Effects of field of view and stereo graphics on memory in immersive command and control

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Effects of field of view and stereo graphics on memory
in immersive command and control
by
K.C. Kurt Chris Dohse

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
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ABSTRACT

Understanding what factors contribute to performance in virtual environments is key to designing future systems for training and teleoperation. The military is already a large user of virtual reality for training and may use virtual reality for real-time operations in the future for command and control. This research aims to identify what effects manipulating the field of view and the use of stereoscopic graphics have on performance of memory-based tasks. Presence, situation awareness, workload and simulator sickness were measured. The results of a controlled study with 100 subjects did not find a statistically significant relationship between field of view or stereo and memory performance. The results also indicated that memory performance is significantly correlated positively with situation awareness and negatively with frustration. This research indicates that the use of stereo graphics and large displays do not necessarily increase situation awareness in all contexts, but that systems should strive for higher situation awareness in order to increase a user’s memory of the simulation.
CHAPTER 1 OVERVIEW

This research at the Virtual Reality Application Center (VRAC) of Iowa State University is to address the question: How does the degree of immersion and sense of presence within a virtual reality (VR) command and control operation affect performance on memory-based tasks? Related to that core question are the additional issues of how the factors of situation awareness, workload, and simulator sickness are related to immersion and task performance.

1.1 Introduction

The goal of any military mission is to complete the mission as efficiently and as safely as possible. To accomplish this, the military relies on state of the art weapons systems and the ability to make good decisions and act upon them as quickly as possible. One way to keep soldiers safe is to keep them out of the theater of operation; the United States Department of Defense (DOD) Roadmap 2015 indicates that the goal is to have 25% of military aircraft be comprised of unmanned aerial vehicles (UAVs), thereby removing pilots from immediate danger. To make sound decisions, soldiers depend on accurate information to be presented to them in a meaningful way. Current military engagements are becoming increasingly complicated as the battlefield moves to urban areas, which means there is a larger and more diverse set of data to be organized and analyzed. Added to this complexity will be devising a strategy to control and manage numerous UAVs. A potential solution to these problems is using virtual reality to synthetically represent the UAVs and the battlefield.
Virtual reality poses a potential way of viewing all of the relevant information that military personnel need in one unified location, rather than scattered across several disparate interfaces leaving users to consolidate the information mentally. The reduction in the users’ necessity to perform this consolidation task has been shown to allow operators to use more of their time to make decisions (Durbin et al., 1999, Hix et al., 1999).

1.2 Definitions of key terms

1.2.1 Virtual Reality

The term “virtual reality” was coined as a means of unifying the concept of numerous virtual projects such as virtual worlds and virtual cockpits (Krueger, 1991). Thus the term typically refers to three-dimensional displays in which stereo graphics are used and special three-dimensional input methods are employed (e.g. wand or data glove). Other definitions have more stringent requirements on the technology such as tracking the user’s position in order to render the environment more accurately for the user’s viewpoint. Meanwhile other researchers have pushed for definitions that focus more on the experience than the technology itself. For example: “A “virtual reality” is defined as a real or simulated environment in which a perceiver experiences telepresence” (Steuer, 1992).

A definition could be placed anywhere on the continuum from strictly technology based to strictly experience based. In either sense, this experiment varies in the degree by which participants will be using virtual reality. The definition herein will regard virtual reality or virtual environments as three-dimensional computer generated graphics that are displayed large enough to encompass a majority of the user’s visual field and controls that
allow users to interact with the system, thereby creating a virtual world that the user is likely to feel that they are inside.

Typical VR systems include head mounted displays (HMD) that give each user their own headset to create the imagery and CAVE (cave automatic virtual environment) which uses multiple projection surfaces to surround multiple users with imagery.

1.2.2 Immersion

The interpretation of immersion can vary as well, from the user's experience to a hardware-based definition. Slater's definition of immersion, where immersion is described as a quantifiable description of the technology (e.g. screen resolution and the amount that the outside world is shut-out from the user) will be used (Slater et al., 1996). This definition separates the concept from the related idea of presence, which will be defined later. Immersion is increased in two ways, first by using technology that removes a user from the real environment as much as possible in as many ways as possible. The second way to increase immersion is to make the inputs and outputs of the system as real as possible. Thus a system that has a small field of view, low screen resolution, poor sound quality and an obtrusive style of control has a much lower level of immersion than a system with a large field of view, high quality visual and auditory output and more natural modes of interaction.

1.2.3 Presence

Presence is a subjective feeling of being inside of an alternative environment. Presence can be tested for real environments, but is generally discussed in the domain of
virtual environments (VE), in which presence refers to the degree by which a person feels they are inside, or part of, the VE. Presence is separate from the notion of becoming immersed or engrossed in a book and film because although a person may not be paying attention to the external world, they generally do not feel as though they themselves are part of the fictional world. In more traditional VEs users experience higher levels of presence because not only do they remove themselves mentally from the physical world, but they actually interact with the VE and can either influence what is happening or be part of what is happening.

The experiment will focus on the user's field of view and whether the virtual environment (VE) was projected in stereo or mono. Increasing the field of view increases the degree to which the participant's proprioception (the perception of ones position and body) will be appropriately mapped to the simulation. The use of a stereo display will increase realism. Both of these are important factors of presence.

1.2.4 Situation Awareness

One of the research questions concerns the relationship between situation awareness and memory. The definition of situation awareness (SA) established by Endsley states that “SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” (Endsley, 1988). Situation awareness has three levels: the first level is perceiving different elements of the environment, the second level is understanding what the different elements are and what they mean and the third level is interpreting what the near future state of those
elements will be. SA is often thought to be important to good performance (Ma & Kaber, 2007).

