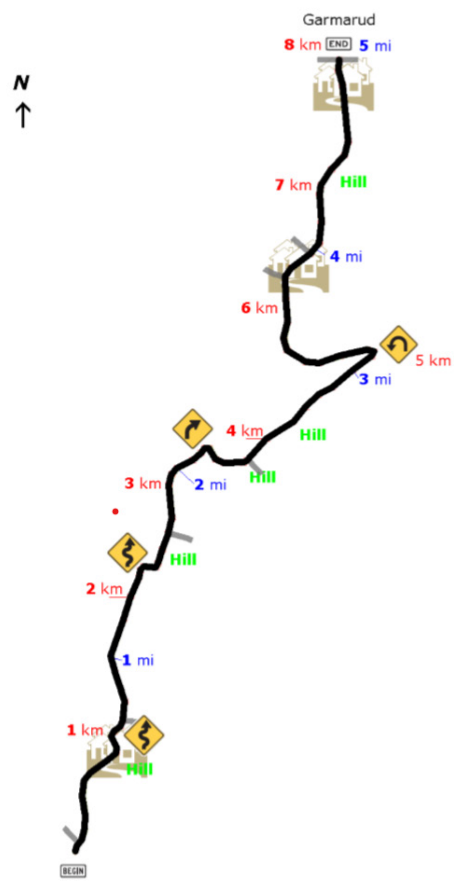

Figure 5.5: Map of Takistan route hung in the RMS cab.

5.1.2.7 Questionnaires

Experiment 3 employed the same questionnaires as Experiments 1 and 2, with the exception that an After-Action Review was added. This AAR was a printed form that was completed by hand (see Appendix A for format and responses of participants).

5.1.3 Design

This study employed a 3 (driving aid) x 3 (visibility) within-subject design. The three driving aid conditions included no driving aid, Radar, and Go/NoGo (GNG). Each participant completed nine trials, driving with no aid and with each of the two driving aids in each of the three DVE conditions (*moderate, severe,* and *extreme*). The order of the nine trials was counterbalanced across subjects according to a digram-balanced Latin-square design. Dependent variables included the NASA TLX score, SUS score, forward velocity, lateral distance, road distance traveled, and number of collisions.

5.1.4 Procedure

Upon entering the laboratory, participants were briefed on the objectives of the experiment, and then they reviewed and completed the Informed Consent Form, the Simulator Sickness Questionnaire (SSQ), and the Demographics Data Sheet. Next, the experimenter briefed participants on the TLX scales, driving aids, and the general functionality, safety features, and safety stops of the simulator.

Following the briefing, each participant completed a 15 to 20 minute practice drive to familiarize himself with the RMS, driver's station, driving aids, and all safety controls.

Participants were instructed to drive safely as far as they could along the road at a speed at which they felt comfortable. They were given 15 minutes to drive and a map to show the route to drive within the crew station. Participants were also informed that they may see entities (people and animals) within the route and that they should avoid hitting them.

Next, participants completed nine trials, one in each of the experimental conditions.

After each trial, participants were unloaded from the RMS to complete the SSQ and the NASA TLX. The session was terminated if the SSQ indicated that the participant was experiencing motion sickness or other adverse effects.

After the final trial, participants completed the SUS for each driving aid and an after-action review sheet, and then they were debriefed and released.

5.2 Results

Data were analyzed using IBM-SPSS version 25. Unless noted otherwise, each dependent variable was analyzed using repeated-measures ANOVA with the three visibility conditions and three driving aid conditions as factors. As noted earlier, due to simulator abnormalities and errors, only 9 of the 14 participants completed the study. For these 9 participants, the order of the trials was counterbalanced across subjects according to a digram-balanced Latin-square design. While all participants drove for 15 minutes, all did not finish the route; unless otherwise noted, the results below represent data from the entire 15 minutes of the drive.

5.2.1 Workload and System Usability Scale

The analysis revealed a significant main effect of visibility, F (2, 18) = 20.24, MSE = 375.94, p = <.001. As shown in Figure 5.6, the *extreme* DVE elicited higher workload ratings than either *moderate* DVE, t (10) = -4.38, p = .002, or *severe* DVE, t (10) = -5.59, p = <.001. There was no effect of technology on workload ratings, F (2, 18) = 0.95, MSE

= 43.95, *p* = .41, nor a significant interaction between driver aid and visibility, *F* (4, 36) = 1.79, *MSE* = 41.20, *p* = .15.

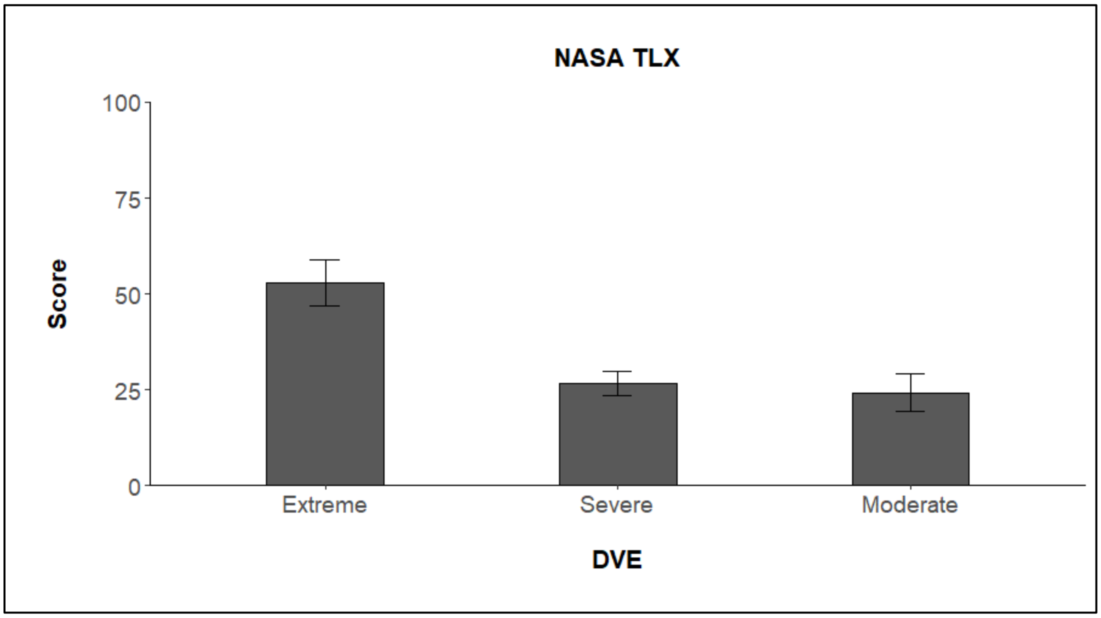

Figure 5.6: NASA TLX ratings for each visibility condition.
Error bars represent within-subject 95% confidence intervals (Cousineau, 2005).

SUS ratings were collected at the conclusion of the experiment for each of the two driving aids. As illustrated in Figure 5.7, participants rated the Radar driving aid significantly more useable than the Go/NoGo driving aid, *t* (10) = -4.11, *p* = .003.

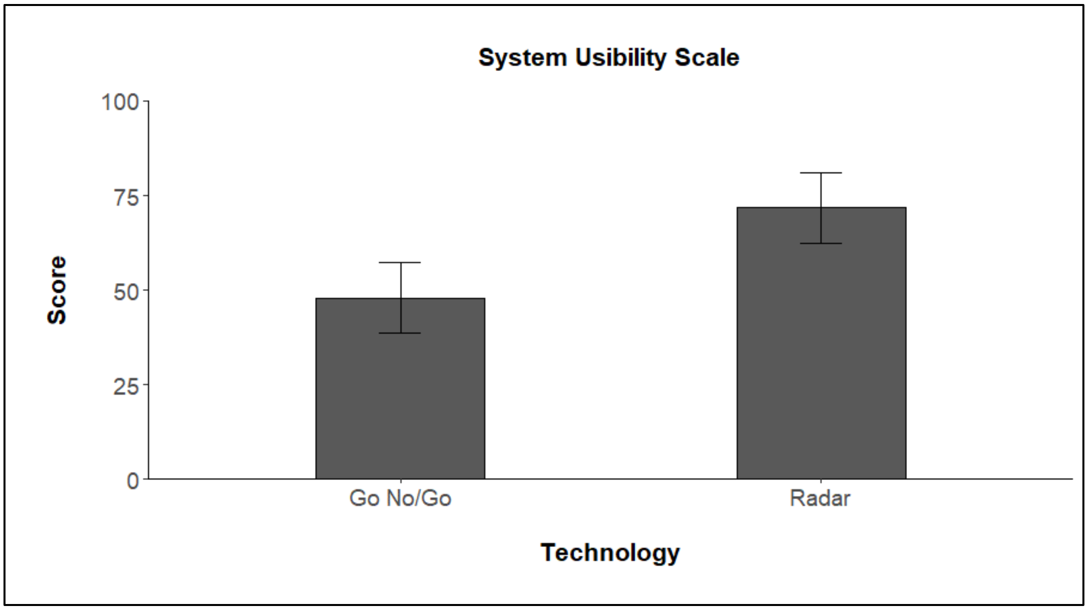

Figure 5.7: SUS ratings for each driving aid.

5.2.2 Average Forward Velocity

The analysis revealed a significant main effect of visibility on average forward velocity, F (2, 18) = 98.80, MSE = 2.30, p =<.001. Participants drove slower in *extreme* DVE (M =7.71, SD = 1.37) than in the *severe* DVE, t (10) = -12.31, p =<.001, and *moderate* DVE conditions, t (10) = -10.06, p =<.001.

The effect of driving aid on forward velocity was not significant, F (2, 18) = 1.78, MSE = 0.41, p = .20, and the analysis did not reveal a significant interaction between driving aid and DVE, F (4, 36) = 0.31, MSE = 0.45, p = .87.

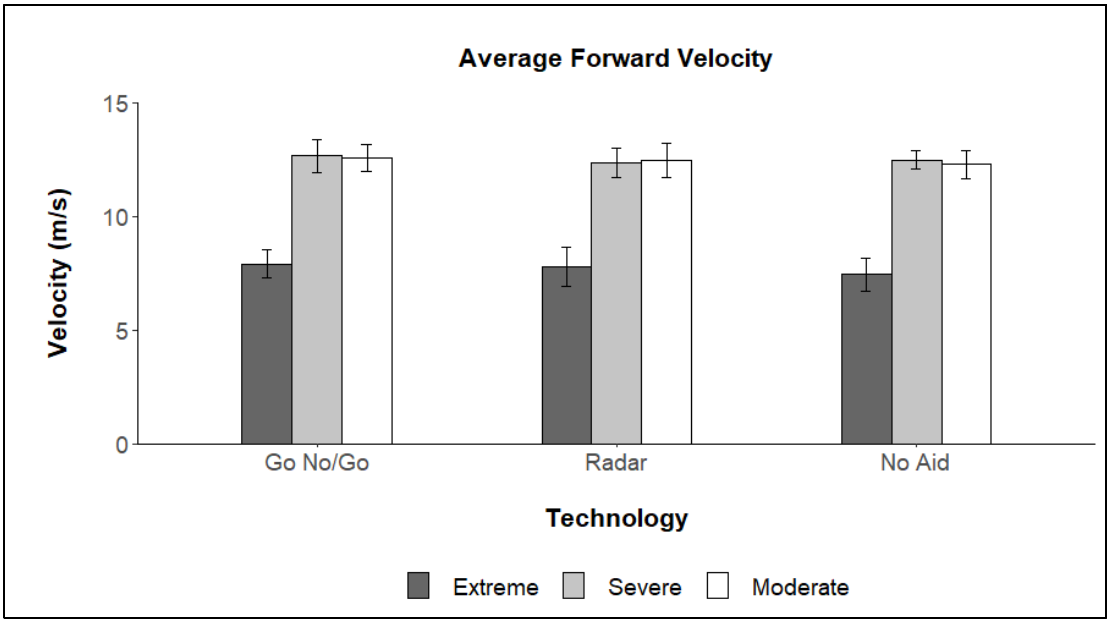

Figure 5.8: Average Forward Velocity for each driving aid in each DVE condition.

5.2.3 Standard Deviation of Forward Velocity

Analyses revealed a significant main effect of visibility on standard deviation of forward velocity, F (2, 18) = 68.38, MSE = 0.42, p =< .001. Drivers maintained a less consistent speed when driving under *severe* DVE conditions t (10) = -8.98, p = < .001; M = 3.87 SD = 0.53, and under *moderate* DVE conditions, t (10) = -9.31, p < .001, M = 4.05 SD =0.58, than when driving under *extreme* DVE conditions, M = 2.27 SD = 0.53.

The effect of driving aid on standard deviation of forward velocity was not significant, F (2, 18) =0.09, MSE = 0.12, p = .91, and the analysis did not reveal a significant interaction between driving aid and DVE, F (4, 36) = 0.24, MSE = 0.19, p = .91. Figure 5.9 illustrates the standard deviation of Forward velocity for each driving aid under the three visibility conditions.

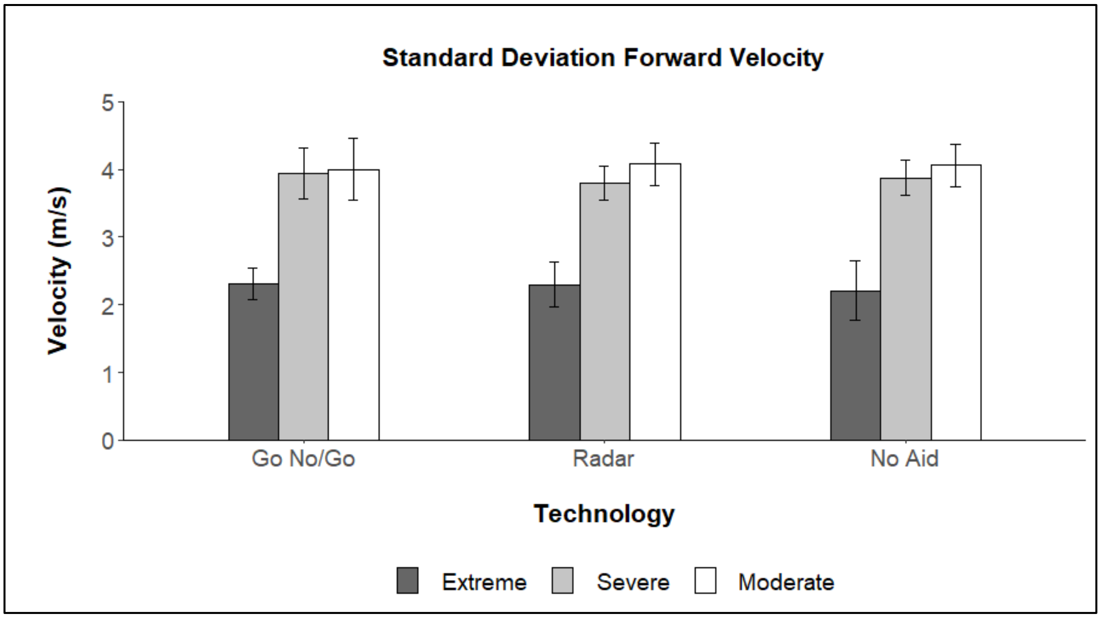

Figure 5.9: Standard deviation of Forward Velocity for each driving aid for each degraded visual environment.

5.2.4 Average Cumulative Road Distance Traveled

The analysis revealed a significant main effect of visibility on average cumulative road distance traveled, F (2, 18) = 18.24, MSE = 944175.77, p =<.001. Consistent with forward velocity, drivers traveled more slowly and for shorter distances in *extreme* DVEs, (M = 6701.33 SD =973.28) than in either the *moderate* DVE, t (10) = -4.28, p =.002, or *severe* DVE conditions, t (10) = -4.28, p =.002.

The effect of the driving aid on vehicle distance traveled was not significant, F (2, 18) = 1.54, MSE = 79342.27, p = .24, and the analysis did not reveal a significant interaction between the driving aid and DVE, F (4, 36) = 1.56, MSE =80410.94, p = .21.

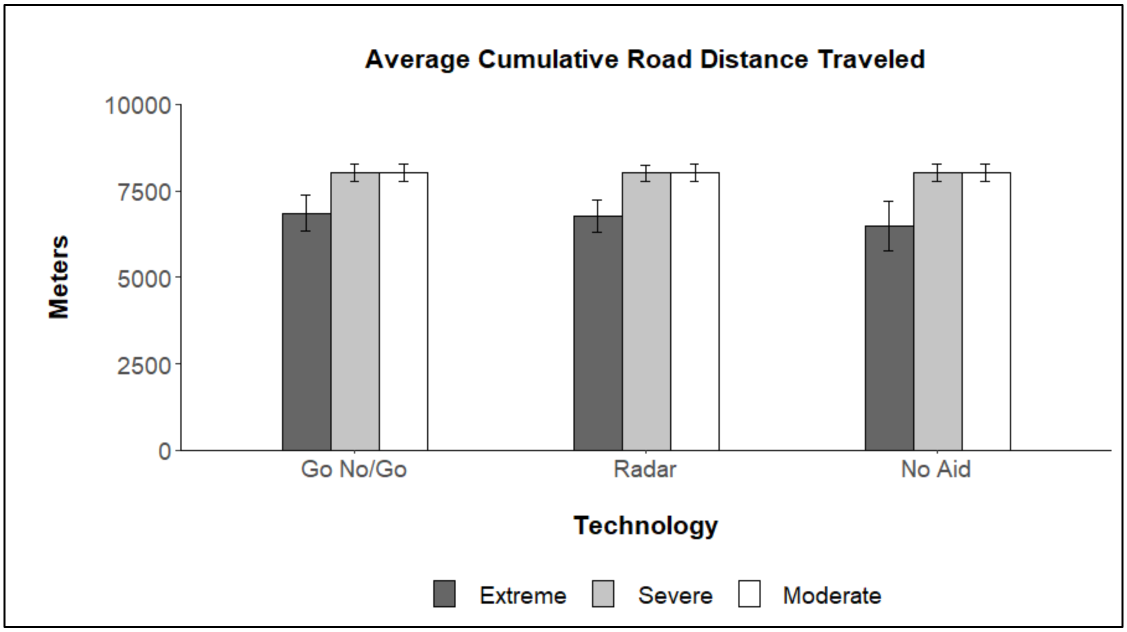

Figure 5.10: Average Cumulative Road Distance traveled for each driving aid in each DVE condition.

5.2.5 Lateral Distance Between Vehicle and Ideal Route

In general, participants were able to maintain the ideal route across conditions. The effect of driving aid on lateral distance between vehicle and ideal was not significant, F (2, 20) = 2.10, MSE = 0.01, p = .15 as well as the effect of DVE F (2, 20) = 0.26, MSE = 0.08, p = .77. The analysis did not reveal a significant interaction between driving aid and DVE, F (4, 40) = 1.30, MSE = 0.02, p = .29.

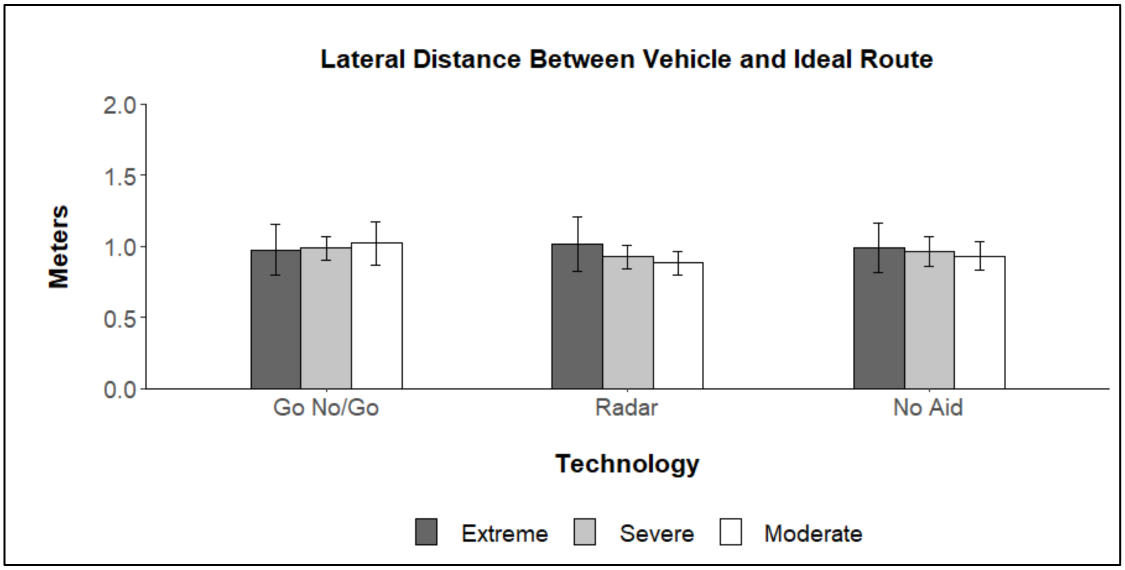

Figure 5.11: Lateral Distance Between Stryker and the Ideal Route for each driving aid in each degraded visual environment.