1.2.5 Simulator Sickness

Another research question concerns the relationship between simulator sickness and the presence of stereo graphics. Simulator sickness encompasses a number of feelings of discomfort that can occur as a result of being inside a VE, such as nausea, disorientation, or ocular problems (Casali, 1986). Simulator sickness can be considered a form of motion sickness, because it involves similar sensations and the primary cause of simulator sickness is cue conflict between the visual and vestibular systems (Tyler & Bard, 1949, Kennedy et al, 1993). The term simulator sickness is not used interchangeably with motion sickness, however, because motion sickness refers to a specific disorder dealing with actual motion, while simulator sickness can be brought about without any motion. Symptoms of simulator sickness can also be influenced by display elements such as resolution and lag.

1.2.6 Workload

Another one of the research questions concerns the relationship between workload and the field of view. Workload refers to the amount of work someone performs within a certain timeframe. Workload is an important concept when designing machines or processes in order to create the most effective and efficient system possible. There is no single definition of workload, but Hart and Staveland identify the key elements as mental and physical detriment to an operator attempting to achieve a certain level of performance (Hart
& Staveland, 1988). There are multiple elements of workload that can be identified, separately measured, or can be combined to determine a single workload score. Physiological measurements can be used to obtain information, but the more common method is subjective questionnaires. Individual differences in definitions and tolerances make the analysis of subjective measurements complicated, but by identifying separate elements and narrowing definitions researchers can obtain consistent results. Cognitive load is similar to workload in that it identifies the extent to which cognitive resources are used by the processes of learning (Chandler & Sweller, 1991). The most significant difference between these two constructs is that workload encompasses mental elements as well as physical elements.

1.2.7 Display elements and the eye

To create the most realistic experience virtual reality must take into account the human visual system. The human field of view for people with two eyes is approximately 200 degrees horizontally and 135 degrees vertically (Gibson, 1979). Thus, using larger fields of view maintains a more unified visual experience of an environment, which creates a more realistic experience.

Another element of realism in virtual reality is mimicking stereoscopic vision. To achieve stereoscopic vision the brain calculates the difference between the input it receives from both eyes in order to determine depth. This occurs because in the real world an object is slightly different distances away from each eye. In virtual reality, there are two separate images projected at alternating times, and shutter glasses are synced to the projectors such that each eye sees the appropriate image at the correct time. This arrangement leads the brain to interpret a single image with 3D depth. Past research motivates this experiment by
indicating that stereo can benefit three-dimensional task (Arthur et al., 1993). Head tracking improves this effect, but was not used in this experiment.

1.3 Hypothesis

Previous research has indicated that increasing the level of immersion in a simulation can have positive effects on performance (Slater). Similarly increasing the size of the display and the field of view can improve memory and increase the sense of presence (Tan et al 2003, Lin et al 2003, and Czewiksi et al 2003). The goal of this research is to determine if the highest level of immersion in the experiment will yield the highest scores on a performance-based memory test. The secondary goal is to determine which factors (presence, situation awareness, simulator sickness and workload) influence performance.

1.4 Battlespace

To understand the background of the experiment, the Virtual Battlespace will be introduced. The Virtual Battlespace is a 3D visualization tool that consolidates the available information about a complex battlefield into a single coherent picture that can be viewed from multiple perspectives and scales (Knutzon et al., 2003, 2004; Bernard et al., 2004). Battlespace visualization attempts to improve a commander’s ability to understand the complex interactions of units in a conflict and facilitates effective and intelligent decisions based on the available information (Posdamer et al., 2001). Visualizing engagements in this way can be useful in a wide variety of contexts beyond command and control in combat situations, including mission planning, mission review, and distributed mission training. The system currently provides an operational environment that informs the operator about
potential threats, allows the operator to query for information, and suggests high-success courses of action.

In the virtual Battlespace environment users view a desert landscape from overhead (Nellis Air Force Base) populated with surface to air missile sites (SAMs), fighter planes, bombers and a target base (Figure 1). Each unit is colored either red or blue to represent which force they are part of and represented with a specific icon (the friendly units are blue and the hostile units are red). Users moved themselves around in the environment by manipulating the two analog thumb sticks on a video game controller (Figure 2). While in the virtual environment, participants have four degrees of freedom with the controller and can get as close to a unit as they desire to investigate what is happening.

Typical tasks performed in the Battlespace include: surveying the battle theater from a “god’s eye view,” tracking threats and deciding the optimal time to deploy weapons against them, determining enemy weapon ranges for UAV way-point plotting, following behind allied planes to see what their pilots are seeing on the battlefield, and reviewing videos of possible threats recorded by UAVs.
Figure 1: Scene from the virtual environment participants viewed during the experiment. A) The scenario contained 1) Bombers 2) Fighters 3) surface to air missiles (SAM) 4) missiles 5) opposing forces. The units are represented with the icon in (2) when the participant is further away and the icon in (5) when the participant is closer. B) A view of the swarm field; the blue patchy regions are the UAVs, the shadowed region represents the assigned search area.
1.5 The Task

The task involved the comprehension and memorization of three-dimensional spaces and objects within Battlespace. Participants completed these tasks under conditions of varying fields of view and with stereo and mono displays. After completion, participants completed an objective memory test and a series of standardized questionnaires designed to
measure situation awareness, simulation sickness, workload, and degree of presence. It is reasonable to think that because the task mimics the real world, increasing immersion and presence would in turn increase performance on the memory test. It has been shown that increasing the quality of sensory modalities increases presence and memory (Dinh et al, 1999).
CHAPTER 2 BACKGROUND

2.1 Command and Control Visualization

The decision-making process leading up to and during a battle is known as command and control. In order to support this process, military personnel rely on different tools to view the battlefield. This process has been occurring ever since the first military was formed and has changed greatly over time, as has the technology used to assist leaders to make decisions.