5.2.6 Collisions with Objects

As not all participants completed the course in 15 minutes, analysis on the number of collisions was done for approximately the first half of the course, which all participants completed. The effect of driving aids on collisions was not significant, F (2, 18) = 1.24, MSE = 0.87, p = .31. There was a significant main effect of visibility on collisions, F (2, 18) = 3.47, MSE = 1.06, p = .05 with *extreme* DVE eliciting more collisions than *severe* DVE, t (10) =2.91, p=.02. This result indicated that the *extreme* DVE made it harder for participants to see anything, including objects with which they could collide. Participants had 45 collisions in the *extreme* DVE compared to 24 collision in *severe* DVE and 35 in *moderate* DVE, respectively.

The analysis revealed a significant interaction between DVE and driving aid, F (4, 36) = 2.94, MSE = 2.81, p = .01. Without a driving aid, participants had more collisions in the *extreme* DVE, *t* (10) = 3.28, *p* =.01 than in the *moderate* DVE. The analysis also revealed that while driving in the *moderate* fog level, the radar driving aid actually increased the number of crashes compared to no driving aid, *t* (10) =-3.10, *p* =.01, and the Go No/Go driving aid, *t* (10) =2.23, *p*=.05.

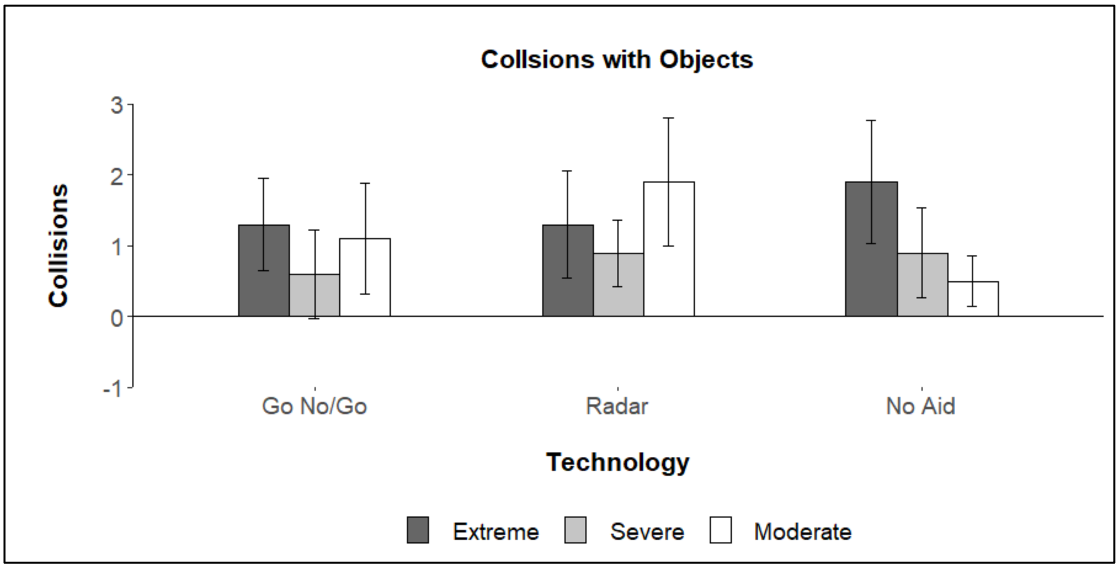

Figure 5.12: Average Collisions with Objects for each driving aid in each degraded visual environment.

5.2.7 Collisions per Distance

Collisions also were analyzed across the full distance driven by each participant but normalized with respect to distance. Along the 5-mile route, a total of 238 collisions were noted for all nine participants, with an average of 26.44 collisions per participant. The effect of driving aid on collisions per distance was not significant, *F* (2, 18) = 1.28, *MSE* = 0.07, *p* = .88, and there was no significant interaction between driving aid and DVE, *F* (4, 36) = 0.27, *MSE* = 0.10, *p* = .89. The analysis did not reveal a significant main effect on DVE, $F(2, 18) = 0.78$, $MSE = 0.11$, $p = .48$. Four participants did not have collisions in one of their trials, with every other trial having at least one collision. Figure 5.13 presents the average collisions per mile for each of the driving aids in each DVE. Figure 5.14 illustrates all 238 collisions on the 5-mile route.

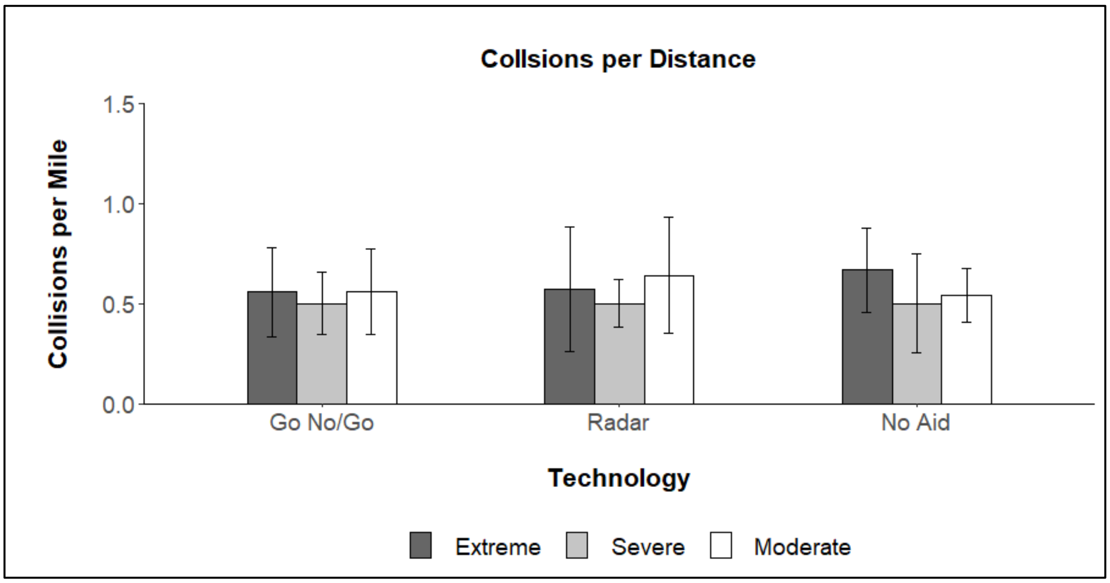

Figure 5.13: Average Collisions per Mile with Objects for each driving aid and for each degraded visual environment

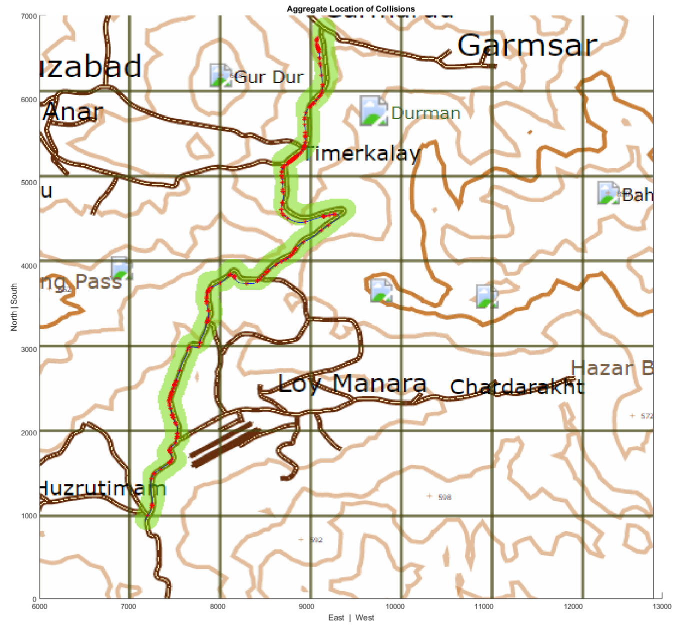

Figure 5.14: Map of collisions on road are denoted by red dots.

5.3 Discussion

Regardless of technology, drivers reduced their speed and drove similar speeds in the *extreme* DVE condition. This finding was consistent with a strategy that prioritized safety over driving speed and the experimental instructions to drive as safely as possible, given the conditions.

I anticipated that average cumulative road distance traveled would be increased due to the help of the driving aids. This result was not the trend, as DVE visibility was the only factor that influenced distance traveled. Specifically, less distance was traveled in the *extreme* DVE condition. There was no effect of technology found on the lateral distance between vehicle and ideal route. This suggested that participants did not diverge from the ideal path more in highly degraded environments, and route-keeping behavior was not affected positively or negatively by technology.

Number of collisions was one aspect of performance in which technology affected performance. As expected, significantly more crashes occurred in the *extreme* DVE than in the *severe* DVE, but an interaction also was found between driving aid and visibility. Without a driving aid, participants had more collisions in the *extreme* DVE than the *moderate* DVE than they did when they had an aid, suggesting that driving aids did in fact support driving performance in the *extreme* DVE.

Although I anticipated that the Radar's visual cues would be particularly beneficial in helping drivers avoid collisions, the data, did not bear this out. The largest number of collisions took place in *moderate* DVE with the Radar driving aid. This finding, in isolation, suggested that the Radar driving aid might have been a distraction to the participants when used in *moderate* DVE, the lowest DVE level in this experiment. This might suggest that the added display clutter impairs performance when objects are still somewhat visible. This design feature needs further research.

Despite inconsistencies in the performance data, drivers preferred the Radar technology. They rated it as more usable than the Go/No Go driving aid. In fact, in the after-action review almost all the comments on the Go/No Go driving aid were negative. Many participants viewed the Go/No Go driving aid as a useless distraction, and ignored it.

The scenario and road type were more realistic to what a Soldier would encounter patrolling. This experiment helped shape the recommendation regarding the selection and refinement of driving aids used in the field tests, specifically the Radar driving aid. This experiment gave the opportunity to implement the Radar driving aid in a simulated environment and refine the sensitivity for field test experiments. There were numerous comments in the after-action review that indicated that the Radar driving aid missed obstacles and had false positives. This experiment also gave a chance to see what participants thought of the candidate driving aids, and with the strong usability that participants reported on the Radar driving aid, assisted in the final selection for the field tests. Overall, the data from this experiment motived further testing of the Radar driving aid in the field test. The experiment also suggested that future work should examine the implementation of the Radar driving aid.

6 DVE Field Test 1 with Prototype Driving Aids

With three simulation studies completed, the next step was a live field test in an actual vehicle with an integrated gDVE mitigation system. The test was performed at the KOFA Dust Course at Yuma Proving Grounds in October/November 2018. Nine U.S. Army Soldiers drove in an oval route following another vehicle. Dust was kicked up by the lead vehicle to create a DVE based on the natural environment of the course. The Soldiers drove as if in a convoy scenario while using various driving aids.

6.1 Methods

6.1.1 Participants

Nine active U.S. Army Soldiers with Stryker driving experience participated in the experiment. Participants were screened ahead of time to make sure they were in good health and were not prone to motion sickness. Eight of the participants were enlisted Soldiers, and one was a Non-Commissioned Officer (NCO).

6.1.2 Apparatus and Materials

6.1.2.1 Modified Stryker

The test vehicle was a modified Stryker with an integrated gDVE mitigation system. The Mitigation system included a drive-by-wire system, image-processing improvement camera view, Friendly Force Position driving aid, and Millimeter Wave Radar (referred to as Radar driving aid) with image augmentation overlays, all on indirect driving screens to highlight potential obstacles. This driving aid was tested in Simulation 3 Experiment. Figure 6.1 illustrates the modified Stryker used in this experiment.

Figure 6.1: Stryker

The cab included vehicle seats, seat belts, and a driving station (steering wheel and pedals) and three 15.6” displays that served as our crew-station configuration. Figure 6.2 illustrates the cab set-up in this experiment.

Figure 6.2: Crewstation Configuration

6.1.2.2 BAE Systems Sensor

The BAE Systems Sensor was a sensor system that has three daytime and three nighttime cameras arranged in an array. Like the standard DVE, it was designed to help vehicle operators navigate their terrains during day, night, and adverse weather conditions such as dust, smoke, and haze. It outputs a 180° field of view at a digital resolution of 1920 x 1280 pixels. The sensor itself combines and filters the information from its sensors before outputting an image to a driver. This image was shown to the driver on an array of three high-definition flat panel displays that is installed within the Driver Station. The BAE sensor system was the baseline condition for this analysis, and it was used with each one of the driving aids because it was integrated into the crew station configuration.

6.1.2.3 Driving Aids

Radar Driving Aid. The Radar Driving Aid presented information from a Delphi radar and Velodyne HDL-32E mounted Lidar, which were installed on the modified Stryker.

The output was integrated into the Warfighter Machine Interface (WMI) as image augmentation overlays on the indirect driving screens, highlighting potential obstacles (See Figure 6.3).

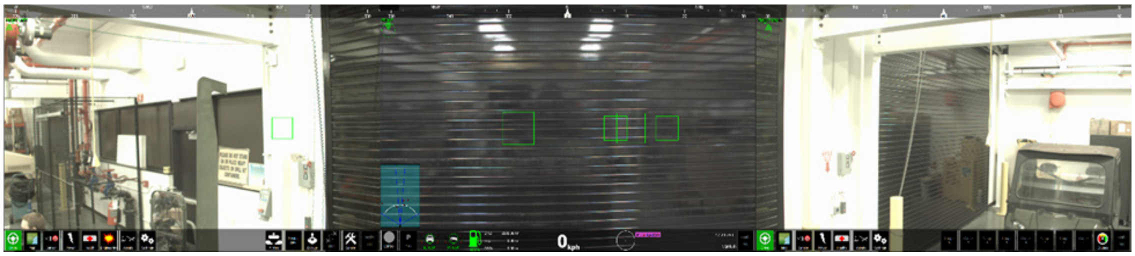

Figure 6.3: ODCA or Radar driving aid in clear environment.

Image Enhancement Driving Aid. The second aid was the Image Enhancement (IE) of a Long-Wave Infrared (LWIR) camera. Although this driving aid was not tested in our simulator experiments, it has had static live field tests and was readily available (Silen, 2017). The BAE Sensor System hosted the image enhancing algorithms. The Image Enhancement feature is a dust/sketch algorithm. It augments contrast differences undetectable by the eye and conveys the geometric properties of the scene and of objects within the scene. The algorithm combines dynamic range compression, edge enhancement, and histogram equalization to maximize acutance and contrast. This dust/sketch algorithm has been previously tested in static environments and has shown to provide a clearer picture to the driver in heavily degraded environments (Silen, 2017).

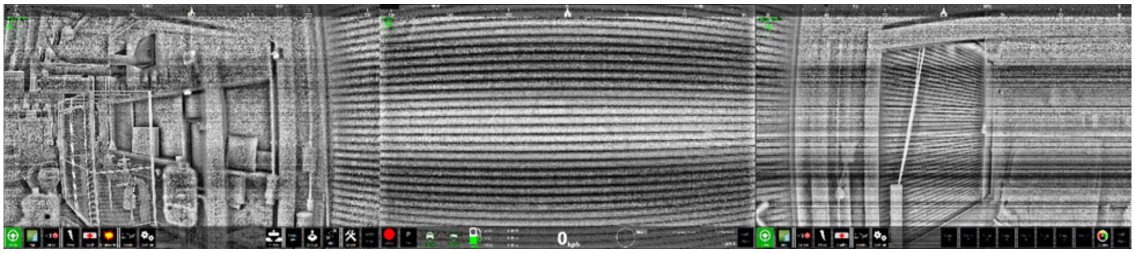

Figure 6.4: IE driving aid in clear environment with dust/sketch algorithm.

Friendly Force Position Driving Aid. The third driving aid, already tested in Simulation 2 Experiment, was intended for use in convoy operations to help the driver maintain prescribed vehicle spacing when the lead vehicle is visually obscured. The Friendly Force Position (FFP) aid indicates the identity, location, and movements of other vehicles. Nearby friendly vehicles are cued with a blue box on the driving screen, and a gap indicator provides real-time depiction of the position with respect to adjacent convoy vehicles. The vehicle's current speed, turn signals, and state of the brake are also displayed on the bottom of the driving screen. The right-hand side of Figure 6.5 shows the gap indicator, a vertical line with a moving pointer that indicates your current position with respect to the two closest same-lane vehicles directly ahead and to the rear of your vehicle.

Figure 6.5: Friendly Force Position (FFP).

6.1.2.4 Armored Personnel Carrier

An M113 Armored Personnel Carrier served two purposes. First, it was used as the lead vehicle in this field test. Second, it created the dust cloud serving as the gDVE needed to test our driving aids.

6.1.2.5 Course

The outdoor environment of Yuma Proving Ground is classified as Köppen, or a hot desert climate. The KOFA Dust Course at Yuma Proving Grounds was flat and oval shaped. Figure 6.6 illustrates the 3.9 kilometers course driven in testing.

Figure 6.6: Red oval is course driven in the convoy.

6.1.2.6 Degraded Visual Environment

Only one level of DVE was tested due to the nature of the scenario. When operating the two vehicles in a convoy in the middle of the desert, it is not possible to have a clear condition. Unlike the simulation studies that used fog as the DVE, the degraded visual environment was generated with airborne dust raised from the natural ground of the test site by the lead vehicle.

6.1.2.7 Questionnaires

Simulator Sickness Questionnaire. Similar to the simulation experiments, the experimenter was ready to verbally administer the SSQ as-needed basis; however, the SSQ did not need to be used in this experiment.

System Usability Scale. Also, like the simulation experiments, the participants filled out the System Usability Scale (SUS) after the field test was complete.

General Questionnaire. The General Questionnaire was created specifically for this field test. This questionnaire measured the usability and workload of the complete system and its component driving aids. The questionnaire includes the following categories, Situational Awareness, Speed, Spacing, Lane Keeping, Threat Detection, and System. This questionnaire was also administered after the field test was completed.

Single Ease Question (SEQ). The SEQ questionnaire used a seven-point Likert scale to obtain feedback on task difficulty from a participant perspective, with 1 indicating very difficult and 7 meaning very easy. It was administered to each participant after each run (Tedesco & Tullis, 2006).

Rating Scale for Mental Effort (SMEQ). The SMEQ (Zijlstra & van Doorn, 1985) is a single item questionnaire with a rating scale from 0 to 150. There are nine verbal labels ranging from "Not at all hard to do" to "Tremendously hard to do" (Sauro & Lewis, 2016). It was administered to each participant after each run. This questionnaire was used instead of the NASA TLX for ease of use.

6.1.3 Design

This study employs a one-way repeated-measures design. The four driving aid conditions included no driving aid, FFP, ODCA (Radar), and IE driving aids. Each participant completed nine trials, driving with no aid and with each of the three driving aids in DVE conditions. The order of the four trials was counterbalanced across subjects according to a digram-balanced Latin-square design. Note that there were a total of seven conditions planned for this experiment, but most participants completed only four of those conditions. Due to technical difficulties and scheduling time constraints, only half of the participants were able to complete the additional three runs, so they were excluded from the analysis.

Dependent variables are listed in Table 6.1. Three new variables were introduced to Field Test 1 based on this particular task and the instructions given to the driver for this experiment. These included percent time too close, percent time too far, and percent time off-road. For the Stryker to be considered too close, the longitudinal distance was less than 33 meters between the two vehicles as measured by GPS. For the Stryker to be considered too far, the longitudinal distance was more than 107 meters between the two vehicles as measured by GPS. The final new variable was percent time off-road. The Stryker vehicle was determined to be off-road when the lateral distance between the vehicle and the center of the road as measured by GPS location was more than 3.8 meters. The center of the road was determined by applying a sliding average over the latitude and longitude coordinates of the lead vehicle, which was assumed to be operated by a trained driver who is directed to operate his vehicle over the centerline of the road.

Table 6.1: Field Test 1 Dependent Variables

Dependent Variables
Average Forward Velocity
Standard Deviation of Forward Velocity
Percent Time Too Far
Percent Time Too Close

Percent Time Off Road
Average Lateral Distance Between the Following Vehicle and Lead Vehicle
Standard Deviation Lateral Distance Between the Following Vehicle and Lead Vehicle
SUS Score
General Questionnaire Questions
Single Ease Question (SEQ)
Rating Scale for Mental Effort (SMEQ)

6.1.4 Procedure

The experiment took place at the KOFA Dust Course at the Yuma Proving Grounds in Yuma, Arizona. Participants were briefed on the objectives of the experiment, and then they reviewed and completed the Informed Consent Form and the Simulator Sickness Questionnaire (SSQ). Next, the experimenter briefed participants on the various surveys, driver's station, driving aids (FFP, Radar, IE), and safety features. Each participant then completed a 15-20 minute hands-on driver practice in the Stryker using the WMI. The participant then practiced driving with each of the driving aids. Participants were instructed to follow the M113 within a closed convoy formation at a following speed of 15 miles per hour, a catch-up speed of 25 miles per hour, and a gap distance of 50 meters. After each trial, participants completed the various questionnaires. The experimenter was in the vehicle to monitor the driver for signs of motion sickness and administer the SSQ or terminate the session as needed. No participants reported motion sickness or other adverse effects.

Figure 6.6: Stryker following M113

After the final trial, the participants completed the SUS for each driving aid and an after-action review sheet and then were debriefed and released.

6.1.5 Research Questions

The current project addressed the following research questions:

1. Which aid supported fastest completion of the course?
2. To what extent did the aids support safe convoy-following behavior?
3. To what extent do each of the aids support workload reduction in DVEs?
4. To what extent did the Soldiers find the IE, FFP, and Radar driving aids to be usable and useful in DVEs?