Early methods for planning and instruction used maps and sand tables for visualization. Sand tables can be made in varying sizes and levels of detail, but their purpose is to give a physical scaled-down representation of the battlefield. Figures can be moved around in the sand table to represent troop formations and strategy. Acetate overlays can be placed on maps and grease pencils can be used for the same function, or in order to update information.

Both of these techniques are still used for visualization and command and control because they are simple to use and understand, but are limited in the ability to rapidly update and share massive amounts of information. As military operations become increasingly complex with more people and factors added to the equation, new technology is needed to more effectively assist the military make the best decisions as quickly as possible.

In modern operations more information is arriving via computers, so a natural extension of that is to use computers in the visualization process. Computers have been making their way into the military visualization process with varying levels of complexity, including virtual reality systems.

2.2 Important Goals of Command and Control

Command and Control activities require a system to achieve four main goals in their design and implementation. The following analytical framework will be used throughout this paper to discuss the advantages and disadvantages of systems used for command and control.
2.2.1 Accuracy

During real-time war gaming, command and control operations can occur rapidly and are time critical, thus the information needs to be dynamic and accurately represented. This means that units on the display need to have positions and statistics continuously updated to be useful.

2.2.2 Spatial Imagery

The combat theater can occur anywhere on the planet and include any type of terrain or manmade structure. The locations of buildings and topography of the area are crucial elements of the planning stages of a mission, thus spatial and geographic information are important. Understanding the spatial relationships between individual units and between units and the environment can be better understood by using three-dimensional graphics.

2.2.3 Information Quantity

With any decision, the amount of information available impacts the quality of that choice. In a command and control scenario, spanning a large geographic space, a larger display is critical for displaying the information required to understand the entire context of the battle and make appropriate decisions. This information often depends on a large but uncluttered data visualization strategy.

2.2.4 Interaction

Command and control is not a passive activity; personnel are actively acquiring specific information, changing viewpoints and manipulating units. During the planning stages, commanders interact with units extensively to decide the best strategy. The ability to easily access and interact with information (e.g. UAV waypoints) engenders faster decisions.
2.3 Command and Control Technology

FalconView is a government off-the-shelf 2D visualization tool currently in use in several branches of the military (FV website). This application displays maps and geographically referenced overlays to visualize the battle theater and perform mission planning. It is used on base and as a moving-map onboard vehicles, but is limited to a two-dimensional representation of the entities involved in the operation.

FalconView fulfills accuracy and interaction goals, but is limited on spatial imagery and information quality goals. FalconView is mostly used on large screens, so there is a lot of information available, but not nearly as much as what is available with a CAVE system (Figure 3). The spatial imagery goal is partially accomplished because there are geographic overlays, but the system is 2D, so it is difficult to convey all of the spatial information possible.

Figure 3 View of FalconView’s overhead 2D interface
To attempt to produce a more realistic representation of the map, a 3D add-on was developed called SkyView. SkyView uses simple 3D representations of units and displays paths with very minimal graphics (Figure 4). Many of the features of FalconView/SkyView are still grounded in the 2D aspects of the application and it is unclear whether this 3D representation is increasing situation awareness or the immersive qualities of the display. Therefore the improvement to spatial imagery is only partially improved upon because spatial relationships between units are more evident, but the terrain is still in 2D. Most of the interface techniques are also still grounded in 2D, so the spatial interaction is limited.

Figure 4 View of SkyView's implementation of 3D graphics to represent planes and paths.
Other systems for battlefield visualization recognize the necessity of shared workspace and varying user roles. One such example has attempted to display information from multiple viewpoints at the same time using projection based systems (Pettersson et al). This system allows four users to have different stereoscopic views of a battlefield on a horizontal viewing surface. Such a system provides users with accurate data and uses stereo graphics to display geographic data. It has a limited amount of information displayed due to being projected on a small table. The developers have approached the goal of data access and manipulation by incorporating a wireless pen-based computer. This interaction technique may work well for interacting with the application, but does not allow the individuals at the display to interact with it. An additional limitation of this system is that with so many different projections, there is some interference between graphics, the amount of impact this has on its usability is not yet known.

Another technique for multiple viewer visualizations within the same space was accomplished using head mounted displays given to each user (Hedley et al. 2002). The experience is shared with this system because the head mounted displays are video see-through and the geographic information is represented with augmented reality (AR). This approach was not designed for command and control, but accomplishes spatial imagery and interaction goals. Tangible objects make it easy for users to manipulate the information and all of the terrain is viewable in 3D. If applied to command and control it currently lacks the ability to display dynamic information and has limited size because it is implemented on a table. Another shortcoming of this system is that like in many AR systems, only people wearing the head mounted display can participate and users cannot quickly switch between other tasks not related to the visualization.

A virtual workbench has also been implemented for battlefield visualization, which is a useful collaborative tool, but is not limited in terms of information quality when compared to a wall or CAVE display. The system, known as Dragon, displays 3D graphical
representations of terrain, friendly and hostile entities as well as other military symbology (Figure 5). Positions and units are continuously updated and viewed from different angles in either mono or stereo graphics, accomplishing accuracy and spatial information goals. The developers also experiment with using egocentric and exocentric modes of navigation, or as they term it, map-centric, which uses the metaphor of moving a physical map, and user-centric, which mimics flying in an airplane. The system is controlled with a modified three-button joystick by pointing a virtual laser into the environment. The “pointer” is moved around as an entity in order to select and interact with other entities and the environment (Figure 5). The interaction based goal is not adequately accomplished because interacting with the environment with the virtual pointer is difficult. Other visualization systems, such as LeatherNet, use CAVE technology in order to train groups of commanders (Carlson and Yi, 1996). This system integrates the 3D CommandVu command and control visualization with the CommandTalk speech interface. This system accomplishes accuracy, spatial imagery, and information quality goals, but relies on speech commands to interact with all aspects of the technology. Speech is useful, but not optimal as the only means to interacting with three-dimensional space.

The Virtual Battlespace was developed with all four of the goals in mind. The Virtual Battlespace has the ability to receive position and status data from another source and accurately display that information in the 3D VE to accomplish the accuracy goal. Geographic and spatial data are available to the user and viewable from any angle. By using a CAVE users are presented with a large amount of imagery that is easily viewed. The value of viewing units and geographic features in the VE is amplified by the additional spatial context provided by such a large and immersive display. Manipulation of Battlespace units is currently limited to a small set of key options, but the interaction methods are very powerful. The Virtual Battlespace is a multimodal application that allows speech commands to select objects or name entities and a game pad is used to navigate effectively in the VE.
Figure 5 View of Dragon, demonstrating the use of the virtual laser tool for interaction on a 3D map with continuously updated 3D units.
2.4 Virtual Reality Research

Virtual reality (VR) is an increasingly utilized tool for visualization and interaction with three-dimensional spaces and objects. Virtual reality excels at enabling individuals or groups to experience and interact with information in ways difficult or impossible to replicate in the real world. Example applications include navigating inside a molecule, prototyping parts for a car, visualizing three-dimensional data, training employees for a future factory and exploring an ancient temple or designing a new building (Figure 6).

It is important to identify which aspects of virtual environments are most critical for them to be effective. This includes the type of display and the method of interaction. Types

Figure 6 Uses of virtual reality: view inside of a molecule (top left), architectural planning (top right), 3D data visualization (bottom left) and employee training (bottom right).
of displays include systems such as a head-mounted display (HMD) or the CAVE system in which images are back-projected onto screens around the user. The type of interaction device used could be speech, gestures, a video game pad, a tracked “wand,” or any number of methods. The effectiveness of the display and the method of interaction are relative to the task being performed. Work that benefits from collaboration in a shared space, for example, is ideal for a CAVE, whereas simulating binoculars or working inside of an existing space is ideal for HMD’s.

Techniques to identify the best uses of VR and methods of interfacing with it broadly fall into one of two categories, quantitative and qualitative research methods. Quantitative research is based upon collecting and analyzing numerical data. Examples of quantitative measurements include time needed to complete a VR task or the number of mistakes made. Qualitative research instead looks at non-numerical data, such as words or pictures. Examples of qualitative measurements include video of users interacting with an interface or responses during an interview or to a questionnaire.

Using both quantitative and qualitative approaches, research has focused on application specific and generic virtual reality environments and uses. Basic VR research uses non-domain specific environments and attempts to identify factors that make virtual reality more effective, such as evaluating different information displays, for example, auditory displays (Lee et al, 2003). Research also compares techniques for displaying information, such as the role of multi-sensory input on memory (Dinh et al, 1999). Novel interaction techniques are frequently developed and researched as well, such as image plane interaction (Pierce et al, 1997). Finally, the methods by which researchers collect data are evaluated, such as using physiological measures instead of subjective questionnaires for measuring presence (Meehan et al, 2002).

Application-specific research tends to focus more on usability issues and how to best use virtual reality to solve a given problem. Techniques used in this type of research include
heuristic evaluations, which are assessments based on predefined guidelines regarding good interface design. Formative evaluations use several people to evaluate a system and are used early in the design phase, often as part of an iterative process. Formative evaluations focus on the processes that are involved, such as performing a task analysis (i.e. determining what is required for a set of events to occur necessary for a given outcome). Summative evaluations are performed at the end of development and focus on the outcomes. Multiple interfaces can also be compared to one another using basic quantitative performance metrics such as time to completion; this can be part of a summative evaluation.

An application-specific battlefield visualization study that uses these techniques was developed by the researchers of the Dragon system. The researchers perform heuristic evaluation, formative evaluation, and summative evaluation, with an iterative phase wherever needed. They used this method to test their Dragon visualization system. The experiment consisted of users navigating through simple scenarios using either egocentric or exocentric modes of control, viewing with or without stereopsis and using one of four display apparatuses. The dependent variable in the experiment was time of completion in the four types of displays, which were a monitor, a four-wall CAVE, a VR workbench and a single cave wall. There were problems with the projectors they used, so it is unclear which display performed best, but within the cave condition there was an interesting result in the mode of navigation variable. Participants completed task significantly faster using exocentric motion navigation then egocentric. This is in opposition to the traditional belief that egocentric motion is best for immersive displays and exocentric motion works best for systems that the user is looking into.

There is inherent overlap between basic and application-specific types of research because there are elements of each in both types of research. Basic research often tends to lend itself more toward one area of application than another due to the equipment used.
Application-specific research can identify issues important to a broad spectrum of virtual reality research, such as identifying new research methodologies.