6.2 Results

Data was analyzed using IBM-SPSS version 25 as well as R. Each dependent variable was analyzed using repeated-measures ANOVA with four driving aids conditions.

6.2.1 Average Forward Velocity

The analysis revealed a significant main effect of technology on average forward velocity, F (3, 24) = 4.35, MSE = 0.10, p =.01. Participants drove faster with the FFP technology (M = 7.37 SD =0.28) than with no aid technology, t (8) = -3.93 p =.004. Participants also drove faster with the Radar technology (M = 7.18 SD =0.31) than with no aid technology, t (8) = -2.46, p =.04. There was no difference between the IE technology and the no aid technology. There was also no difference between the FFP technology and Radar technology.

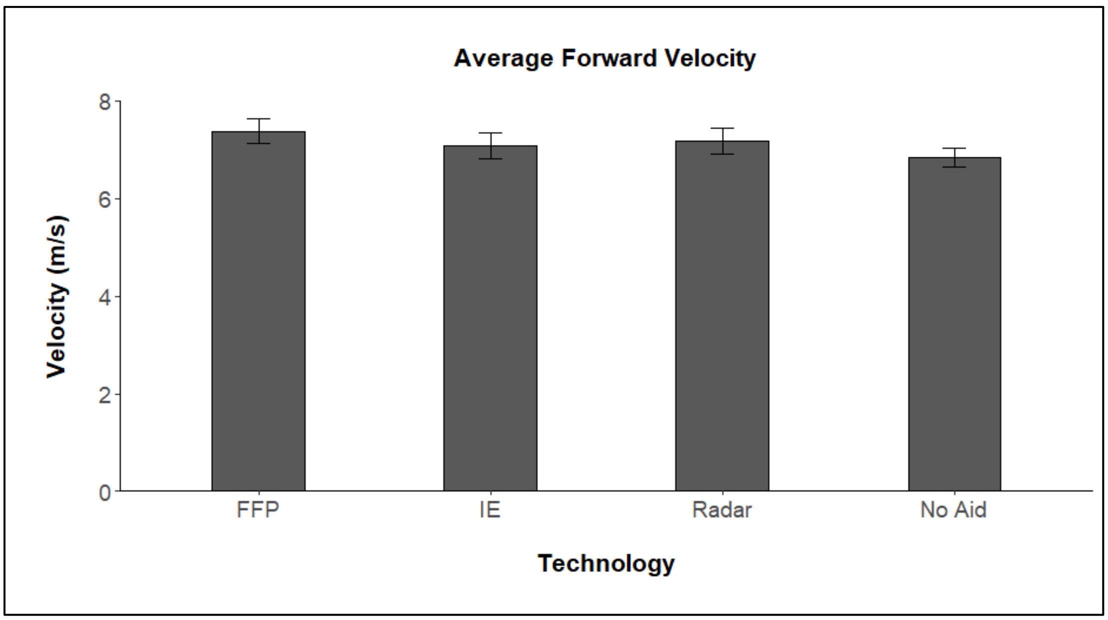

Figure 6.7: Average Forward Velocity for Each Driving Aid Condition.
Error bars represent within-subject 95% confidence intervals (Cousineau, 2005).

6.2.2 Standard Deviation of Forward Velocity

The effect of technology on standard deviation of forward velocity was not significant, F (3, 24) = 2.47, MSE = 0.03, p = .09. The average standard deviation of forward velocity across all conditions was 1.76 m/s.

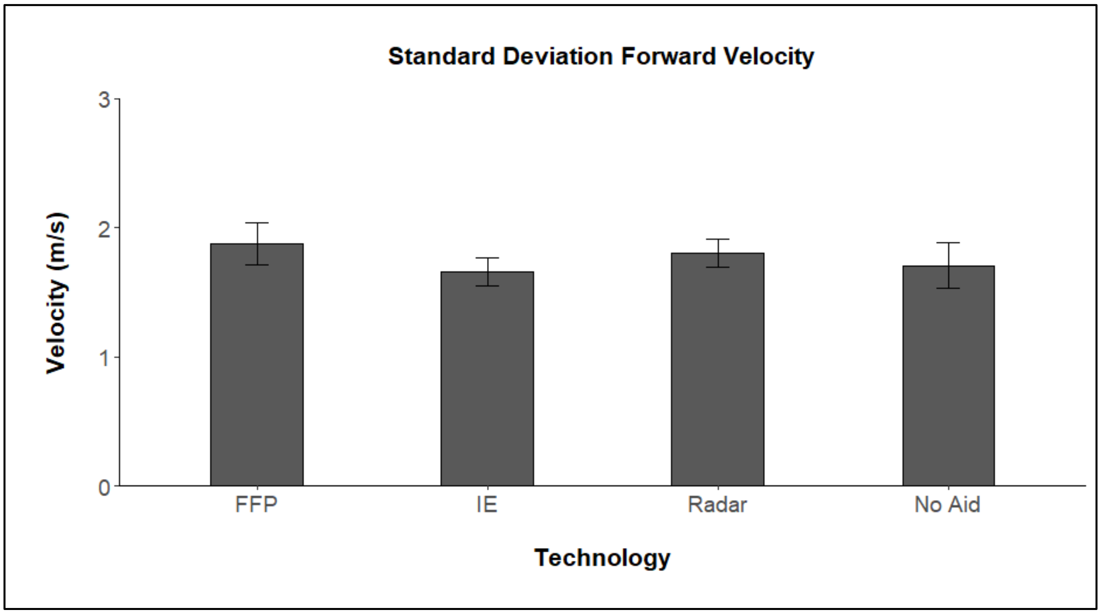

Figure 6.8: Standard Deviation Forward Velocity for Each Driving Aid Condition.

6.2.3 Percent Time Too Close

The effect of technology on percent time spent too close was not significant, F (3, 24) = 1.33, MSE = 34.16, p = .29. The average percent time too close across all conditions was 4.31% (SD=11.34%), but one sample t-test revealed that the percent time too close did not significantly differ from zero in any of the conditions (all ps > 0.21).

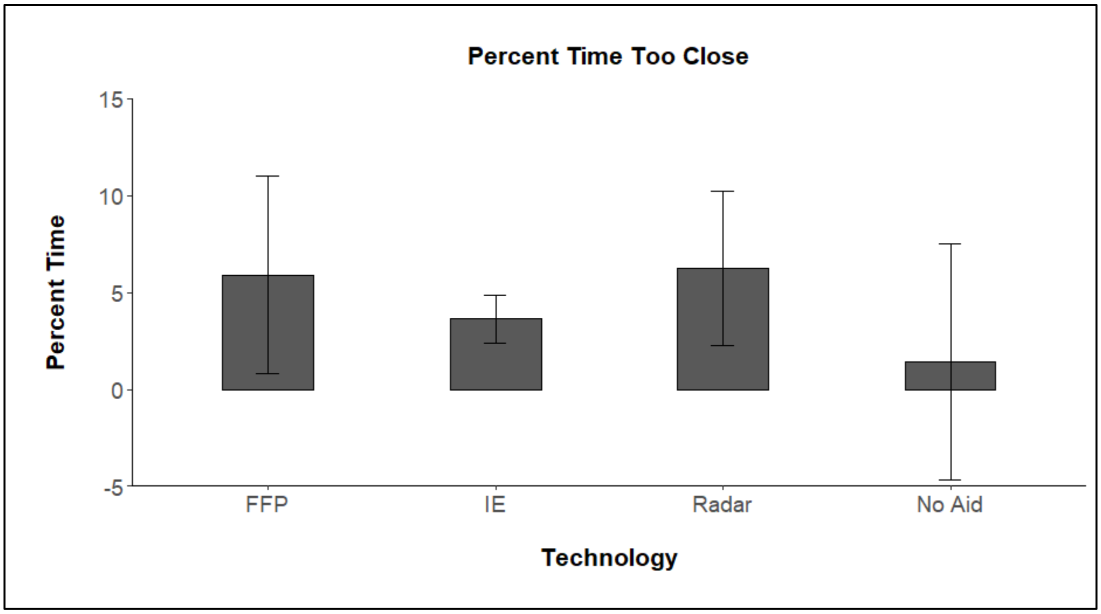

Figure 6.9: Percent Time Too Close for Each Driving Aid Condition.

6.2.4 Percent Time Too Far

The effect of technology on percent time spent too far was not significant, F (3, 24) = 0.17, MSE = 472.96, p = .92. The average percent time too far across all aids is 25.81% (SD=22.84%).

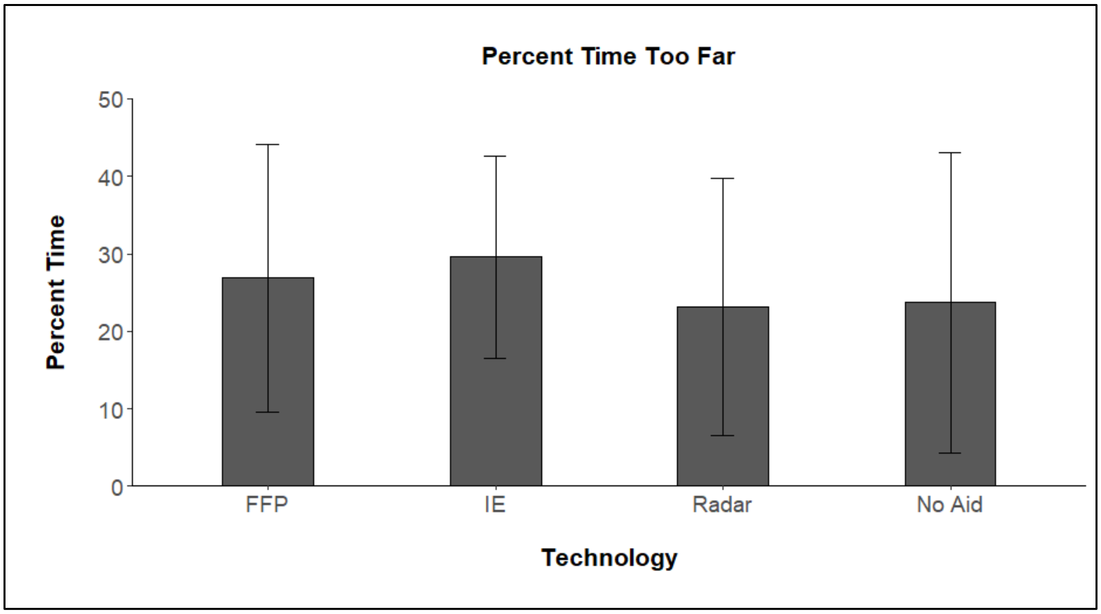

Figure 6.10: Percent Time Too Far for each Driving Aid Condition.

6.2.5 Percent Time Off Road

The effect of technology on percent time spent off road was not significant, F (3, 24) = 1.02, MSE =6.36, p = .40. Across all conditions, the percent time off road across all aids was 2.25%, (SD=2.81%).

There was a significant difference between percent time spent off road (being zero) and FFP (t (8) =3.35, p=.01), Radar (t (8) =2.90, p=.02), and no driving aid technology (t (8) = 2.56, p =.03.

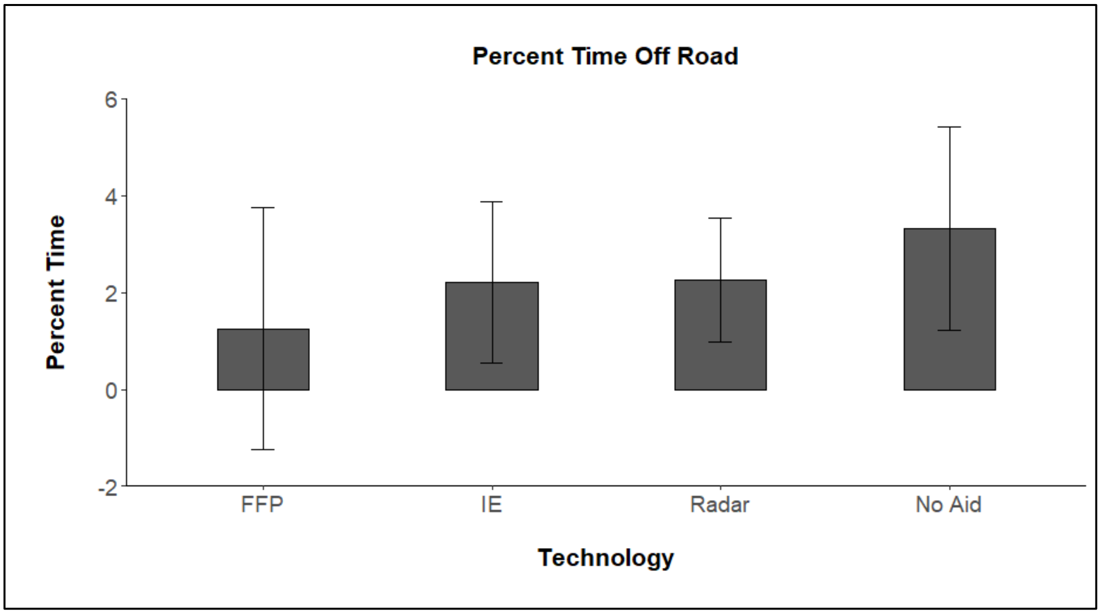

Figure 6.11: Percent Time Off Road for each Driving Aid Condition.

6.2.6 Average Lateral Distance between the Following Vehicle and Lead Vehicle

The effect of technology on average lateral distance between the following vehicle and lead vehicle was not significant, F (3, 24) = 0.34, *MSE* =0.133, p = .80. The average lateral distance between the following vehicle and lead vehicle across all driving aid conditions was 1.29 meters (SD=0.44).

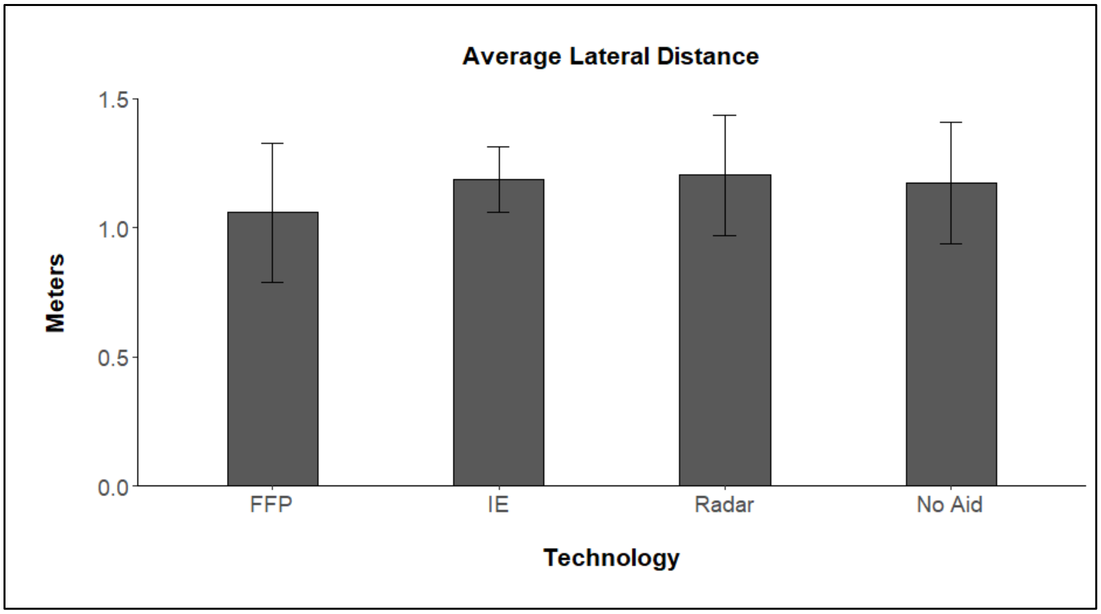

Figure 6.12: Average Lateral Distance with each Driving Aid Condition.

6.2.7 Standard Deviation of Lateral Distance between the Following Vehicle and Lead Vehicle

The effect of technology on standard deviation of lateral distance between the following vehicle and lead vehicle was not significant, F (3, 24) = 0.14, MSE =0.06, p = .96. The average standard deviation of lateral distance between the following vehicle and lead vehicle across all driving aids was 1.03 meters (SD=0.26).

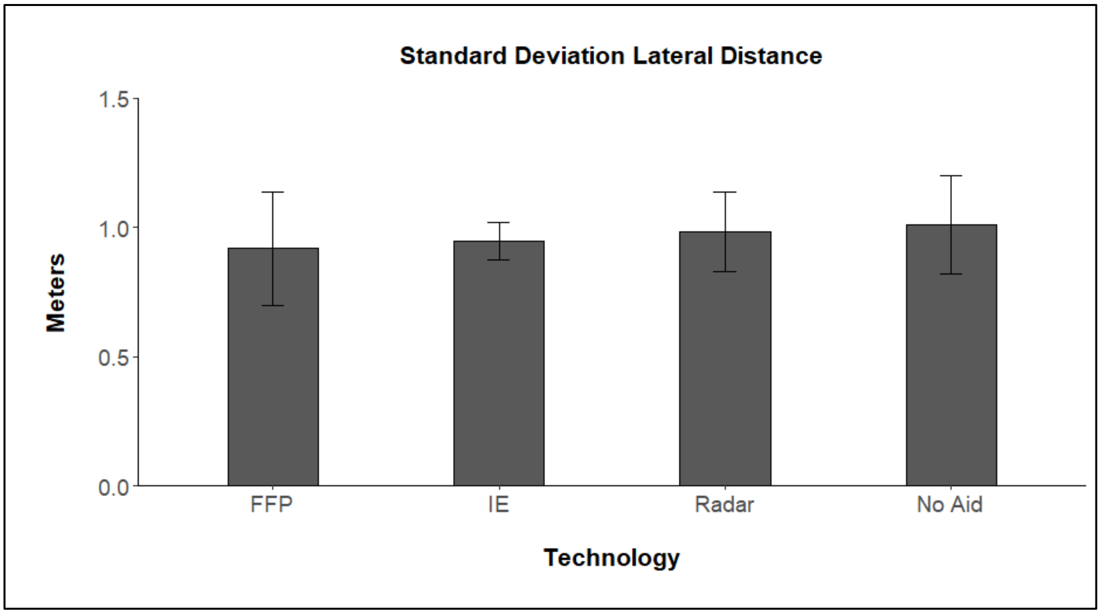

Figure 6.13: Standard Deviation Lateral Distance with Each Driving Aid Condition.

6.2.8 System Usability Scale (SUS)

SUS ratings, illustrated in Figure 6.15, were collected at the conclusion of the experiment for each of the three driving aids as well as the system as a whole. The effect of technology on SUS was significant, F (3, 24) = 5.18, MSE =170.83, p = .007. Participants rated the IE driving aid significantly more useable than the FFP (t [8] =-2.37, p = .05), Radar (t [8] = -3.23, p = .01), and the overall system (t [8] = 2.79, p = .02). This outcome shows that participants rated the IE driving aid as more usable in this type of scenario.

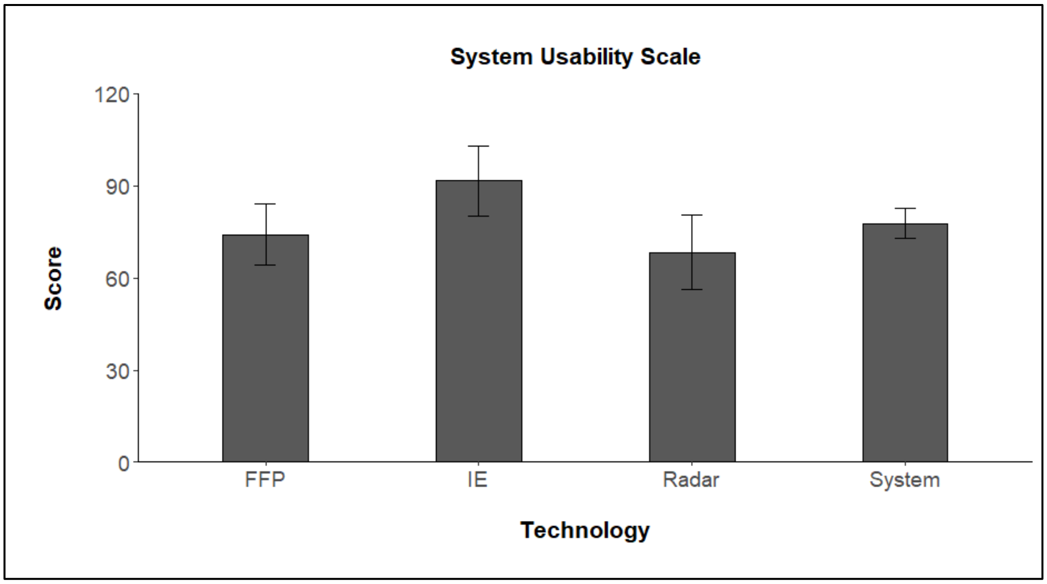

Figure 6.14: Average SUS Scores for each Driving aid and System.

6.2.9 General Questionnaire

The General Questionnaire was broken down into 12 questions that corresponded to six different categories: situational awareness, speed, spacing, lane keeping, threat detection, and system. The effect of technology on the six different question categories was not significant: Situational Awareness (F [2,16] = 1.11, p = .35, MSE = 0.52), Speed (F[2,16] = 0.36, p = .71, MSE = 0.56), System (F [2,16] = 1.90, p = .18, MSE = 1.58), Lane Keeping (F [2,16] = 1.85, p = .19, MSE = 0.98), and Threat Detection (F [2,16] = 1.55, p = .24, MSE = 1.01). Overall, the ratings were good across all conditions (See Appendix A for Questionnaire).

6.2.10 Single Ease Question (SEQ)

The effect of technology on Single Ease Question (SEQ) was not significant, F (3, 21) = 1.31, p = .30, MSE =0.54. The average score for all the driving aids was 6.56 on a seven-point scale, with 1 indicating very difficult and 7 meaning very easy, indicating that the participants thought the task was easy in all conditions.

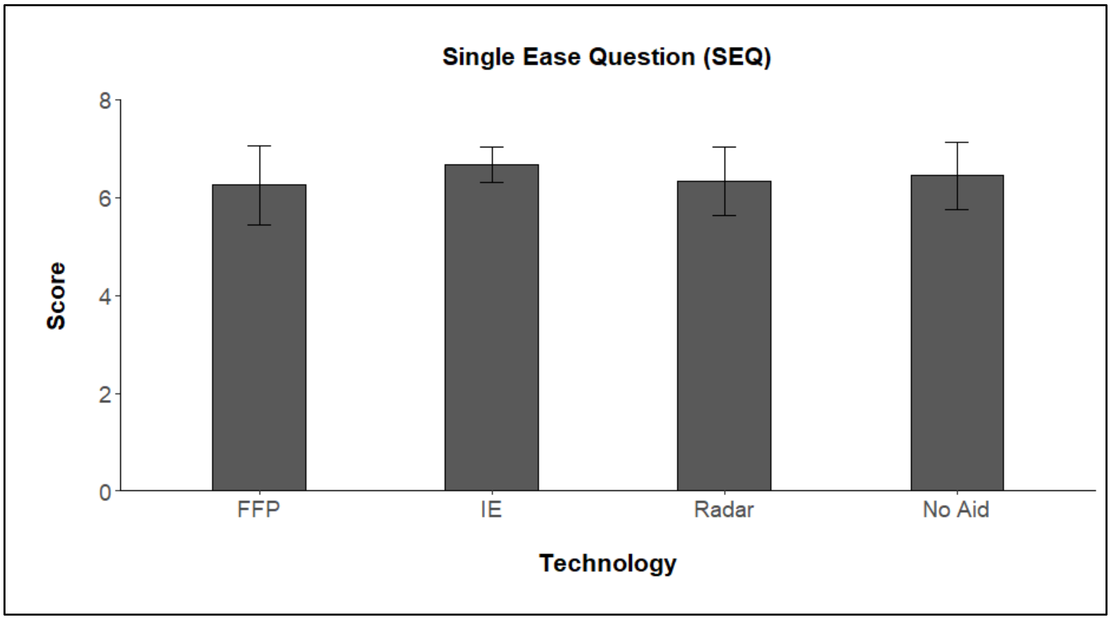

Figure 6.15: Single Ease Question.

6.2.11 Rating Scale for Mental Effort (SMEQ)

The effect of technology on Rating Scale for Mental Effort (SMEQ) was not significant, $F(3, 21) = 0.63$, $p = .60$, $MSE = 92.74$. The average score for all the aids was 8.13; overall, the score is low because the score could range from 0 (Not very hard to do) to 150 (Tremendously hard to do).

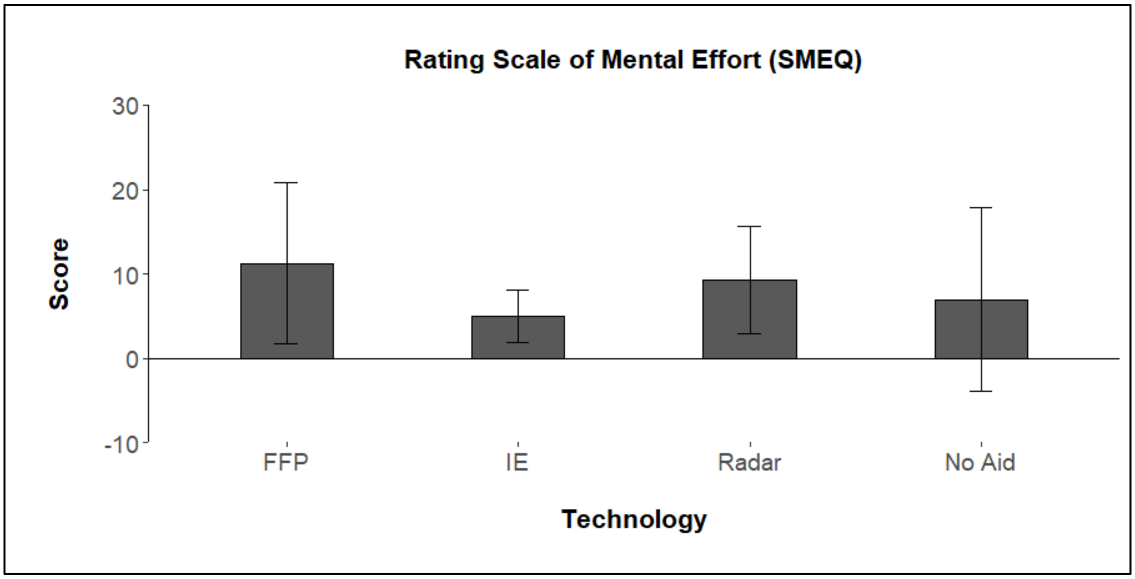

Figure 6.16: Rating Scale for Mental Effort (SMEQ).

6.3 Discussion

This was the first of two field tests with the implemented driving aids. The scenario and road type were realistic to what a Soldier would encounter. In this experiment, the FFP driving aid could be implemented and used in a convoy scenario. This experiment also gave the opportunity to implement the Radar driving aid and IE driving aid on the Stryker and to understand what the Soldiers thought of the different aids in this driving scenario.

While I hypothesized that the IE driving aid would increase average forward velocity relative to other aids, in contrast, both the FFP and Radar supported faster travel relative to the no aid condition. I also hypothesized that the FFP driving aid would best support safe convoy-following behavior. Participants were rarely too close but often way too far away, across all conditions. This would suggest that maybe the driving task was too easy or the DVE was not dense enough to cause a visual disturbance in regards to the location of the lead vehicle.

I hypothesized that the participants would rate driving aids as usable and workload would be reduced when using driving aids. Drivers rated the IE technology more usable than the FFP, Radar, and System. In terms of workload, there were no differences noted with each of the driving aids. The SMEQ scores across all conditions (low) also support the suggestion that the task was too easy.

The next field test builds off of this field experiment with a different scenario. In future studies, the execution of the data collection during runs needs to be monitored closely. There were some sets of data that needed to be eliminated from analysis due to false starts and quality errors.

7 DVE Field Test 2 with Prototype Driving Aids

Field Test 2, which occurred in March/April 2019, was the final experiment in the gDVE program. Just as in Field Test 1, an implemented drive-by-wire system was tested by having human operators drive a Stryker through obstacle courses under off-road field conditions with and without driving aids. In the previous field test, the Radar driving aid, IE driving aid, and FFP driving aid were compared in a convoy driving task, but in this field test, operators drove a Stryker through an obstacle course and the FFP was not tested. The IE driving aid is the same aid used in Field Test 1, and the Radar driving aid is the same driving aid used in Simulation Experiment 3 and in Field Test 1. This testing was being completed to test sensors and augmented reality aids designed to enhance driving under degraded conditions. In this field test experiment, the focus was on object detection, with the participants traversing an obstacle course with and without a DVE.

7.1 Methods

7.1.1 Participants

Twenty participants completed the experiment. All were U.S. Army Soldiers with Stryker training and driving experience. Participants were screened ahead of time to make sure they were in good health and were not prone to motion sickness. All participants were male and between 18 and 45 years of age.

7.1.2 Apparatus and Materials

7.1.2.1 Ground Padding

Metal padding was installed and used to cover the test site, which was approximately 300' x 50', as shown in Figure 7.1. This interlocking padding is traditionally used to create temporary air landing sites in the field, and it had two purposes: (a) it was used to efficiently mark the obstacle course set up and (b) it created a way to define a testing area for safety purposes.

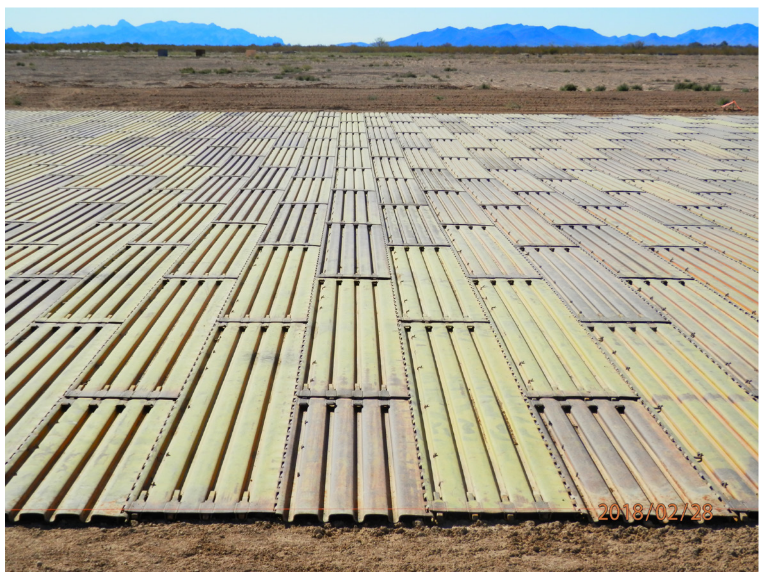

Figure 7.1: Metal Padding.

7.1.2.2 Tiller

Prior to blowing the dust, the ground soil surrounding the perimeter of the testing area was tilled. This ensured that the DVE was consistent. Figure 7.2 illustrates the tiller preparing the test site.

Figure 7.2: Tilling at Test Site.

7.1.2.3 Blown Air Dust and Sand System (BADSS)

Two levels of DVE were tested: no DVE (clear) and degraded (DVE). The no DVE was the default state of the test site with no disturbance to the ground and minimal airborne dust. Unlike the simulation studies that used fog as the DVE, the DVE visual environment was artificially generated, with airborne dust raised from natural ground at the test site by the operations of fans.

The BADSS is a semi-portable fan that moves dust that has been dispersed by tilling. The system, illustrated in Figure 7.3, generated the dust cloud needed for the dust condition. Two BADSS were moved via pickup truck and placed into position. Figure 7.4 shows the location of the two systems at the test site, but in general, they were positioned to propel dust in the direction opposite that which the participant vehicles were moving.

Figure 7.3: Blown Air Dust and Sand System (BADSS).

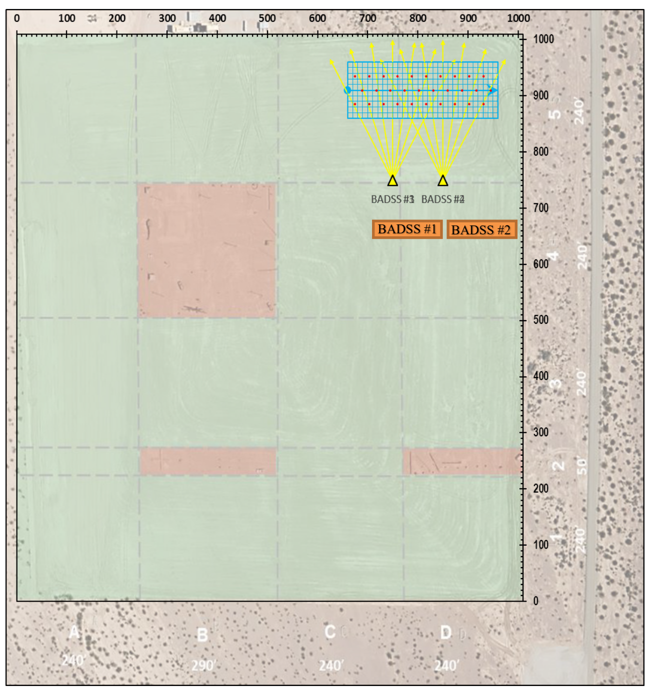

Figure 7.4: Test Site with BADSS Locations.

7.1.2.4 Terrain and Obstacle Course

There were 12 unique courses presented in the same sequence for all subjects. They were designed to be of comparable level of complexity, which was achieved by using mirror-reversal variations to maintain the same local and global density distributions. The obstacles consisted of Jersey Barriers with a weight sand bag placed on top. Figure 7.5 illustrates the Jersey Barriers that were used as the obstacles in testing.

Figure 7.5: Jersey Barriers Used as Obstacles

The obstacle routes illustrated were placed within the region of the dust cloud generated by the BADSS. Figure 7.6 illustrates the obstacle courses used in testing. A survey was done using Differential Global Positioning System (DGPS) on the test site to record the positions and vectors of the perimeter (where the metal padding ended) as well as the obstacle locations.

Figure 7.6: Course Layouts

7.1.2.5 Modified Stryker Vehicle

The experiment was conducted in a modified Stryker Infantry Carrier Vehicle (ICV) with an integrated gDVE mitigation system. The Mitigation system included a drive-by-wire system, image-processing improvement camera view, and Millimeter Wave Radar

(MMWR), with image augmentation overlays on the indirect driving screens to highlight potential obstacles. Figure 7.6 illustrated the Stryker Vehicle used for this experiment.

Figure 7.7: Stryker Vehicle with gDVE System Integrated.

7.1.2.6 Crewstation Configuration

The cab included a vehicle seat with a five-point harness, driving station (steering wheel and pedals), keyboard, and three touchscreen Z Micro Hydra 17” monitors. Figure 7.8 illustrates the yoke and pedals. Figure 7.8 illustrates the whole crewstation.

Figure 7.8: Yoke and Pedals.

Figure 7.9: Crewstation Configuration.

7.1.2.7 BAE Visual Sensor

The BAE Systems Sensor, used in Field Test 1, was used in this experiment. The BAE sensor system was again the baseline condition for the data analysis, and it was used with each one of the driving aids because it was integrated into the crewstation configuration.

7.1.2.8 Driving Aids

Radar Driving Aid. There were two aids tested in this experiment. The first aid was the Radar driving aid, with functionality and set-up identical to that of Field Test 1. An illustration of the Radar Aid highlighting potential obstacles is shown in Figure 7.10.

Figure 7.10: Radar driving aid in clear environment.

Image Enhancement Aid. The second aid was the Image Enhancement (IE) driving aid. The functionality and set up was exactly the same as in Field Test 1. Figure 7.11 illustrates the IE driving aid.

Figure 7.11: IE driving aid in clear environment with dust algorithm.

7.1.2.9 Questionnaires

Demographics Data Sheet. Similar to the simulation experiments, a demographics data sheet was used to record general information about the participants and their background. A copy of this data sheet is located in Appendix A.

Simulator Sickness Questionnaire. Similar to the simulation experiments and Field Test 1, the experimenter was ready to verbally administer the SSQ on an as-needed basis, but the SSQ did not need to be used in this experiment.

System Usability Scale (SUS). Similar to the simulation experiments and Field Test 1, the System Usability Scale was administered. The participants filled out the System Usability Scale (SUS) after every trial was completed.

NASA Task Load Index (TLX). Similar to the simulation experiments, the NASA Task Load Index (TLX) was administered after every trial. Participants filled out the TLX via hardcopy.

After-Action Review. An After-Action Review questionnaire was created specifically for this experiment. This allowed the recording of qualitative information about the participants' experience as related to the tasks performed in the study. A copy of the After-Action Review and its responses are located in Appendix A.

7.1.3 Design

This study employs a 3 (driving aid) x 2 (visibility) within-subject design. The three driving aid conditions included no driving aid, Radar, and IE. Each participant completed six trials, driving with no aid and with each of the two driving aids in each of the two DVE conditions (no DVE and DVE). The order of the six trials was counterbalanced across subjects according to a digram-balanced Latin-square design.

The dependent variables are: average forward velocity, standard deviation of forward velocity, number of obstacle collisions, obstacle avoidance distance, standard deviation of obstacle avoidance distance, average lateral distance, standard deviation of lateral distance, NASA TLX score, and System Usability Scale.

7.1.4 Procedure

The experiment took place at the Degraded Visual Environment (DVE) LZ Site in North Cibola, Arizona. Participants were briefed on the objectives of the experiment, and then they reviewed and completed the Informed Consent Form, the Simulator Sickness Questionnaire (SSQ), and the Demographics Data Sheet. Next, the experimenter briefed participants on the various surveys, driver's station, driving aids (Radar & IE), and safety features. Each participant then completed a 15-20-minute hands-on practice at driving the Stryker via the WMI using each driving aid under clear and degraded conditions. The participants drove through the obstacle course, which was configured uniquely for each trial. They were instructed to drive the course safely, maintain clearance around obstacles, and avoid hitting obstacles. Participants completed six trials, one in each of the experimental conditions, one time. Fifteen of the 20 participants completed each of the six conditions two times. Figure 7.12 illustrates a test run with dust on the course.

Figure 7.12: Test Run with Dust.

After each trial, participants completed the NASA TLX and SUS questionnaire. The experimenter was in the vehicle to monitor the driver for signs of motion sickness and administer the SSQ or terminate the session as needed. No participants reported motion sickness or other adverse effects. After the final trial, the participant completed an after-action review sheet and then was debriefed and released.

7.2 Results

Data were analyzed using IBM-SPSS version 25 and R. Each dependent variable was analyzed using two factor repeated-measures ANOVA with the visibility and driving aids as factors. A total of 20 Soldiers participated in the second field experiment, and data were analyzed on the first run of each participant. Data validation was completed to identify data quality issues with the datasets. Specifically, the data was checked to see if it satisfied two conditions. First, each dataset was checked to confirm that the Stryker drove within the geographical region that contained the test course. Second, each dataset needed to indicate that the Stryker initiated the trial from a stopped position and ended the trial at a stopped position. Three datasets, one run by one person, failed to meet the two conditions and were excluded from all analyses (all three datasets had the Stryker not showing movement).

Two additional participants were excluded from analysis of velocity-related dependent variable because of missing velocity data at either the start or end of several of their trials. In addition, three other trials with other participants were excluded due to missing velocity data.

7.2.1 Average Forward Velocity

The effect of technology on average forward velocity was not significant, F (2, 24) = 0.36, MSE =0.08, p = .70. The effect of visibility on average forward velocity was not significant, F (1, 12) = 3.52, MSE =0.15, p =. 09. The analysis revealed no significant interaction between technology and visibility, F (2, 34) = 0.10, MSE =0, p = .87. The means were virtually the same for each of the six conditions, approximately 2.05 m/s, but in all instances the no dust factor (2.08 m/s) was faster than the with dust factor (2.03 m/s), although not significant. Figure 7.13 illustrates the average forward velocity values.

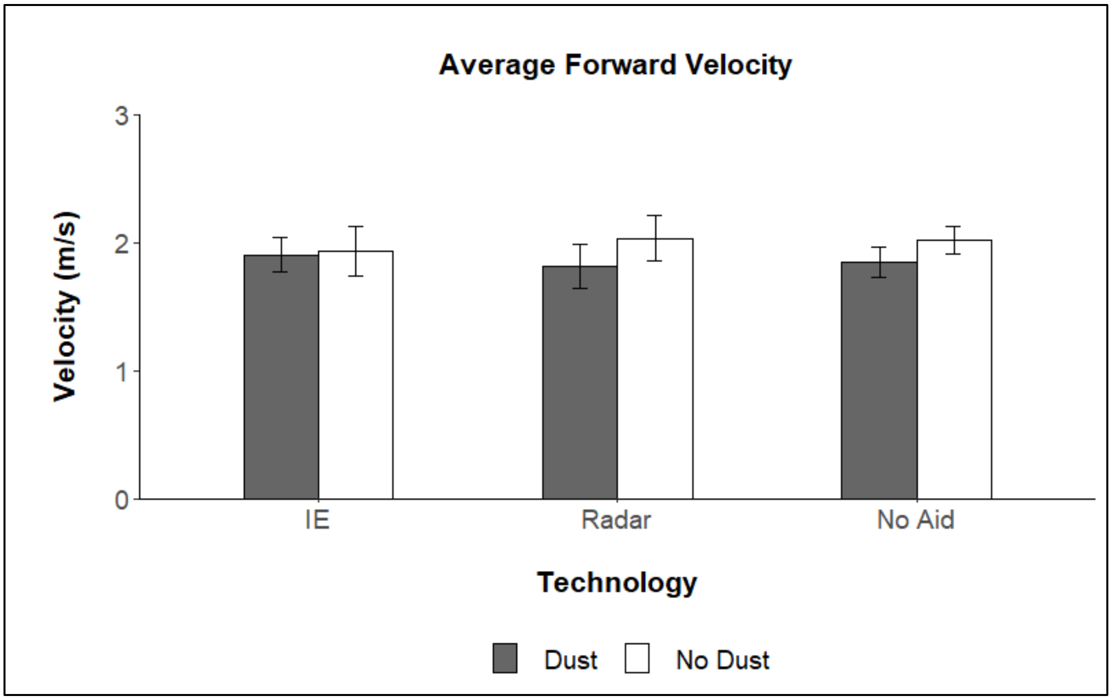

Figure 7.13: Average Forward Velocity for each Technology under the Dust and No Dust Condition. Error bars represent within-subject 95% confidence intervals (Cousineau, 2005).