2.4.1 Immersion Research

In a study conducted using HMDs, research has shown that increased immersion and egocentric viewpoints increase task performance (Slater et al, 1996). This research did not find a correlation between presence and performance. The level of immersion was specified as high when participants wore the HMD and as low when they viewed on a monitor. Performance was measured according to how many chess moves a participant could accurately mimic from the Tri-dimensional game they witnessed in the VE.

Researchers have found that “when a display exceeds a certain size, it becomes qualitatively different” (Swaminathan & Sato, 1997). On desktop-sized monitors, increasing size has shown improvement in complicated cognitive tasks, recall memory, and in peripheral awareness (Czerwinski et al, 2003). Very large displays such as CAVE systems have been shown not only to have the highly valuable social interactions that result from using a shared display (Bly & Minneman, 1990), but also to benefit single user performance on spatial tasks (Tan et al, 2003). In the Tan et al experiment, participants engaged in mental rotation activities on both a desktop monitor and large projection display while maintaining similar visual angles. Researchers believe that the improved performance was due to a greater sense of presence and participants imagining the objects from an egocentric viewpoint on the projection display and exocentric on the monitor. Increasing field of view also increases the sense of presence, when researchers increased the FOV from 60 degrees to 105 degrees.
(Prothero & Hoffman, 1995). Although a larger field of view may increase presence, it can also have the negative effect of increased simulator sickness (Seay et al, 2001).

Stereo graphics have been shown to improve 3D task performance (Arthur et al, 1993, Sollenberger & Milgram, 1991). However, stereo has inherent limitations in simulations that do not mimic real-life situations involving stereo vision, such as flight simulation, because objects are generally very far away from the eye. Stereo can also produce the undesired effect of increased simulator sickness (Mollenhauer, 2004).

2.5 Summary

The complexity of modern warfare and the volume of information available necessitate increased computer involvement for command and control. Different systems have been explored to meet these needs, such as SkyView, Dragon, and the Virtual Battlespace. The command and control systems have used a variety of VR platforms (e.g. HMDs, virtual workbench, and CAVE) and interaction techniques (e.g. wand, speech, and game pad). When designing these systems, researchers and developers must keep in mind the main goals that a command and control visualization must strive for -- accuracy, spatial imagery, information quality, and interaction -- as well as the best practices for using VR. Research on VR command and control has shown to be a valuable medium for displaying and interacting with large 3D datasets. Previous research pertaining to the Virtual Battlespace is especially connected to immersion, which has indicated that increased field of view and stereo graphics can improve task performance, but can also contribute to simulator sickness.
CHAPTER 3 METHODS AND PROCEDURES

This chapter describes in detail how the experiment was designed and carried out.

3.1 Methods

3.1.1 Participants

One hundred people participated by responding to fliers posted on the Iowa State University campus and parts of Ames. Participants were at least 18 years old and indicated that they had normal vision. Participants were also required to have console video game experience (e.g. Xbox, Playstation) so that they would be familiar with the control device. The average reported number of hours spent playing video games per week was 10.88 (sd=9.45). If potential participants did not have prior video game experience they were not allowed to participate. All participants signed informed consent paperwork before the experiment started. Participants were paid ten dollars for their time.

3.1.2 Apparatus

The experiment was conducted using two immersive VR devices at Iowa State University, the C6 and the C4. The C6, shown in Figure 7, is a six-walled CAVE display device with each wall consisting of a 10’x 10’ stereoscopic screen (Cruz et al, 1992, Iowa State, 2005).

The C4 is a similar system, but is a four-walled CAVE and the walls measure 9'x12'. The horizontal viewing angle for three vertical walls was 259.6° and for one horizontal wall, 81.2°. The vertical viewing angle for one vertical and one horizontal wall was 113.19° and for one vertical wall alone, 63.8°. Conditions that needed four walls were run in the C6 and conditions that needed three walls or one wall were run in the C4. For the condition in which stereo was used, participants wore CrystalEyes LCD shutter glasses. Participants used a
Logitech Cordless Rumblepad to control their movement and selections in the virtual environment. Participants stood facing the front screen from 84” and did not move from that spot until the simulation was over. Participants were allowed to look in any direction that they wanted while the simulation was running.

### 3.2 Procedures

#### 3.2.1 Design

Participants were randomly assigned to one of five conditions (4 walls stereo, 4 walls glasses mono, 4 walls no glasses mono, 3 walls no glasses mono and 1 wall no glasses mono) in order to test the two experimental factors; the presence of stereo and field of view (FOV) while operating the Virtual Battlespace (Table 1 and Figure 8). Three of the conditions contained twenty participants, but the other two conditions had twenty-one and nineteen participants due to a labeling error (4 walls stereo and 4 walls glasses mono, respectively). This level of error does not impact the validity or reliability of the results.
Field of view (FOV) was tested by altering the number of projection walls used for three different conditions. The smallest FOV was one wall in front of the participant. The medium FOV was one wall in front of the participant and one wall on each side. The largest FOV was achieved using one wall in front, one on each side and one beneath the participant. One experimental condition used the large FOV setup of four walls, but the participant wore shutter glasses and the display was projected in stereo. The final condition had the same setup as the stereo condition, but the display was projected in mono in order to account for the potential effects to users in the stereo condition just from wearing active shutter glasses (Figure 8).

<table>
<thead>
<tr>
<th></th>
<th>Glasses</th>
<th>No Glasses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Stereo</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 The five experimental conditions
Participants were instructed that their task was to explore the environment so that they would be able to take a memory test on what was present and what was occurring during a battle simulation in the environment, while at the same time periodically focusing on alerts generated by the UAVs to classify videos of convoys as either “hostile” or “friendly.”