7.2.2 Standard Deviation of Forward Velocity

The effect of technology on standard deviation of average forward velocity was not significant, F (2, 24) = 0.67, *MSE* =0.03, p = .52. The effect of visibility on standard deviation of average forward velocity was not significant, F (1, 12) = 1.25, *MSE* =0.03, p = .29. The analysis revealed no significant interaction between technology and visibility, F (2, 34) = 0.36, *MSE* =0.04, p = .70. The mean was the same for each of the six conditions, as illustrated in Figure 7.14.

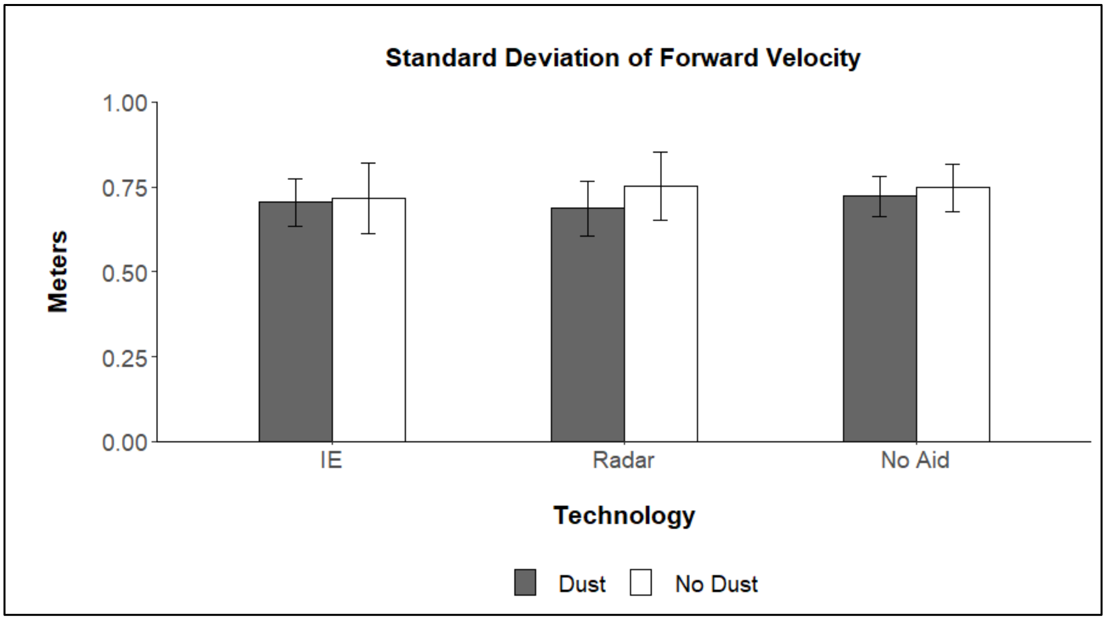

Figure 7.14: Standard Deviation of Forward Velocity for each Technology under the Dust and No Dust condition.

7.2.3 Collisions

As illustrated in Figure 7.15, there were relatively few collisions during the experiment. Across 117 runs, there were a total of 22 collisions; seven Soldiers were collision free across all of their runs. I had anticipated that there would be more collisions due to the DVE, so this was not expected. Neither the main effect of technology, F (2, 34) = 0.90, MSE =0.20, p = .42, nor the effect of visibility, F (1, 17) = 0.38, MSE =0.22, p = .55, was significant. Likewise, the analysis revealed no significant interaction between technology and visibility, F (2, 34) = 2.0, MSE =0.10, p = .15.

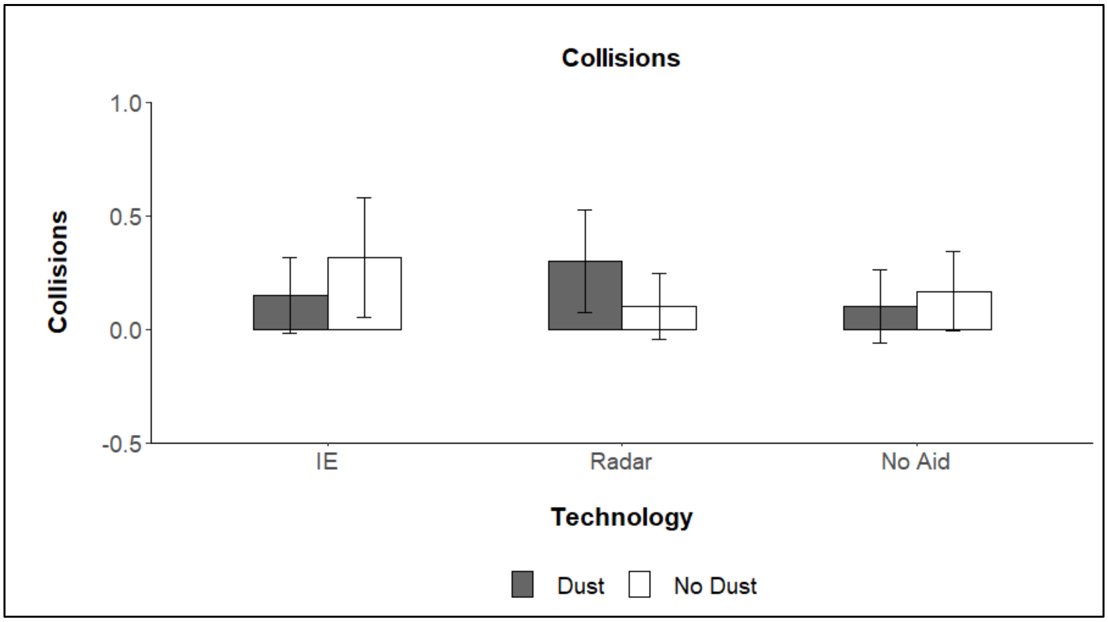

Figure 7.15: Collisions for each Technology under the Dust and No Dust Condition.

7.2.4 Average Minimum Distance from Vehicle to Obstacles

The average minimum distance from vehicle to obstacle was produced by computing the minimum distances between the vehicle and each of the nine obstacles in the trial and afterward, computing the average of these nine values. Across all conditions, the average minimum distance was 3.84 meters (SD=1.97), as illustrated in Figure 7.16. The effect of technology on average minimum distance was not significant, $F(2, 34) = 0.44$, $MSE = 5.06$, $p = .65$. The effect of visibility on average minimum distance was not significant, $F(1, 17) = 0.44$, $MSE = 4.28$, $p = .52$. The analysis revealed no significant interaction between technology and visibility, $F(2, 34) = 0.78$, $MSE = 3.72$, $p = .47$.

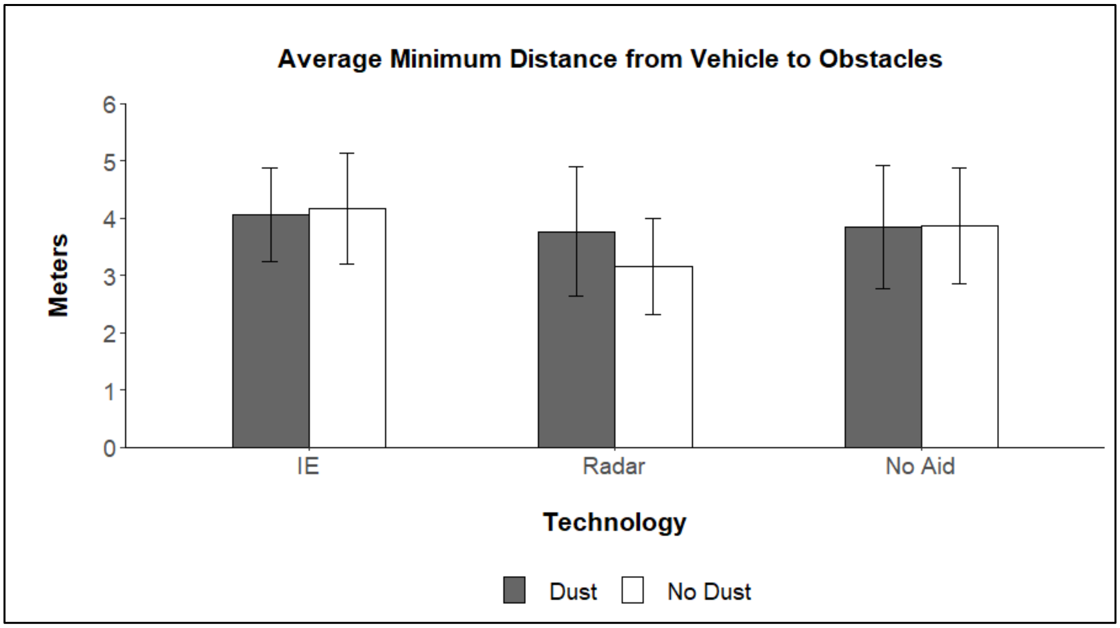

Figure 7.16: Average Minimum Distance from the Stryker to the Obstacles for each Technology under the Dust and No Dust Condition.

7.2.5 Standard Deviation of Minimum Distance from Vehicle to Obstacles

As illustrated in Figure 7.17, the standard deviation of minimum distance was consistent across conditions (M= 2.55; SD =0.49). Neither the effect of technology, on standard deviation of minimum distance from the Stryker to the obstacles was not significant, $F(2, 34) = 2.20$, $MSE = 0.25$, $p = .13$, nor the effect of visibility on standard deviation of minimum distance from the Stryker to the obstacles was not significant, $F(1, 17) = 0.51$, $MSE = 0.20$, $p = .49$. The analysis revealed no significant interaction between technology and visibility, $F(2, 34) = 0.34$, $MSE = 0.23$, $p = .72$.

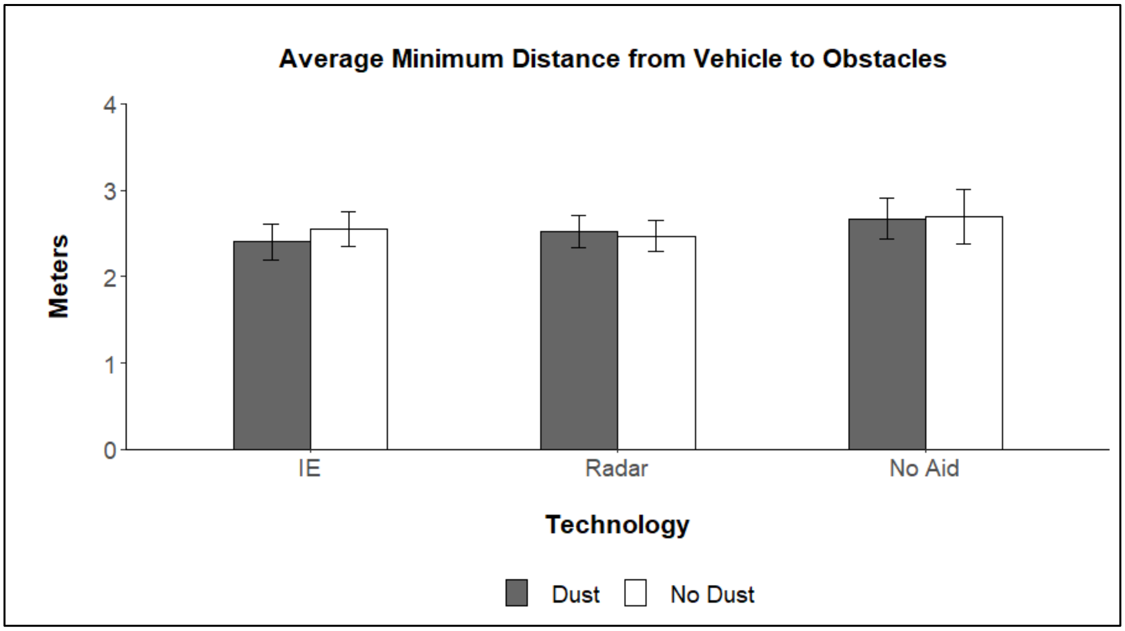

Figure 7.17: Average Minimum Distance from the Stryker to the Obstacles for each Technology under the Dust and No Dust Condition.

7.2.6 Average Lateral Distance

In the current task, the driver's route was defined by the path of the lead vehicle rather than by a road or lane lines. To calculate average lateral distance from the participant vehicle to the route, the centerline was determined by computing a sliding mean on the latitude and longitude coordinates of the participant vehicle, which is presumed to be operated by a trained driver who is directed to operate his vehicle over the centerline of the road. At each time step, this variable was identified by locating the 10 points from the center of the road that are closest to the current location of the following vehicle, obtaining a best-fit line through those 10 points, and then calculating the normal distance between the following vehicle and that best-fit line. The mean of these measurements was calculated to generate the dependent value.

The average lateral distance between the participant vehicle and the centerline was 0.08 meters (*SD* =0.02). As illustrated in Figure 7.18, this distance did not significantly vary across conditions. Neither technology, F (2, 34) = 1.34, *MSE* =0, p = .28, nor visibility, F (1, 17) = 0.03, *MSE* =0, p = .86, significantly affected the lateral distance between the participant vehicle and the centerline. Likewise, the analysis revealed no significant interaction between technology and visibility, F (2, 34) = 0.37, *MSE* =0, p = .69.

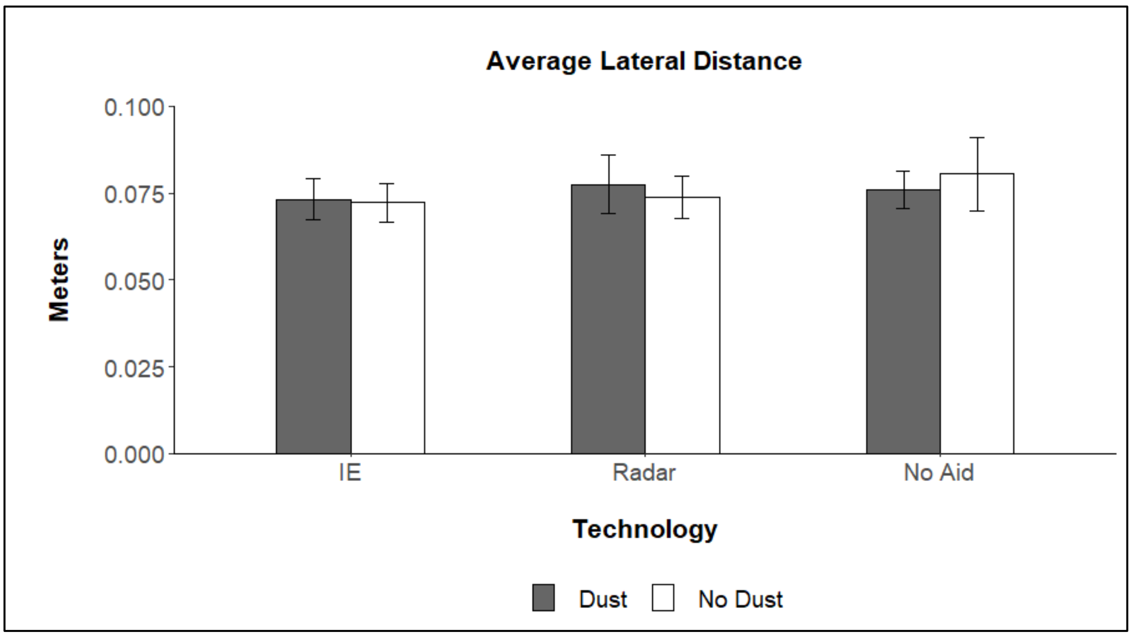

Figure 7.18: Average Lateral Distance between Stryker and Centerline of the road for each Technology under the Dust and No Dust Condition.

7.2.7 Standard Deviation of Lateral Distance

The standard deviation of lateral distance between the participant vehicle and the centerline was 0.87 meters (*SD* =0.02). As illustrated in Figure 7.19, this distance did not significantly vary across conditions. Neither technology, F (2, 34) =0.33, *MSE* =0, p = .72, nor visibility, F (1, 17) = 0.52, *MSE* =0, p = .48, significantly affected the standard deviation of lateral distance between the participant vehicle and the centerline. Likewise, the analysis revealed no significant interaction between technology and visibility, F (2, 34) = 0.14, MSE =0, p = .87.

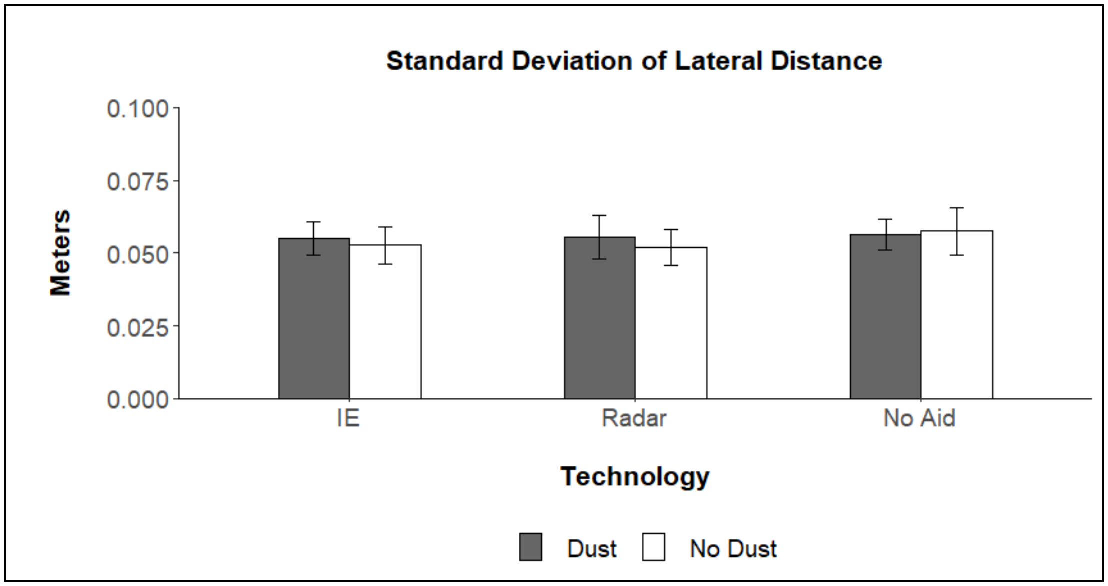

Figure 7.19: Standard Deviation of Lateral Distance between Stryker and Centerline of the road for each Technology under the Dust and No Dust Condition.

7.2.8 Workload

Consistent with the behavioral measures, the analysis revealed no significant effects of driving aid, F (2, 32) = 1.32, MSE = 62.65, p = .28, or visibility, F (1, 16) = 0.02, MSE = 34.62, p = .90, on ratings of workload. There was no significant interaction between driver aid and visibility, F (2, 36) = 0.58, MSE = 64.05, p = .57. The average workload score for all conditions was 17.56 (SD=16.60), as illustrated in Figure 7.20.

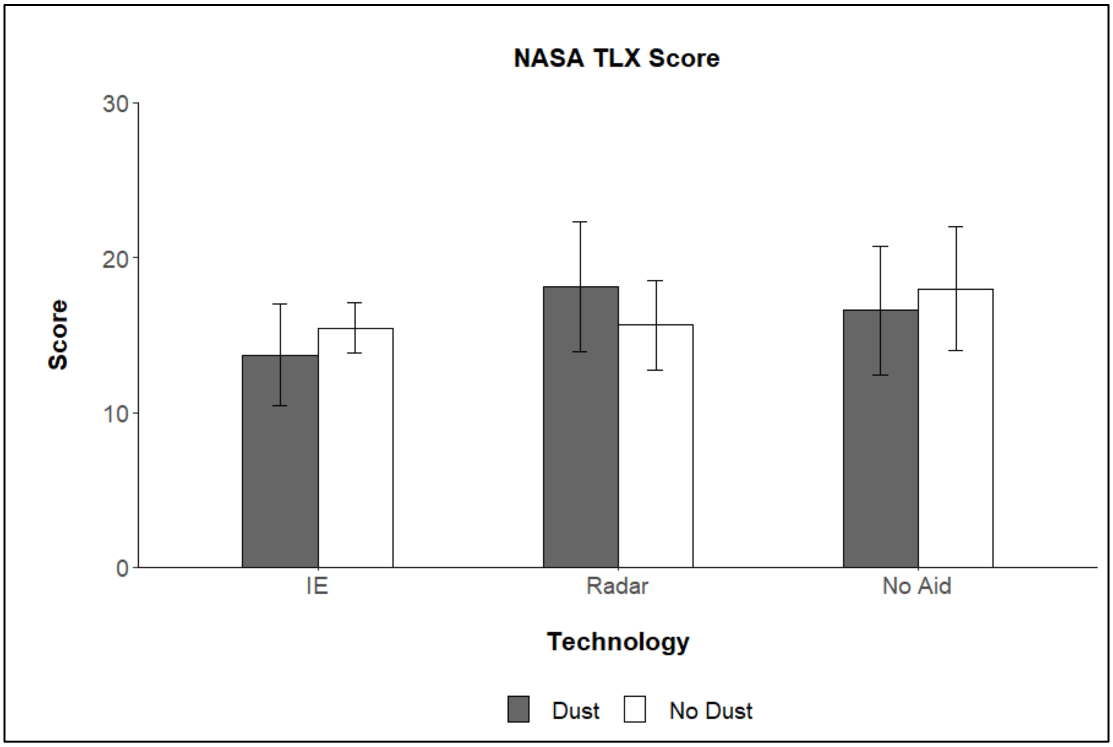

Figure 7.20: NASA TLX Score for each Technology under the Dust and No Dust Condition.

7.2.9 System Usability Scale

SUS ratings were collected at the conclusion of each trial for each of the six driving conditions. The average SUS rating for each of the six driving conditions was 72.73, as illustrated in Figure 7.21. With no aid, participants rated the system as 73.41, which corresponds to usable. Notably, the addition of the IE or Radar aid neither positively nor negatively affected ratings of system usability. The analysis did not reveal any significance due to technology, visibility, or interaction.

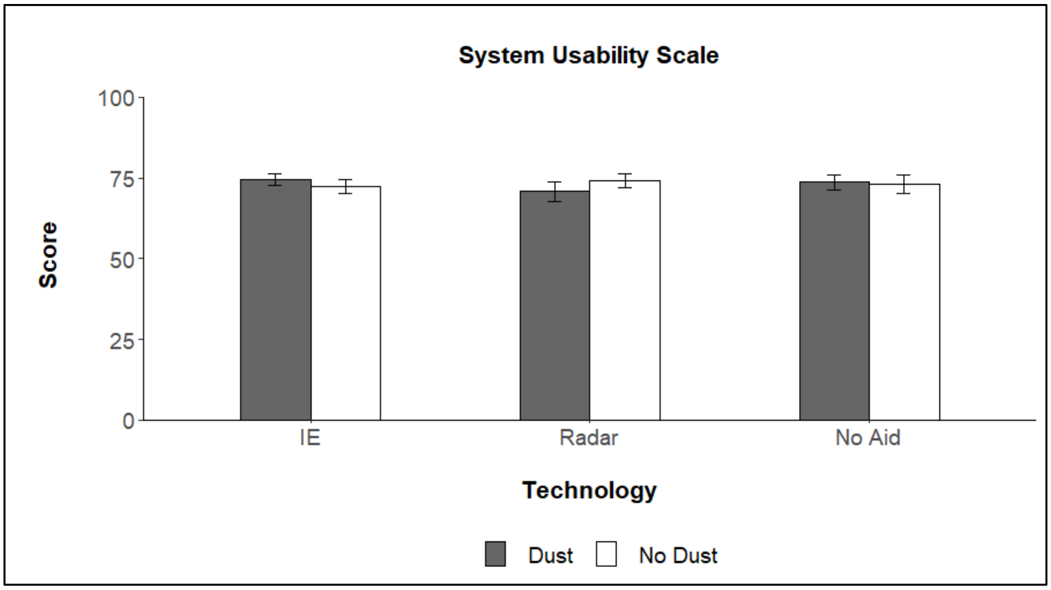

Figure 7.21: SUS Rating for each Technology under the Dust and No Dust Condition.

7.3 Discussion

I hypothesized that participants would drive more efficiently, quickly, and safely when using the IE and Radar aids in degraded visual environments. I expected that the Radar driving aid, in particular, would support obstacle avoidance and that the IE aid would especially support faster driving in DVEs. Across all measures, however, there were no benefits or costs associated with either aid.

One major factor was gDVE level, and it is possible that issues related to gDVE led to insignificant results. Every effort was made to maintain consistent levels of dust within the dust condition runs, but from observations made at the test site, it was noted that the amount and timing of dust during those trials varied. For example, in certain runs, the dust generated by the BADSS units would be very dense in the correct location, but then the dust would dissipate such that there was minimal difference between the dust and non-dust conditions. Within the after-action review, numerous participants had concerns over the amount of dust generated and the lack of DVE. Drivers did not perform differently in the no aid condition in DVE and no DVE. This suggests that the DVE was not dense enough to require the use of an aid.

Another potential issue was that the baseline gDVE sensor was much better at seeing through dust than the Driver Vision Enhancer currently used. Due to safety restrictions, the participants were not able to drive with a Driver Vision Enhancer. In the after-action review when comparing the gDVE system to the Driver's Vision Enhancer, all the participants strongly preferred the gDVE system. The driver visual enhancer is a step up compared to gDVE, and several participants complained about the DVE's lack of sight around the vehicle, which is solved with the new gDVE. This would suggest that the gDVE system and driving aids do in fact provide a benefit, if we were able to compare performance with the Driver Vision Enhancer.

More experiments need to be run to find the root cause of these results. Designing an experiment that relies on the consistent generation of dust in an open environment is extremely difficult. One suggestion for future experimentation is to add more BADSS. This would help ensure a denser cloud of dust. Another suggestion would be to make the obstacle course more difficult, as the lack of collisions it suggests that the course was potentially too easy. Due to the complexities of field test experiments with dust generation, these types of tests might better rely on subjective feedback and surveys instead of objective component measurements.

8 General Discussion

Degraded visual environments have not been studied in the context of military ground vehicles. The work of the gDVE program introduced technologies that have the potential to provide a safer, more efficient way to operate ground vehicles on the battlefield in degraded visual environments. This research contributes to understanding how Soldiers interact with this new technology and the overall impact of implementing driving aids in degraded visual environments.

The current research program used a combination of simulator-based experiments and field testing to investigate Soldier performance with the driving aids. Much of the testing that occurred was competed in simulation which gave a consistent degraded environment in comparison to field testing. Some of the driving tasks were unsafe to test in the field necessitating simulator experiments. The practicality of simulation testing not only helped test tasks and more extreme DVE conditions that could not yet be tested in the field, it also provided the opportunity to test the implementation and integration of the driving aid technologies.

8.1 Workload and System Usability Scale

Across all studies, usability and workload were assessed for each of the driving aids. In Figure 8.1, all the SUS scores are grouped by technology with the different experiments color coded. These SUS scores were collapsed across all levels of DVE because the DVEs were not consistent across all the experiments. In general, most of the technologies were rated usable by the SUS scale with the average being 73.5 on a scale of 1 to 100 with 100 being the most usable. The lowest rated technology was the Go/NoGo driving aid, with a score of 48, and the highest rated technology was the Image Enhancement driving aid, with a score of 91.7. These findings are consistent with participants' comments in the after-action review. Participants made the most negative comments about the Go/NoGo driving aid and the most positive comments about the IE driving aid. It is important to note that scores in the 70s and 80s, although promising, do not guarantee high acceptability in the field (Bangor, Kortum & Miller, 2008).

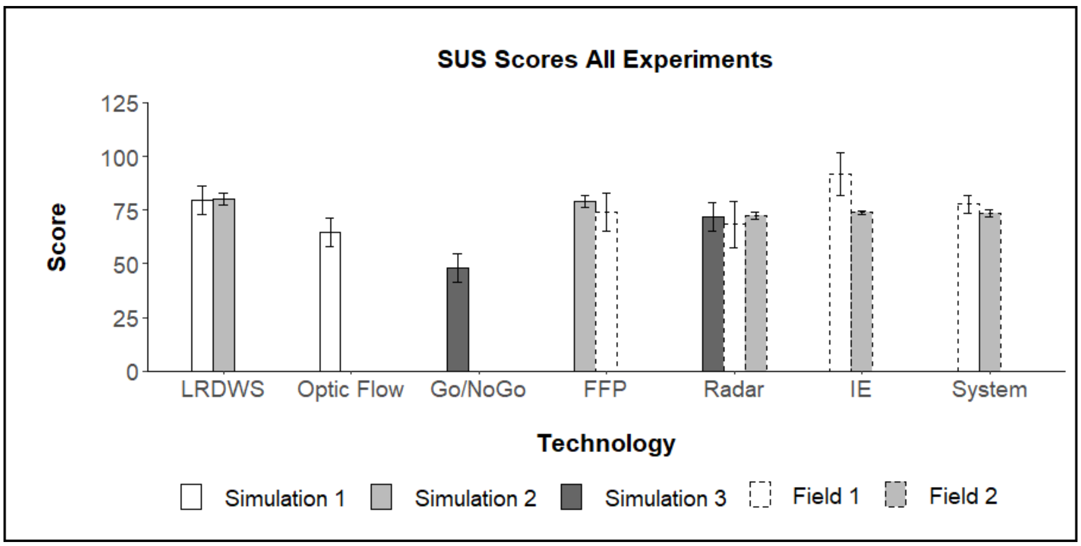

Figure 8.1: SUS Scores from all experiments.

NASA TLX scores were collected across all the experiments except Field Test 1 (Scale for Mental Effort (SMEQ) was collected). In Figure 8.2, all the workload scores are grouped by technology with the different experiments color coded. These TLX scores, like the SUS scores, were collapsed across all levels of DVE because the DVEs were not consistent across all the experiments. In general, the average workload across all technologies and all experiments was 27.6 (out of 100 with 100 being the highest workload) which is overall low. The highest workload score occurred with no driving aid technology, with a score of 35.6 in Simulation Experiment 3. This finding is consistent with the fact that Simulation Experiment 3 had the most degradation in terms of DVE. Simulation Experiments 1 and 2 tested a lower level of DVE, and in the field tests, producing a consistent dust cloud was a struggle. The lowest workload score of 14.33 was for the IE driving aid. This is not surprising because the IE driving aid did receive the most positive comments in the after-action review located in Appendix A.

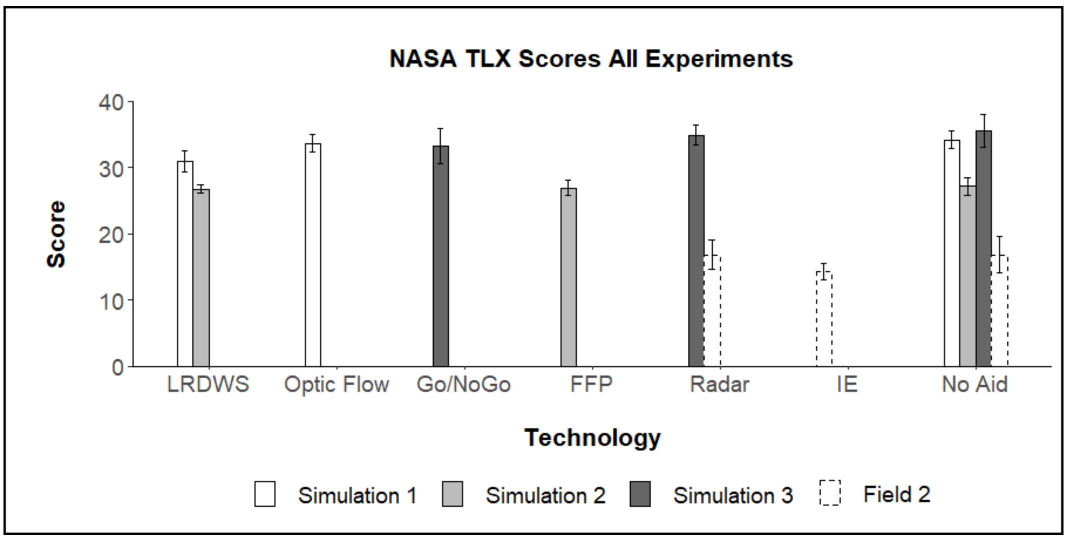

Figure 8.2: Combined NASA TLX Scores

Egar (2012) stated that one of the greatest challenges for any type of technology used for DVE activities was to provide the information the driver needs while maintaining a low workload. When designing the driving aids, this was one of the top concerns. Based on the TLX results, workload was not increased due to the additional technology. Consistently across all the experiments, driving without an aid elicited the highest workload scores. Knowing this, using the aids, in general, decreases perceptions of workload. The workload scores of the Field Test 2 Experiment were quite a bit lower than those of the simulation experiments. This difference may have existed because the dust cloud was not consistent enough on the course, and therefore, the task was not hard enough, which was reflected in the TLX scores. The after-action review comments suggest just that, as multiple participants mentioned that the dust cloud was not consistent.

8.2 Human Factors Issues

During simulator-based testing, a few human factors issues emerged. The first issue was with how the Radar Driving aid was implemented. In Simulation Experiment 3, without a driving aid, participants had more collisions in the *extreme* DVE than the *moderate* DVE. In this instance, the driving aids helped with driving in the highest degraded visual environments. Even with this performance benefit, in the after-action review, multiple participants reported that the Radar driving aid failed to indicate some obstacles and committed false positives. This feedback is noteworthy because there were no false positives in experiment 3. Participant comments, therefore, revealed a potential human-factors design flaw. Within the Rader aid display, all obstacles were indicated at ground level, regardless of their location within the real world. Although many obstacles were located at ground level, not all of them were. For example, the radar system detected the presence of overhead wires, which the Radar aid indicated at road level. Although this was explained to participants at the beginning of the experiment, participant comments suggest that this was confusing. Better instructions to the driver may help, ideally the mapping between hazards and cues should be clear and not require the operator to make inferences about whether a cue is representing a target at that location or above it. Further human factors research should be continued to determine the best way to represent hazards. This particular issue emphasized why considering human factors is so vital when designing and implementing driving aids. Driving aids are useless if they present data in a way in that leads the operator to believe the system is committing an error.

Simulation 3 revealed another human factor issue. I hypothesized that the Radar's visual guides would be particularly beneficial in helping drivers avoid hitting objects. Although this prediction held in *severe* and *extreme* conditions, the number of collisions was actually greatest in the *moderate* DVE Conditions (the lowest level DVE in this experiment). This finding suggests that the Radar driving aid's obstacle indicators may have actually been distracting when the obstacles were not completely occluded. This finding is consistent with Yeh and Wickens, (2001) who found that augmented reality displays can increase attentional tunneling and results in the lower rates of detection.

Driving speed (or forward velocity) was a key measure of driving performance in degraded visual environments. Ideally, a driving aid should allow a driver to drive as quickly in smoke, fog, or dust as he or she would in clear conditions. In Simulation Experiment 1, with the LDWS driving aid, drivers were able to maintain similar speeds across visibility conditions, which implies there was a performance benefit to this driving aid. To make the DVE in the simulation experiment more realistic, the level of degradation was increase in the third simulation experiment. Doing so revealed that drivers slowed down at the highest level of DVE. In contrast, in the third simulation experiment, drivers reduced their speed with all technology conditions in the *extreme* DVE condition (highest degradation) and drivers were able to maintain similar speeds in the *extreme* visibility condition with all technologies. The higher degradation may have led to this finding. Further study in performance tradeoffs would help understand the implications of the driving aids and their impact on safe travel in degraded visual environments.

Overall, the simulator-based testing revealed important human factors issues and yielded insights in to how the technologies affected driver performance, workload, and perceptions of system usability. The field tests, in contrast, didn't yield as many useful insights. The field tests didn't reveal any costs for using the aids, but also didn't reveal any benefits; unfortunately, it appears that the DVE used in field testing didn't sufficiently degrade visibility to elicit performance decrements. In the no aid condition, for example, no differences in performance were observed between the no DVE and DVE condition, indicating that the DVE wasn't extreme enough context for testing the utility of the aids. This limited my ability to answer if any performance benefits observed in the driving simulator scale up to the field test experiments.

8.3 Comparison of Aids

The current project tested six driving aids over a series of five studies. Figure 8.3 synthesizes the findings for each driving aid in order of perceived performance, utility, and preference. The Go/No Go Technology had the lowest usability scores and no documented performance benefits; however, this data should be cautiously interpreted as this finding may be driven by the scenarios used in the current studies which did not require the driver to traverse difficult terrain. Perhaps reflecting this, participants were very critical of this technology in the after-action review and indicated that this aid was “useless” and “distracting”. It is possible that, effects would emerge in future testing with more extreme unimproved road scenarios.

Only tested in simulation, the Optic Flow Enhancer driving aid had a lower usability score and a higher workload rating than the LRDWS driving aid. Although the LRDWS driving aid supported faster driving, lower workload and higher usability than the Optic Flow Enhancer driving aid, this aid can only be used on improved roads. There were also participant complaints about the implementation of the audio and visual feedback including comments about the system being overbearing and unnecessary.

Among the more accepted driving aids, the Friendly Force Position aid was designed for convoy scenarios and supported faster driving in the field with generally had high usability scores, but received mixed reviews in the after-action review with participants disliking its utility and noting that it was “distracting”. These findings are limited due to simulation experiment 2’s data being excluded from analysis and further work is needed to examine the utility of the FFP in convoy situations within more extreme DVE conditions.

The Radar driving aid supported faster driving in the field and was rated as more usable than the Go/No Go driving aid. This aid is relevant in many contexts (improved and unimproved roads), but as noted earlier this aid will require further research to resolve implementation issues. Research should be continued to determine the best way to represent hazards with this driving aid.

Lastly, the Image Enhancement aid had no documented performance benefits or costs, but was rated more usable than the Radar driving aid and the FFP. In the after-action review this aid had a general acceptance among the participants in the field tests and was a key part of the overall gDVE system.

Go No/Go (Sim 3)

- Lowest Usability Scores
- No documented performance benefits
- Very critical comments in AAR

Optic Flow Enhancer (Sim 1)

- No documented performance benefits
- Lower usability score and higher workload than the LRDWS

LRDWS (Sim 1 & 2)

- Supported faster driving than optic flow
- Higher usability score and lower workload than OFE
- Driver complaints about implementation of audio/visual feedback
- Aid only relevant in improved road conditions.

Friendly Force Position (Sim 2 & Field 1)

- Limited conclusions due to Sim 2
- Supported faster driving in the field
- Generally high usability score in simulator and field test
- Mixed reviews in AAR (Utility and distraction)

Radar (Sim 3, Field 1 & Field 2)

- Relevant in many contexts
- Rated more usability than Go/NoGo
- Supported faster driving in the field
- AAR indicated several implementation issues that require research

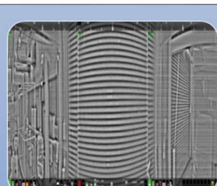

Image Enhancement (Field 1 & 2)

- Highest Usability in Field Test 1
- No documented performance benefits or costs
- AAR indicated general acceptance of the aid

Figure 8.3: Driving Aid Comparison.

8.4 Limitations and Recommendations for Future Research

Driving responses in degraded visual environments can be examined through different approaches: questionnaires, driving simulators experiments, and field testing. Designing driving aids for military vehicles is dependent on a system that Soldiers will utilize. Soldiers need to be given more opportunity to provide feedback so the driving aids can be refined and optimized for realistic scenarios to provide usability and situational awareness.

The current work employed a mix of both simulation and field test experiments. Simulator testing is an important step in the R&D process as it provides an opportunity to more rapidly iterate the design of the aids and to test them in a safe environment. Field Testing in DVEs is expensive, time consuming, and can put Soldiers at undue risk if the technologies have not been sufficiently tested and at the right readiness levels. The Army puts a higher value on data generated in field tests, but even when field tests are deemed safe, they are far more challenging to execute than the simulator experiments. The current project represents one of the first known gDVE field tests with generated dust clouds. Despite careful planning and pilot testing, the dust cloud generated in the field tests was difficult to maintain. In the real-world testing, the weather cannot be controlled. Although we did not have rain during our testing, this could have a significant impact on testing. Wind speed and wind directions can also affect the ability to create consistent dust clouds. Inconsistencies in the dust cloud may have made the courses too easy and limited our ability to assess performance and workload in extremely degraded visual environments and under high levels of workload. This is a methodological issue that should be addressed in the future to ensure more consistent, degraded visibility. One possibility would be to add more fans to increase the area and intensity of the dust cloud. Exact fan configurations would have to be investigated. Another possibility would be to place some sort of filter over the camera feed inside the vehicle that would give the illusion of a DVE and force the drivers to rely on sensor data. Designing experiments that are more difficult and realistic for participants to execute is imperative for eliciting useful performance measures to guide the design process.

Follow-up work should include further refinement and testing of the driving aids in degraded visual environments. Specifically, future work should target the human factors issues uncovered in the current project. One focus is on the symbology the aids used and how obstacles should be presented when designing individual displays. Also, the Radar driving aid should be redesigned to better represent the location of hazards. False positives degrade the reliability of an in-vehicle warning system, and driver behavior is influenced by them. Drivers may start to ignore the Radar driving aid due to mistrust and may consequently miss potential hazards. Real world systems will not be perfect and they will have misses and false alarms. Accordingly, future work should examine how to calibrate the Radar driving aid, guided by findings from the empirical literature on how false alarms and misses influence operator trust. Another human factor issue to address is in low levels of visibility when using the Radar driving aid, there were actually more collisions potentially caused by attentional tunneling. This exactly experiment should be re-run to see if the effect is replicated. If so, future work should determine whether aids can or should be disabled in clear visibility settings and whether or not that should be automatic or under the control of the drivers.