Figure 8  Graphical representation of the five conditions
Participants were told to “Investigate what is happening in the environment so that you will be able to take a memory test at the end of the simulation about the events of the scenario and units involved”. All participants were then given the same instructions on how to use the game pad and some examples of what the scenario would look like and how to correctly identify the convoys. A hostile convoy was classified by any vehicle in the convoy carrying a weapon and the friendly convoy was devoid of weapons (Figure 9).

The simulation ran for approximately fifteen minutes. During this time participants navigated around the VE with the game pad to attempt to get their best possible understanding of what was occurring. Twelve alerts at a frequency of one per minute were given to the participant while they were observing and navigating around the VE. When the participant was ready to view the alert, the simulation automatically moved them to the location that the alert was generated from (Figure 10). The task of determining whether or not the convoy is a threat serves two purposes for the experiment. The first is to identify the visual acuity difference between different experimental conditions. The secondary purpose of the alerts was to prevent the participants from staying in one location the entire time and to force them to constantly reorient themselves in the environment. Participants were only questioned about the scenario that played out in the VE and the units involved, but not their responses on the alerts.

The scenario is a simple, but representative, Air Force mission. Real missions would have a great deal more activity and visual clutter, but because participants were not experienced military personnel, information was kept to a minimum. The scenario centers on blue forces attempting to destroy the red base. Initially, red forces circle between the base
and red SAM sites and blue forces approach from the northeast. The swarm field is located to the south of the SAM sites and shows activity throughout the scenario. Eventually the blue

Figure 9 Enlarged example of vehicles participants saw in the convoy. A) has a weapon indicating it is hostile. B) has no weapon; thus it is friendly.
units reach the SAM sites and lose some units, but continue west to destroy all of the red air units and finally attack the red base.

3.2.2 Measures

Seven measures were used after the experiment in order to evaluate participants’ performance on memory tasks as well as aspects of their experience in the simulation. Six were qualitative, and one, the memory questionnaire, was quantitative. All instruments can be found in Appendix B. They first took a five-minute immersive tendency questionnaire,

Figure 10 Example of an alert video. The participant sees a convoy driving down a road from an unmanned aerial vehicle.
then after receiving instructions, they did the simulation (15 minutes) and then completed six other questionnaires within the hour.

The research focused on the measures of memory performance, but additional instruments were chosen for two purposes: to explore potential correlations between the conditions and these measures (i.e. immersive tendency, situation awareness and presence), as well as noting factors that would add potential noise to the data (i.e. simulator sickness, usability and workload).

### 3.2.2.1 Immersive Tendency Questionnaire

The first questionnaire that participants encountered was the Immersive Tendency Questionnaire (ITQ), which was used to infer the degree to which someone is likely to become immersed in a virtual environment (Witmer and Singer, 1998). Participants completed this questionnaire before the simulation started. The ITQ uses a Likert scale (1-7) containing 29 items and asks questions such as “Do you easily become deeply involved in movies or TV dramas?” Ratings are averaged over the 29 questions to calculate the final instrument score. Higher scores indicate a greater tendency to become immersed in a virtual environment. The score can be used to predict scores on a presence questionnaire and determine if there is a difference between participants’ presence scores due to experimental manipulations, or internal differences.

### 3.2.2.2 Memory Test

After the simulation was complete, participants took a memory test consisting of 15 multiple-choice and fill-in-the-blank questions about the number of military units shown in
the simulation at given times, where units were located, and what they were doing. The questions were designed to test whether increasing FOV or incorporating stereo displays would affect participants’ retention of information about their environment. This instrument was scored by assigning one point to each question, such that a perfect score was a 15.

3.2.2.3 User Questionnaire

Participants then answered open-ended questions about their experience during the simulation for additional usability information. Several of the questions asked participants to identify the strategies they used to view the environment, determine what was occurring and how they would move between different areas (i.e. from swarm to general battlefield). Other questions inquired as to what they liked and disliked about the simulation. The questionnaire also included how many hours per week the participant played video games.

3.2.2.4 Situation Awareness Rating Technique

Situation awareness was measured using the situational awareness rating technique (SART) (Taylor, 1989). This method was chosen rather than the SAGAT (Endsley, 1998) because of the need to stop the simulation to perform it, whereas the SART is administered at the conclusion. The SART is a subjective test that can be used in several versions that use different numbers of questions. This experiment used the 10D SART, which uses ten dimensions (one question for each dimension) that can be simplified into three main components of situation awareness. These components include attentional demand, attentional supply, and understanding. Attentional demand includes instability of situation,
variability of situation, and complexity of situation; attentional supply includes arousal, spare mental capacity, concentration, and division of attention; and understanding involves information quantity, information quality, and familiarity. Situation awareness is calculated by subtracting the 'supply' factor from the 'demand' factor, then subtracting that from the 'understanding' factor (SA = U – (D – S)). Each factor score can range from 1-7 and the overall score can range from 0-14, with higher numbers indicating higher levels of that component.