Although the field tests didn't yield strong performance measures, the after-action reviews did suggest that drivers were accepting of the gDVE system. When asked to compare the Drivers Visual Enhancer System to the gDVE system, all comments toward the gDVE system were positive. This is promising, especially for an initial testing. The current studies implemented numerous driving aids into a Stryker vehicle for the first time. Like any engineering effort, multiple iterations and implementations should be pursued to effectively design driving aids that help performance and lower workload in degraded visual environments. In the future, a more human-centered design process must be pursued to optimize the human-system interaction and to ensure that the benefits of the driving aids are realized without unintended performance decrements.

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A Appendices

A.1 Questionnaires

A.1.1 Participant Data Sheet Used in Simulation Experiment 1, 2, and 3

PARTICIPANT DATA SHEET

Participant ID: ____ Project #__________ Date: __________

1. MOS: _______	2. AGE: ____	3. SEX: ☐ Male ☐ Female	4. EDUCATION: ____ years

5. What is your CURRENT ROLE or job? ______________________________

6. How many YEARS OF EXPERIENCE do you have in this role? ____years ____months

7. How many YEARS OF EXPERIENCE do you have with the following?

Driving a HMMWV or civilian vehicle (incl. jeeps/vans/pickups)?	____years	____months
Driving a military vehicle (other than HMMWV) or a large commercial truck (other than vans/pickups)?	____years	____months
Using a "Driving Aid" (e.g. GPS Navigation, Lane Departure System, Crash Avoidance System)?	____years	____months
Performing "indirect driving" (e.g. driving via vision blocks, NVG, EO/IR)?	____years	____months
Operating a Driving Simulator?	____years	____months
Flight simulators, virtual reality, 3D games, etc.?	____years	____months

8. Do you have a COMMERCIAL DRIVER'S LICENSE? ☐ No ☐ Yes

If "Yes" please circle any of the following that apply:

Class:	A B C
Endorsement:	P H M N T X L S
Restriction:	B C D E F G K O

9. Do you often get MOTION SICKNESS? ☐ No ☐ Yes *If "Yes", please tell the experimenter.*

10. Do you have any form of COLOR-BLINDNESS? ☐ No ☐ Yes *If "Yes", please tell the experimenter.*

11. Do you have any VISUAL PROBLEMS that glasses or contacts can't correct?

☐ No ☐ Yes *If "Yes", please tell the experimenter.*

12. HANDEDNESS: ☐ Right-handed ☐ Left-handed ☐ Ambidextrous/other

A.1.2 Demographic Questionnaire in Simulation Experiment 1, 2, 3 and Field Test 2

GENERAL INFORMATION

1-4	**Age**:	**Gender**:	**Handedness**:	**Height**:

5 How long ago was your most recent **eye exam**? (Check one)

□ 6 months □ 1 year □ 2 years □ 4 years □ Longer

6 Do you have any of the following? (Check all that apply)

□ Astigmatism □ Farsighted
□ Nearsighted □ Other: ____________

7 Do you have corrected vision?

□ None □ Glasses □ Contact lenses

If so, do they correct for items listed in question 6 above? □ No □ Yes

8 Do you have any **hearing loss** or other hearing impairments?

□ No □ Yes If Yes, please explain: ________________________________

9 Please rate your past experience with **MOTION SICKNESS** - a variety of symptoms including drowsiness, sweating, nausea and vomiting induced **as a result of motion** (e.g., sea sickness, car sickness, carnival rides, etc.).

□ None □ Mild □ Moderate □ Severe

10 Please rate your past experience with **SIMULATOR SICKNESS** - a variety of symptoms similar to those seen in motion sickness, however they are **caused by a simulation** or a video/computer game.

□ None □ Mild □ Moderate □ Severe

MILITARY EXPERIENCE

11-12	What is your **MOS**?	How long have you been in the military? Years: Months:
13-14	What is your **rank**?	**Time** in grade (rank)? Years: Months:

15 Please list all **combat deployments** (Iraq, Afghanistan, etc.) and the length (Years / Months) of each.

16 Do you have operational experience in **complex urban terrain**?

□ No □ Yes If yes, where: ________________________

17 Do you have any experience with **scanning tasks** (e.g., searching for targets)?

□ No □ Yes If yes, please explain: ______________________________

18 Have you ever conducted **security patrols** in **complex urban terrain**?

□ No □ Yes If yes, where: ____________________________________

19 Have you ever used **camera systems** to conduct **local security**?

□ No □ Yes If yes, which systems: _________________________________

EDUCATIONAL EXPERIENCE

20 What is your **highest level** of education received? (Check one)

▫	▫	▫	▫	▫	▫
HS/GED	some college	BA/BS	MA/MS	PhD	other:

If applicable, what **area** is your degree in? ___________________________________

DRIVING EXPERIENCE

21 How many years of experience do you have driving a **civilian vehicle** (car, truck, SUV, etc.)? Years: Months:

22 **How often** do you drive a civilian vehicle? (Check one)

▫	▫	▫	▫	▫	▫
Never	Daily	Weekly	Monthly	Yearly	Other:

23 How many years of experience do you have driving a **military vehicle**? Years: Months:

24 **How often** do you drive a military vehicle? (Check one)

▫	▫	▫	▫	▫	▫
Never	Daily	Weekly	Monthly	Yearly	Other:

25 **Which military vehicles** do you have experience driving? (Check all that apply)

▫ Stryker ▫ Abrams ▫ Bradley ▫ HMMWV ▫ MRAP ▫ LMTV ▫ Other:

26 How much experience do you have with "**indirect vision" driving** (i.e. driving with cameras such as DVE)? Months: Days: Experiments:

27 How much experience do you have playing **driving-based video games**? Years: Months:

28 **How often** do you play **driving-based** video games? (Check one)

▫	▫	▫	▫	▫	▫
Never	Daily	Weekly	Monthly	Yearly	Other

COMPUTER EXPERIENCE

29 How long have you been using a **computer**? (Check one)

▫	▫	▫	▫	▫	▫
Never	Less than 1 year	1-3 years	4-6 years	7-10 years	10 years or more

30 **How often** do you use a computer?

▫	▫	▫	▫	▫
Daily	Weekly	Monthly	Few times a year	Never

31 **Where** do you currently use a computer? (Check all that apply)

▫ Home ▫ Work ▫ Library ▫ Classes ▫ Other ▫ Don't use

32 How often do you play **computer/video games**? (Check one)

▫	▫	▫	▫	▫	▫
Daily	Weekly	Monthly	Yearly	Rarely	Never

33 What **type** of computer/video games do you most often play?

END

Date:	ID:	Condition:	Trial:	Notes:	Project #:

A.1.3 After-Action Review in Simulation Experiment 2

After-Action Review

Date:__________ **Subject No.:**______

Instructions: Please provide any comments you have related to the day of testing you have just completed in the following areas:

1. Lane/Road Departure Warning System Driving Aid (e.g. lane markings, seat haptic feedback, audio alerts, etc.)

____

____

2. Friendly Force Position Driving Aid (e.g. maintaining speed, formation, appropriate comms, convoy flow, overlays, audio alerts, etc.)

____

____

3. Crew Station Hardware (e.g. displays, yoke, driving pedals, etc.)

____

____

4. Vehicle Environment (e.g. handling & feel of a large wheeled vehicle, realism of terrain & visuals etc.)

____

____

5. Simulated DVE Conditions (e.g. moderate and severe fog levels, etc.)

____

____

6. Scenario (e.g. mission relevance, workload, etc.)

____

____

7. Other:

____

____

A.1.4 After-Action Review Results in Simulation Experiment 2

1. Lane/Road Departure Warning System Driving Aid (e.g. lane markings, seat haptic feedback, audio alerts, etc.)

Positive	**Negative**
Audio/visual signals can be very helpful.	I believe the seat "buzzers" are a waste of resources. Military vehicles often vibrate no matter what kind of surface they travel on. And with the amount of gear soldiers wear, the driver probably wouldn't notice the "buzz".
The systems markings of lanes, and virtual indicators of drift were intuitive and showed immediate response. The system's audio cues were helpful, but usually more delayed than visual.	The physical warning system was somewhat overbearing in that it sometimes caused me to lose train of thought.
It was a great tool; I would use it in the future. The lane markings were effective and I would definitely recommend this on military vehicles.	When it was clear I felt no need for it, just something more to look at.
I thought this was very helpful during the times the view was limited. Helped notify when an intersection was coming up so I didn't need to slam on the brakes when the convoy was stopped.	Made it hard to guess where the other vehicles were on the road. Distracting.
Easy to learn. Helps a lot when driving in DVE situation. Good for the overall mission and awareness of the driver.	Audio/Haptic feedback unnecessary; return on investment low for ground vehicles, maybe better suited for aerial vehicles; scenarios for use on ground vehicles too infrequent when current systems suffice (i.e. thermal cameras/displays).
It helped a lot with Severe fog conditions.	I found this to be useful only when weather dictates. I would obviously not use during optimal driving conditions.
I liked it	Seat haptic feedback was not working during my use.
The seat would vibrate sometimes when going across a lane, other than that easy to use.	Didn't feel that the lane markings through the curves were accurate. Looked like the lines were doubled up.

I liked this because if you have heavy fog / degraded road conditions it gives you a pathway.	Everything worked well except I couldn't understand what the system was telling me. Audio unclear.
I think everything worked fine; more interested in how it will work in real life.	
I would also use this during long road marches.	

2. . Friendly Force Position Driving Aid (e.g. maintaining speed, formation, appropriate comms, convoy flow, overlays, audio alerts, etc.)

Positive	**Negative**
If this works in all weather conditions, i.e. thunderstorm, sandstorm, not only will it help the driver and vehicle, it could be beneficial at a strategic level. I found it very easy to use and reference quickly.	The system performed as I understood it is designed to, however, maintaining exact speed is impossible even with the alerts.
The pronunciation of the forward vehicles action: breaking, signaling, turning was greatly helpful.	The FFP was almost too much information at once, overloading the driver with information.
Friendly Force Position Driving Aid is easy to figure out. Friendly Force Driving Aid helped me maintain my spread and interval in a convoy.	This function, though helpful in some ways, is a distraction. I like the VR brake lights but found myself paying too much attention to the distance between myself and the vehicle in front of me. You need to be more situationally aware than worried about distance.
I found this one most helpful because it would let me know when the convoy was stopping at an intersection especially when I was catching up. During the Clear one it helped me know my distance gap so I didn't need to guess.	Almost hit vehicle in front because the two blue boxes mixed together and I could not tell which was further but other than that it worked well and was useful.
Easy to learn and understand. Good for maintaining convoy spacing. Flowed with bring awareness to the driver. Audio alerts were clear and loud.	Info overload may be too distracting for driver (usually junior soldier).
It helped me with the friendly positioning in Severe fog conditions. This is only useful in Severe weather conditions.	I did not like the gap indicator; it took away my focus on the road. I found myself looking at the gap indicator too much.
My favorite. Good to know distance and speed of other vehicles.	Distracting.
Worked very well	
Useful for 3D battle-tracking; use by vehicle commander primarily	
This was a great feature during heavy/dense fog.	

I think in actual vehicles it will be easier to use and see if it is functional and practical.	
It took time to adjust to the system. Once it was figured out it became much easier to drive & focus on the specific indicators.	
What was on the screen is all I felt is necessary. If you add overlays or comms it will confuse driver making him not be able to focus on getting from A to B safely.	

3. Crew Station Hardware (e.g. displays, yoke, driving pedals, etc.)

Positive	**Negative**
The crew station was very close to driving a Stryker	I would have preferred a steering wheel. All others worked well.
Driving pedals were easy to press downward and displays were easy to understand	The only issue I had was the yoke steering, as I have always trained on a steering wheel.
Station wasn't bad, comfortable, easy to use, wasn't cramped up, a lot of room	Good. Steering wheel too touchy.
Very clear. Comfortable	The helmet made me feel like a Russian cosmonaut, I didn't think it was necessary for getting in or out of that seat. If you fall and hit your head getting out of that thing you should figure out why your other limbs didn't break your fall first.
Served purpose	Some give in controls / lag in system.
I found the movement of the yoke not consistent with my response. Very little movement of the yoke caused a big unnecessary over-adjustment	The steering is not accurate to that of a Stryker or most military vehicles that I have driven.
System worked well	The pedals were stiff but was able to get a feel for them.
Good.	Not a fan of the pedals — first three tries I had to look down for Brake.
All displays & functions worked well.	

4. . **Vehicle Environment (e.g. handling & feel of a large wheeled vehicle, realism of terrain & visuals etc.)**

Positive	**Negative**
Spot on. Just as good as I've ever seen the army use.	Wheel was a bit loose. Strykers or other armored vehicles feel heavier.
The environment was as close to actually driving a Stryker as I've experienced. The pitch and yaw changed, reacting as a Stryker suspension actually does. The accelerator and brake pedals reacted as an actual truck as well.	Visuals had a few hiccups such as civilians popping out of the screen when going from center screen to left hand screen during sharp right hand turns. Stryker in front of you lags sometimes.
The vehicle environment was pretty realistic. The terrain and visuals were easy to read and the handling and feel of the large vehicle was also realistic.	Pretty real (I've never driven a Stryker) feeling but I was unsure if I had hit stuff or if it was just curbs or the Stryker rocking
It was touchy at first but after a few times it definitely got easier to use. Sounds were spot on.	Maybe do different scenarios or different routes to break up the monotony.
Handling and feel of the wheel felt like a car. Real looking terrain and visual cars.	
Made the system a bit more interesting to use.	
Pretty realistic. Vehicles can stop quickly.	
Consistent enough for simulation.	
No issues with this.	
The rocking of the vehicle was very accurate to that of a Stryker (good job)!	
I think since it's a simulation it's probably as good as it's going to get.	
It was very similar to driving in a Stryker. In real life you feel more of a body roll from the vehicle during turns. Terrain and visuals were realistic.	

5. Simulated DVE Conditions (e.g. Moderate and Severe fog levels, etc.)

Positive	Negative
The conditions were complicated at first but with practice I got it figured out.	I can't tell the difference between Moderate and Severe. Can you add more? Rain? Sand?
The fog levels were spot on. Severe you could hardly see anything in front of you till you were pretty much on it. Moderate was a little easier where I could see fully.	The DVE conditions were correct, however there are standard spreading procedures in place at most units which normally involve slowing convoy movement.
Great under those conditions. We should throw snow and heavy rain into the simulation.	However, there should be more than just fog settings. What about rain? And snow?
Was helpful.	
Good	
Worked well, it was challenging to see	
Facilitates conditions well; close to reality.	
Heavy fog seemed to be realistic.	
Fog levels were very realistic. I have no issues.	
The levels were good.	
In real life conditions can get real crappy. The heavy fog mode simulated realistic conditions quite well. As well as the other modes.	
Seems as close to real as you could get	

6. **Scenario (e.g. mission relevance, workload, etc.)**

Positive	**Negative**
It's a typical patrol route.	Was too repetitive. Not everything on the list were actually in play. After the 2nd intersection, everyone would know exactly what will come next.
The mission relevance was spot on. The workload was slightly more than normal for a driver. A Stryker crew usually has a vehicle commander who manages comms and spacing, however with the driving aids the work was manageable for an individual.	I would like to have seen maneuvering in vegetation or field environment. CMTC rotations (Ft. Irwin. Hohenfelds, Germany).
The scenarios are realistic and pretty easy to maneuver through.	I guess in some aspect it is good but I've hardly driven improved roads and cities while deployed
It wasn't bad especially with all the info being brought up. A lot was irrelevant to me but it is still info that needed to be passed up. At first it seemed like a lot but you get used to it	Throw in different scenarios or routes. No one mission in real life is exactly the same.
Not at all a high demand of workload.	
Good, not hard.	
Pretty easy scenario, does not need changing	
Consistent with actual operations	
Scenarios were great! Was not difficult to understand what you needed to do. Workload very easy.	
Good.	

7. **Other:**

Positive	**Suggestions**
System can definitely help in dust since that's what we see most. Look forward to see if it goes further.	Arm rests would be nice. Not being lazy but there are plenty of places in a military vehicle to rest your elbows on. Might help with the fatigue of holding your hands on the steering yoke all the time.
Overall it was good training & the exercise went well	A marker or indicator for turns on the two side cameras to indicate when one can make a safe "hard" turn, +90° left or right, would be greatly helpful in the future.
	The truck's speed after a turn is kind of a pain. Especially in the rural area because it's pretty much a catch-up game till the straightaway.
	Take LRDWS concept and bolster FFP functions: highlight planned routes, display checkpoints, plot hazard warnings for other vehicles/convoys.

A.1.5 After-Action Review in Simulation Experiment 3

After-Action Review

Date: __________ **Subject No.:**_________

Instructions: Please provide any comments you have related to the day of testing you have just completed in the following areas:

1. Obstacle Detection and Collision Avoidance System

____

____

2. Go/NoGo Driving Aid

____

____

3. Crew Station Hardware (e.g. displays, yoke, driving pedals, etc.)

____

____

4. Vehicle Environment (e.g. handling & feel of a large wheeled vehicle, realism of terrain & visuals etc.)

____

____

5. Simulated DVE Conditions (e.g. moderate and severe fog levels, etc.)

____

____

6. Scenario (e.g. mission relevance, workload, etc.)

____

____

7. Other:

____

A.1.6 After-Action Review Results in Simulation Experiment 3

1. Obstacle Detection and Collision Avoidance System

Positive	**Negative**
I was happy with this tool as an aid; I felt confident with it.	Instances where contact was tagged in middle of road but no contact exists. Suggests moving contacts be given a different color for easy identification.
Liked this better than the Go/NoGo. Was a good heads up of when things were crossing the road. Wish it would have been [on?] road signs too. The yellow blinking helped with knowing how much the steering was turning.	I would like to see the RADAR pick up signs. Maybe buildings too. Didn't really help in heavy fog.
Easy to use. Mostly reliable.	Sometimes the system didn't detect the obstacle and in rare occasion give false alarm
Works well, liked the system. But light, and fog, it worked well.	Mostly useless. Only useful for objects directly in my line of travel, but otherwise I ignored it. Too much information to process and the box doesn't tell me anything important other than an object is there.
Slightly less useless than the Go/No Go Driving Aid.	Too many boxes. Attention shifts to boxes and off of task. Few false positives were confusing.
Very useful and easy to use.	Not helpful when cresting hill-tops… (i.e. what is coming next)
Great driving aid and that's useful to detect objects. Would be nice to differentiate between a static object and a moving object if possible.	
Overall radar worked well and provided a good estimate of distance. W/o the radar I found myself braking too soon to avoid obstacles. With the radar system on I was able to be much more effective w/ braking.	
Useful, easy to master	

2. **Go/NoGo Driving Aid**

Positive	**Negative**
Displaying upcoming terrain (see through) is useful, but similar color as current terrain marks can cause confusion.	I was not happy with this aid. It was not reliable. I felt it was simply distracting, with no positive side.
	Seemed to lag behind screen. Range was too far away to assist in road NAV. Would be more helpful in unimproved terrain.
	Cool in concept. But I didn't ever use it. Seems useful if you are to go off-road. But if you stay on the Road seems useless.
	I ignored it. They would sometimes appear on a clear road right before me. I found them to be a distraction.
	Entirely useless. I completely ignored it. Did not provide useful information to me. In low visibility, the markers in grey space are meaningless.
	This aid did not help me at all. I still do not know how to interpret this data correctly and how to make use of it. I did not find this driving aid useful during today's runs. This could be beneficial in an off-road scenario when you're not trying to follow a road. I did not use this aid and though it just cluttered my screen.
	This system, although useful verses [sic] not having it, did not help as much as the radar. The Go/NoGo indicators bounces w/ vehicle movement but sometimes "stuck" above the horizon.
	Didn't seem to come in to play. Didn't help driving simulation. Seemed more of a distraction. l. Can be distracting with overlays far in distance. User friendly otherwise.

3. Crew Station Hardware (e.g. displays, yoke, driving pedals, etc.)

Positive	Negative
Very happy with all of the tools	Display went out momentarily a couple of times and it was weird reaching the pedals without the seat and monitor moving up and down
Worked great	Would be nice to be able to adjust yoke. Other controls.
It was ok.	Add the ability to adjust displays height, Braking cause the operator feels dizzy.
Mostly acceptable. Would like the pedals centered better so I can drive w/ both feet easier.	The gas pedal felt very hard and the brakes were operating a little bit too strong. The graphics card / pc which was used for the simulation could be a little stronger (performance).
A+	Would be nice to have vertical [sic] adjustment of displays. Yoke's buttons are sharp & get in way of driving. Can you lock tipping fore & aft?
The yoke and displays were good.	
The displays were great and motion was fluid when moving from one display to the next. The yoke worked well but may work better if slightly angled up to increase ergonomic comfort. The pedals, especially the brake, were well dampened and easy to modulate.	
Adequate for task.	

4. **Vehicle Environment (e.g. handling & feel of a large wheeled vehicle, realism of terrain & visuals etc.)**

Positive	**Negative**
The vehicle environment was very well laid out. Quality setup	Sudden breaking of the vehicle was disorientating.
Seemed realistic and okay. Never been in a moving military vehicle before.	Visuals can use some improvements, but then again this is simulator not video game.
Seemed like a realistic experience. Would have been nice to have odometer marking for NAV in heavy fog.	Vehicle braking is unrealistically fast and touchy. Brake distance at higher speeds unrealistically short, especially considering repetition (brake fade)
Was fun	The behavior of the humans was sometimes unrealistic.
Terrain & visuals were very realistic.	Road was definitely more bumpy/rough than what it looked like. Need to add a horn to help move animals/people.
Scenario and environment is very good compared to where it was last time. Great work.	Audio could be louder.
The simulation felt – besides occasional delays – very real.	
Although I do not have experience driving a large wheeled vehicle the simulator felt great and very realistic. Haptic feedback from the terrain felt consistent and realistic.	
Adequate for simulation	
Very realistic.	