3.2.2.5 Simulator Sickness Questionnaire

The Simulator Sickness Questionnaire (SSQ) was used to determine the perceived physical effects of the simulation (Kennedy et al, 1993). The SSQ is a standard test issued to determine subjective simulator sickness values. The SSQ allows participants to identify symptoms they may have experienced during the simulation on a scale of 0-3 (none to severe). The SSQ has three additional sub-scales to further analyze participants' discomfort, oculomotor, nausea and disorientation. There are 16 items, with each item's score used in the sum of one or more of the sub-scale totals (e.g. Headache is included in the oculomotor sum, but not the other sub- scales), the sums of each sub- scale are multiplied by a specified weight giving their final scores. The total SS score is calculated by multiplying a specified weight to the sum of each sub-scales sum. There is a different range of scores for each subscale and total (Table 2). To give an idea of what potential score ranges indicate, table 2 displays the scores participants would receive if they were to indicate the same response for each element of subscale. For example, if a participant selected ‘3’ or ‘severe’ on each element that corresponded with the nausea subscale, that score would be 200.34.
### Table 2 All of the possible score ranges for each subscale and total score for the SSQ.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Nausea</th>
<th>Oculomotor</th>
<th>Disorientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slight</td>
<td>78.54</td>
<td>66.78</td>
<td>53.06</td>
<td>97.44</td>
</tr>
<tr>
<td>Moderate</td>
<td>157.08</td>
<td>133.56</td>
<td>106.12</td>
<td>194.88</td>
</tr>
<tr>
<td>Severe</td>
<td>235.62</td>
<td>200.34</td>
<td>159.18</td>
<td>292.32</td>
</tr>
</tbody>
</table>

#### 3.2.2.6 Presence Questionnaire

The Presence Questionnaire (PQ) was used to determine what degree of presence the participants felt during the simulation (Witmer and Singer, 1998). The PQ uses a Likert scale containing 32 items and asks questions such as 'How much did the visual aspects of the environment involve you?' Several items are reverse scored and then the questionnaire is summed to generate a total presence score, ranging from 32-224. Higher scores indicate a greater degree of presence experienced by the participant while in the virtual environment. Each question in the PQ is also scored as one or more of four factors related to presence: control, sensory, distraction and realism.

#### 3.2.2.7 Workload Questionnaire (NASA-TLX)

Participants’ perceived workload was measured using the NASA-TLX (Hart and Staveland, 1988). This is a subjective questionnaire that uses six factors with descriptions of each that the participant uses to indicate a higher or lower (score) with a Likert scale ranging from 1-7. The factors are mental demand, physical demand, temporal demand, effort, performance and frustration. Each factor is scored independently and all of the scores are averaged to generate a total workload score ranging from 1 - 7, where a higher number indicates perception of a higher workload or worse performance. This method is as effective as the original weighted scores method, but much easier to employ (Moroney et al, 1992).
CHAPTER 4 RESULTS

This chapter describes the analysis of the data. There are three main analyses performed; correlational analysis was used to compare scores across conditions on each of the measures, ANOVA was performed on the three conditions of field of view manipulations, and t-tests were used to compare stereo versus mono displays and the use of shutter glasses. The measures tested include simulator sickness (SS), situation awareness (SA), workload (WL), memory, hours gaming and presence.

4.1 Correlation

A correlation matrix was created comparing every participant's scores on each instrument (across groups), rather than between the different groups of participants, to determine how all of the factors in the study were related. The memory tests, the number of hours playing video games per week, and all of the subjective questionnaires, including their subscales, were compared. Aside from intra-scale correlations, correlations were not higher than 0.45. However, there were statistically significant correlations. Three positively correlated regions emerged from the data; SS and WL, ITQ and PQ and SA, memory and hours played. SS and WL have an $r^2 = .29$, $p < .01$. ITQ and PQ have an $r^2 = .33$, $p < .01$. SA and memory have an $r^2 = .35$, $p < .001$ and SA and hours played only have an $r^2 = .14$, but the SART sub-scale supply is correlated with hours played at $r^2 = .21$, $p < .05$. Memory and hours played have an $r^2 = .2$, $p < .01$.

One method of highlighting these groupings is by graphing them using a software tool called PERMAP that enables a dataset to be viewed as nodes spaced out in relation to one another in multiple dimensions to identify how objects interact (Figure 11) (PERMAP v11.6). PERMAP uses a multidimensional scaling (MDS) algorithm in order to determine
object-to-object proximity or dissimilarity. To standardize the data for PERMAP, all of the correlations were added by one and then divided by two, which made all of the values range from zero to one instead of positive and negative correlations. PERMAP then maps out the nodes with their proximity to one another based on their value. By doing this, items that were positively correlated were closer to each other and further away from items that were negatively correlated to them. Figure 12 indicates the correlations among the different measures. Note that memory and SA are most highly correlated, while memory and presence are not highly correlated.

Figure 11 Spatial mapping of the relationships between dependent variables. Closer proximity indicates a stronger positive correlation and further away indicates a negative correlation.
Figure 12 Correlations between measures. Red (darker lines) indicates negative correlation and green (lighter lines) positive. Line thickness indicates correlation strength.
Aside from statistically significant results, the positive and negative correlations between the measures provided valuable information about the general trends in the data, for example, SS appears to have negative impact on presence and memory, but is reduced with higher levels of video game playing. SA is positively related to hours of gaming and immersive tendency (Table 3).

There were many intra-scale correlations: the presence scale correlated positively with the sensory, control, realism and distraction scales ($r^2 = .82, .84, .62$ and .32, respectively). The SART scale correlated positively with the understanding and supply subscales: $r^2 = .73$ and .71. The SART scale was negatively correlated to the demand subscale: $r^2 = -.59$. The workload scale was positively correlated with the mental, physical, temporal, performance, effort and frustration scales $r^2 = .64, .57, .68, .64, .39$ and .52. The simulator sickness questionnaire total was positively correlated with the nausea, oculomotor and disorientation scales $r^2 = .90, .93$ and .95.