5. Simulated DVE Conditions (e.g. Moderate and Severe fog levels, etc.)

Positive	Negative
Simulation was accurate. Happy with the level of realism.	Difference btwn low [= Moderate] and moderate [= Severe] not significant. High fog levels were very challenging.
very realistic and it was easy to tell the difference between them	The difference between low and medium fog did not have a big effect on the difficulty of the task. The high fog level was very challenging.
Realistic conditions, helpful for testing.	I didn’t really notice a difference between light and medium fog conditions. The severe fog conditions are definitely difficult to drive in.
Really good sim.	Light and medium fog seem the same. Severe fog seemed to be to [sic] severe to drive [illegible: “satisfactorily”? possibly “safely”] even with driving aids.
Moderate fog was ok. Severe fog was next to impossible!	
The DVE conditions were accurate and it was easy to distinguish between the two. The conditions were realistic. It would be interesting to add tire/soil changes to the vehicle under heavy fog.	
Fog was realistic. I wouldn’t attempt driving in severe fog levels in real life. Too hard to see anything	

6. Scenario (e.g. mission relevance, workload, etc.)

Positive	Negative
Scenario was realistic.	Would be helpful to have horn & local population response. Also an indication (visual or audio) that you hit an obstacle.
Was good. The road and drive trials were long enough that it didn't feel like I knew what was coming next.	Overall very good. I would like to be challenged more. Add civilian traffic or more dangerous roads to challenge the driver. Provide consequences for failure = going off road hitting pedestrians etc.
Good for testing	The roads were so bumpy that there was not much of a difference between the roads and the gravel besides [sic] the roads.
Was good. Hopefully provided relevant data	Might want to include extra mental burdens. Not sure when you could ever be 100% focused on driving. (i.e. looking for person X or building Y).
Good	
The scenario was well chosen. Sometimes I asked myself, if I could simply have driven off-road to avoid going through a town.	
Pretty easy to drive & avoid obstacles/animals/people	
The workload was manageable although severe. Fog scenarios were very difficult to navigate (although it was realistic). The mix of no aid, Go/NoGo, and radar made sure I was not under heavy workload for back to back scenarios.	
Adequate for simulation	

7. Other:

Positive	Negative	Suggestions
Great staff to work with! Glad to have had the chance to volunteer.	These two driving aids entirely miss the mark of what I need to drive in DVE 1) Range to obstacles, decluttered to only the ones in my path 2) Relative motion of obstacles to me (are they moving toward or away from my trajectory) 3) shape or outline of the obstacle (busy person, dog, tree, etc) Add the road edge plotting device used a few iterations ago and I think that's real close to a successful pairing of tools.	It would be great to see some part of the vehicle chassis. It was hard to figure the dimensions of the vehicle and to keep it in the "lane". Whenever obstacles came too close to the vehicle, I had no chance to see whether it already moved away or not.
Great experiment team!	Simulated civilians don't seem to care a Stryker is coming right at them. Not realistic	
I'm excited I got to be a part of this experiment and had a great experience. The simulator is a great tool and it works very well. I can see why it is a coveted R&D tool at TARDEC. The experiment staff was great too (clear in their instructions, friendly, and professional). Thank you!		

A.1.7 General Questionnaire for Field Test 1

Friendly Force Position (FFP)

1. The FFP helped me know where the **lead vehicle** was.	1 2 3 4 5 6 7 DDD DD D N A AA AAA
2. The FFP helped me to maintain the **appropriate speed**.	1 2 3 4 5 6 7 DDD DD D N A AA AAA
3. The FFP helped me to avoid going **too fast**.	1 2 3 4 5 6 7 DDD DD D N A AA AAA
4. The FFP helped me to avoid going **too slow**.	1 2 3 4 5 6 7 DDD DD D N A AA AAA
5. The FFP helped me to maintain the appropriate **gap distance**.	1 2 3 4 5 6 7 DDD DD D N A AA AAA
6. The FFP helped me to avoid getting **too close**.	1 2 3 4 5 6 7 DDD DD D N A AA AAA
7. The FFP helped me to avoid falling **too far behind**.	1 2 3 4 5 6 7 DDD DD D N A AA AAA
8. The FFP helped to make driving in the **center of the road** easy.	1 2 3 4 5 6 7 DDD DD D N A AA AAA
9. The FFP helped me detect **nearby objects** (3-5 meters) in front of my vehicle.	1 2 3 4 5 6 7 DDD DD D N A AA AAA
10. The FFP helped me detect **distant objects** (>50 meters).	1 2 3 4 5 6 7 DDD DD D N A AA AAA
11. The FFP helped me maintain my **situational awareness**.	1 2 3 4 5 6 7 DDD DD D N A AA AAA
12. Rate your **overall opinion** of the FFP performance.	1 2 3 4 5 6 7 Poor High
Do you have any other comments about the FFP:	

Image Enhancement (IE)

1. The IE helped me know where the **lead vehicle** was.	1 DDD	2 DD	3 D	4 N	5 A	6 AA	7 AAA
2. The IE helped me to maintain the **appropriate speed**.	1 DDD	2 DD	3 D	4 N	5 A	6 AA	7 AAA
3. The IE helped me to avoid going **too fast**.	1 DDD	2 DD	3 D	4 N	5 A	6 AA	7 AAA
4. The IE helped me to avoid going **too slow**.	1 DDD	2 DD	3 D	4 N	5 A	6 AA	7 AAA
5. The IE helped me to maintain the appropriate **gap distance**.	1 DDD	2 DD	3 D	4 N	5 A	6 AA	7 AAA
6. The IE helped me to avoid getting **too close**.	1 DDD	2 DD	3 D	4 N	5 A	6 AA	7 AAA
7. The IE helped me to avoid falling **too far behind**.	1 DDD	2 DD	3 D	4 N	5 A	6 AA	7 AAA
8. The IE helped to make driving in the **center of the road** easy.	1 DDD	2 DD	3 D	4 N	5 A	6 AA	7 AAA
9. The IE helped me detect **nearby objects** (3-5 meters) in front of my vehicle.	1 DDD	2 DD	3 D	4 N	5 A	6 AA	7 AAA
10. The IE helped me detect **distant objects** (>50 meters).	1 DDD	2 DD	3 D	4 N	5 A	6 AA	7 AAA
11. The IE helped me maintain my **situational awareness**.	1 DDD	2 DD	3 D	4 N	5 A	6 AA	7 AAA
12. Rate your **overall opinion** of the IE performance.	1 Poor	2	3	4	5	6	7 High
Do you have any other comments about the IE:							

Obstacle Detection & Collision Avoidance (ODCA)

1. The ODCA helped me know where the **lead vehicle** was.	1 DDD 2 DD 3 D 4 N 5 A 6 AA 7 AAA
2. The ODCA helped me to maintain the **appropriate speed**.	1 DDD 2 DD 3 D 4 N 5 A 6 AA 7 AAA
3. The ODCA helped me to avoid going **too fast**.	1 DDD 2 DD 3 D 4 N 5 A 6 AA 7 AAA
4. The ODCA helped me to avoid going **too slow**.	1 DDD 2 DD 3 D 4 N 5 A 6 AA 7 AAA
5. The ODCA helped me to maintain the appropriate **gap distance**.	1 DDD 2 DD 3 D 4 N 5 A 6 AA 7 AAA
6. The ODCA helped me to avoid getting **too close**.	1 DDD 2 DD 3 D 4 N 5 A 6 AA 7 AAA
7. The ODCA helped me to avoid falling **too far behind**.	1 DDD 2 DD 3 D 4 N 5 A 6 AA 7 AAA
8. The ODCA helped to make driving in the **center of the road** easy.	1 DDD 2 DD 3 D 4 N 5 A 6 AA 7 AAA
9. The ODCA helped me detect **nearby objects** (3-5 meters) in front of my vehicle.	1 DDD 2 DD 3 D 4 N 5 A 6 AA 7 AAA
10. The ODCA helped me detect **distant objects** (>50 meters).	1 DDD 2 DD 3 D 4 N 5 A 6 AA 7 AAA
11. The ODCA helped me maintain my **situational awareness**.	1 DDD 2 DD 3 D 4 N 5 A 6 AA 7 AAA
12. Rate your **overall opinion** of the ODCA performance.	1 Poor 2 3 4 5 6 7 High
Do you have any other comments about the ODCA:	

System Overall

1. Did looking at the three screens cause any problems with **motion sickness** or disorientation?

None	Slight	Moderate	Severe
0	1	2	3
☐	☐	☐	☐

2. Did looking at the three screens cause you any problems with **eyestrain**?

None	Slight	Moderate	Severe
0	1	2	3
☐	☐	☐	☐

3. In your own words, describe any **problems encountered** while driving with the system:

A.1.8 Participant Questionnaire in Field Test 2

Participant ID: ____ Project #___________ Date: __________

1.	MOS: _______	2. AGE: ____	3. SEX: □ Male □ Female	4. EDUCATION: ____ years
5.	What is your CURRENT ROLE or job? ____			
6.	How many YEARS OF EXPERIENCE do you have in this role? ____years ____months			
7.	How many YEARS OF EXPERIENCE do you have with the following?			
	Driving a HMMWV or civilian vehicle (incl. jeeps/vans/pickups)?			____years ____months
	Driving a military vehicle (other than HMMWV) or a large commercial truck (other than vans/pickups)?			____years ____months
	Using a "Driving Aid" (e.g. GPS Navigation, Lane Departure System, Crash Avoidance System)?			____years ____months
	Performing "indirect driving" (e.g. driving via vision blocks, NVG, EO/IR)?			____years ____months
	Operating a Driving Simulator?			____years ____months
	Flight simulators, virtual reality, 3D games, etc.?			____years ____months
8.	Do you have a COMMERCIAL DRIVER'S LICENSE? □ No □ Yes			
	If "Yes" please circle any of the following that apply:		Class: Endorsement: Restriction:	A B C P H M N T X L S B C D E F G K O
9.	Do you often get MOTION SICKNESS?		□ No □ Yes	If "Yes", please tell the experimenter.
10.	Do you have any form of COLOR-BLINDNESS?		□ No □ Yes	If "Yes", please tell the experimenter.
11.	Do you have any VISUAL PROBLEMS that glasses or contacts can't correct? □ No □ Yes If "Yes", please tell the experimenter.			
12.	HANDEDNESS: □ Right-handed □ Left-handed □ Ambidextrous/other			

A.1.9 After-Action Review in Field Test 2

Date: __________ **Subject No.:**_________

Instructions: Please provide any comments you have related to the day of testing you have just completed, on the following topics 1-7:

1. Radar Driving Aid
2. Image Enhancement Driving Aid
3. Crew Station Hardware (e.g. displays, yoke, driving pedals, etc.).
4. Vehicle Environment (e.g. handling & feel of the vehicle, etc.)
5. Training Session
6. gDVE Conditions (e.g. dust levels, visibility, etc.)
7. If you have experience with the “Drivers Visual Enhancer” system, how does it compare to the “gDVE” system? (e.g. clarity, field of view, displays, etc.):
8. Other:

A.1.10 After-Action Review Results in Field Test 2

1. **Radar Driving Aid**

Positive	**Negative**
It's helpful, it also helps avoid objects.	Sure, it would be better if we could use it actually.
I personally loved the entire system. Definitely can see a future with this system.	Needs work.
Once I got used to it, proved to be quite useful.	The radar was nice but sometimes I felt like it was just picking up random stuff.
This was very useful during concentrated dust conditions.	Didn’t really use too much.
The driving aid was very helpful in making me aware of nearby objects.	It helps with dust filter on both can also get in the way of the driver.
The aid proved useful for objects that had gone unnoticed or were slightly in the peripherals.	A little difficult to navigate.
It was nice using this when going through dust as you could see obstructions in path before you could see with own eyes.	I don’t think it worked very well needs more work.
Good	It needs some work. The radar driving had the box needs to find the right size for thing in the way it was going for everything.
Works well. Provides early warning in low visibility.	It was a good system. Calibration was off. With the dust it didn’t works well.
	To inaccurate needs fine tuning.
	Was a little jumpy at times.

2. **Image Enhancement Driving Aid**

Positive	Negative
Perfect	Needs to have a wide view.
Felt very confident with this one. Very clear and crisp. Easy to see.	I didn’t notice a difference with this filter.
Easy to see through dust.	Dust filter works a lot better than clear filter in dust tends to blur during high speeds and sharp turns.
Made for a great clear picture regardless of conditions.	
The image was actually really good and clear. A lot better than what we use now.	
The imagery was crystal clear and I did not have any problems judging the depths of most obstacles.	
Very helpful would use every time	
Works way better than the old DVE better view	
it was nice to be able to see clearer things but while moving kinda hindered vision but made obstacles easier to see	
good	
better than normal	
had really good image quality which was nice	
All the filters worked so they were good	
The different filters were good touch, the dust filter was good while dust was flying everywhere. I could see everything still.	
Image was better	

3. Crew Station Hardware (e.g. displays, yoke, driving pedals, etc.).

Positive	**Negative**
I liked how easy it was to use it	Steering wheel is a bit difficult to get used to
All hardware was good. Pretty impressive on how the layout was inside the vehicle	Instead of yoke, it needs steering wheel
Displays and pedals were great	yoke was sensitive & seemed to be delayed in my opinion….took some getting used to
The station was easy to use,	Yoke needs steering feedback.
Displays were nice being so visible, clear. The driving pedal (brakes were real light) steering yoke was different with sensitivity	The right camera screen kept going out & the yoke was weird at first
good	Displays felt a little too close together (bunched)
useful to a point	It would just take some time to get used to the delay between the turning of the yoke & the turning of the tires.
really sensitive but just takes some getting used too	Took some getting used to. Would like to see the delay between the turn and the tires shortened
The crew station hardware was a good setup. The pedals were too sensitive and steering wheel was sensitive.	really sensitive
Everything was set to make it easy to use	very delayed compared to regular steering wheel
	The pedals need some work
	Breaks very sensitive, steering yoke can make it difficult to make small corrections

4. **Vehicle Environment (e.g. handling & feel of vehicles, etc.)**

Positive	**Negative**
Fast and easy mobility but also very sensitive	The breaks were really sensitive
Easy to operate	Very sensitive. Was not expecting it. Hard to get used to.
Felt great	Sensitive/delayed yoke.
Handled very well	Seems like there is input delay for steering.
The vehicle handling was good once you got the control of it.	Handling was pretty sensitive
Felt very natural, would love to drive like this.	The vehicle handled nicely, once adjusted to the delay from yoke to tire it was easy to maneuver.
Vehicle environment worked amazing	Brakes too sensitive and steering not responsive enough
gDVE was nice	Feels delayed as discussed in Q3.
touchy but well put together	Hard to steer, wheel was to sensitive
Stryker handled perfectly	
The heading with driving yoke thing worked	
The handling took some getting used to. Overall once I drove a few times it become simple.	

5. Training Session

Positive	Negative
Training sessions were good. Good idea with the black screen. Short not long. Very challenging but easy.	Hours were prefect but course was a little too short
Great	Lots of info for little time
Fairly relaxed but very educational	Should have made the track/test area longer but other than that it was good.
The runs were simple and relaxed. I did not feel rushed or pressured to perform at a certain level.	Would like to drive system through a mount sight/ urban area
taught a lot about the different feature and how it helps in different situation	I think this is a very poor way of truly testing this new gDVE
I had fun & felt it would be really cool feature to implement in hostile environment & garrison	
good	
perfect hours	
it was good	
Training session was a great learning process, learned a lot about system.	
Training was straightforward and to the point	

6. gDVE Conditions (e.g. dust levels, visibility, etc.)

Positive	Negative
I could see everything great	Challenging
I enjoyed driving in various conditions and seeing the contrast between different displays throughout	need more dust to use image enhancement better
Radar aid worked well.	Very challenging, couldn't see much on a few.
The dust filter is real nice a sure helps in the dust.	I only had one run with complete obscuration from dust.
Conditions were helpful for the dust and no dust scenarios.	The local weather was not helpful for creating good dust conditions.
through the gDVE with all sensors on I could see better than normal DVE	Not too much adverse conditions to make a proper assessment.
good	The dust level can be worked a little better
helps visibility with dust filter	With the dust levels it was really hard to see some times
no change	
great filters and image quality	
Even though the dust was high, the gDVE could handle it. The different filters were helpful	
This gDVE works much better with dusty cond.	
visibility was a lot better	

7. **If you have experience with the "Drivers Visual Enhancer" System, how does it compare to the "gDVE" system? (e.g. clarity, field of view, displays, etc.):**

Positive	
very clear but I think we should be able to see closer to the vehicle	It was a lot better to see all sides in front of me while I was driving, not just middle of Stryker
Driver visual enhancer is pointless compared to gDVE	The DVE we use now sucks compared to the gDVE.
The typical DVE doesn't hold a candle to the newly designed gDVE. The gDVE is more advanced in every way.	The gDVE definitely is more sensitive with its displays.
My experience with DVE was during dense fog. DVE was not helpful and I resorted to hatch-open.	I think the gDVE is better in all aspects.
The gDVE was much clearer and more realistic looking.	It's better all-around a major step up from the normal DVE
actually can see 10x a lot more and clear	The gDVE is by its way more advanced. way more clear & it was nice to see for 180°
Better than DVE	field of view is much larger
a little bit more maneuverability	biggest problem with the DVE is lack of sight around the vehicle which is solved with the new gDVE

8. Other:

Positive	**Negative**
Course was great, training was amazing	the only thing is the obstacle course was a little short
Enjoyed the training overall. Would love to see this new system implemented across the Army.	Issues with picture as we turn
Overall, I would enjoy driving with this system and look forward to seeing it in the future.	Only thing that bothered me was the slight delay after you turn, takes a second to refocus and adjust.
This system will save lives. Integrate with boomerang	Right side camera freeze.
	will take some time getting use to

9. Things you Liked

Liked
screen space
view angle
radar collision detection
top-down radar aid
ease of use
how clear the picture was
how affective the dust filter is
The bucket seats. should replace all seats
like having all the different driving aids
radar picked up objects what you could hit
Front of the truck was clearly visible
Sides from the mirror to front were visible
Radar detects objects you could possibility hit
Ability to drive through heavy dust
Image clarity
radar overview
obstacle display (boxes)
Easy ability to change filters, radar, etc
seats were comfortable
clarity
field of view
radar box's
ease of use
transition between settings
gDVE work better
dust filter
touch screen helps
it's all in front of you
see more than just one screen
could actually see through heavy dust
can be more visibly aware of surrounding
distance you can see is increase with clarity
Love the radar feature. It shows objects before I can get to them. The feel of driving is more relaxed.
able to left and right of vehicle
clarity of cameras
compos on the top of screen
radar
dust screen
Dust filter works great in low visibility

field of view is greatly improved
radar is great and provides early warning to obstacles
layout is easy to understand and navigate
seats were comfortable
clarity
radar
different modes
field of view
effectiveness
I really liked the image quality everything was very clear and visible
The filters were really good too. I would definitely use them.
the filters
easy to use
dust filter
cameras on every side
easy to use
lots of different modes
driving aid
dust filter
180° field of view
dust filter
easy to use
everything is touchscreen
visibility is better
side screens

10. Things you Disliked

Disliked
lack of steering feedback
poor steering responsiveness
accuracy/precision of radar boxes
camera freeze
The camera kept freezing
the yolk was weird felt like there was a slight delay in turning
felt like the radar was picking up obstacle what weren't there
I don't know if I like that it's only in thermal or is there a day camera too?
Camera would freeze
Handling was a bit sensitive
Brakes were sensitive
Not sure how tough equipment will be (i.e. going through thick brush)
Lack of dusty conditions due to local weather
Longer obstacle course, more time to use equipment.
delay between yoke and tire
didn't use the radar (at bottom left of screen)
screens would go in & out
color thermal
steering wheel instead of yoke
hard to measure how close something is to vehicle
brakes were to touchy as to normal so might have slowed trial times
some dust runs were thicker & thinner
cut outs to refocus gDVE
steering wheel was little laggy with big corrections
steering not responsive enough
brakes too touchy
driving from the rear was awkward
steeing yoke was awkward
not being able to see directly in front of Stryker
steering in the vehicle is delayed
brakes were very touchy
with dust filter, screen tends to blur at high speeds
systems seem to have bugs with crashes
touchy breaks/steering
depth perception
to confined
radar

I personally wouldn't use the new gDVE unless I had to. I can't say for sure how good it is because the way we used and tested it wasn't efficient at all. Driving on a small path for a minute is in no way going to properly test out the gDVE. Maybe if the testing trails were better, I might be able to fully use and really test out this gDVE but at the current time I would not use it.
The radar with the dust so many boxes that did not matter
pedals
radar
radar too inaccurate to be useful
breaks & steering too sensitive
radar
vision was jumpy at times