<table>
<thead>
<tr>
<th></th>
<th>Hours</th>
<th>ITQ</th>
<th>Presence</th>
<th>Memory</th>
<th>SA</th>
<th>WL</th>
<th>SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours</td>
<td>0.13</td>
<td>0.08</td>
<td>0.2</td>
<td>0.14</td>
<td>-0.14</td>
<td>-0.15</td>
<td></td>
</tr>
<tr>
<td>ITQ</td>
<td></td>
<td>0.33*</td>
<td>0.02</td>
<td>0.13</td>
<td>0.04</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>Presence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Memory</td>
<td></td>
<td>0.04</td>
<td>0.23*</td>
<td>0.07</td>
<td>-0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.35*</td>
<td>-0.07</td>
<td></td>
</tr>
<tr>
<td>WL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.06</td>
<td>-0.31*</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.29*</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Correlations between dependent variables. *=p<.05
4.2 Field of View

An ANOVA was performed to determine any significant differences between the field of view manipulated conditions. There were two statistically significant results from the field of view conditions. The first was physical workload (WL), with the four, three and one wall conditions scoring 1.8, 1.7 and 1.2 out of 7 respectively (F(2,58) = 3.154, p=.05) (Figure 13). As shown by the significant bars, the four and three wall conditions did not have significantly different WL, but the WL for one wall was significantly less. The other

![Figure 13 Field of View for Physical Workload (populations significantly different)](image-url)
significant result was presence sub-scale control, (i.e. related to the degree to which participants rated how easily it was to interact with the VE) with the four, three and one wall conditions scoring 4.3, 4.6 and 3.6 out of 13 respectively (F(2,58) = 15.4, p=.001) (Figure 14). Each of the conditions has significantly different levels of control. High scores on these scales indicate higher physical WL and presence control, respectively.

Outliers were calculated to be values that were plus or minus two times the standard deviation. Upon removing outliers from the data (5 scores), the presence scores were found to be significantly different across fields of view, with the four, three and one wall conditions scoring 132.2, 143.1 and 135.8 respectively (F(2,57) = 3.9, p=.03) (Figure 15).
To increase the chance of finding significant results between the different levels of field of view, all of the conditions that used four walls to display the simulation were pooled together. When ANOVA was performed with all of the four wall conditions pooled, the test resulted in the frustration workload becoming significant too, indicating the same trend as the physical workload, that the four wall condition produced the highest workload rating (Figure 16). There was no significant difference between the conditions for memory (Figure 17).

Figure 15 Field of View for Presence (populations significantly different)
Figure 16 Field of View for Frustration Workload (pooled) (populations significantly different)
Other analyses did not indicate significant results, but there were trends in some of the data that may be indicators to be confirmed by future research. The other workload subscales had the highest values for the 3 wall condition. This trend was also displayed on the simulator sickness scores and presence scores (Figure 18(A)).

The opposite result was shown with the hours, SA supply and SA demand scores, with the 3 wall condition yielding the lowest score (Figure 18(B)).
The statistically non-significant data that displayed the downward trend in field of view were memory, disorientation and overall workload (Figure 18(C)).

The data that showed an upward trend for field of view were total situation awareness and understanding (Figure 18(D)).

All of the results for the field of view data, including the non-statistically significant values are contained in Table 4.

![Figure 18 Representations of the four trends displayed in the field of view data, as referenced in the above text.](image-url)
<table>
<thead>
<tr>
<th></th>
<th>4 walls</th>
<th>3 walls</th>
<th>1 wall</th>
<th>F</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Presence</strong></td>
<td>133.8</td>
<td>143.1</td>
<td>135.75</td>
<td>2.83</td>
<td>0.07</td>
</tr>
<tr>
<td>Sensory</td>
<td>3.9</td>
<td>4.1</td>
<td>4</td>
<td>0.3</td>
<td>0.74</td>
</tr>
<tr>
<td>Control</td>
<td>4.3</td>
<td>4.6</td>
<td>3.6</td>
<td>15.4</td>
<td>0</td>
</tr>
<tr>
<td>Realism</td>
<td>3.4</td>
<td>3.6</td>
<td>3.5</td>
<td>0.46</td>
<td>0.63</td>
</tr>
<tr>
<td>Distraction</td>
<td>4.1</td>
<td>4.6</td>
<td>4.3</td>
<td>2.04</td>
<td>0.14</td>
</tr>
<tr>
<td><strong>Memory</strong></td>
<td>8.5</td>
<td>8.3</td>
<td>8.25</td>
<td>0.06</td>
<td>0.95</td>
</tr>
<tr>
<td><strong>Situation Awareness</strong></td>
<td>5.7</td>
<td>5.9</td>
<td>6.4</td>
<td>0.72</td>
<td>0.72</td>
</tr>
<tr>
<td>Understanding</td>
<td>12.9</td>
<td>13.2</td>
<td>13.6</td>
<td>0.15</td>
<td>0.86</td>
</tr>
<tr>
<td>Demand</td>
<td>10.1</td>
<td>9.5</td>
<td>9.7</td>
<td>0.19</td>
<td>0.83</td>
</tr>
<tr>
<td>Supply</td>
<td>14.3</td>
<td>14.6</td>
<td>15.1</td>
<td>0.38</td>
<td>0.69</td>
</tr>
<tr>
<td><strong>Workload</strong></td>
<td>3.04</td>
<td>3.18</td>
<td>2.67</td>
<td>2.88</td>
<td>0.06</td>
</tr>
<tr>
<td>Mental</td>
<td>4.9</td>
<td>4.5</td>
<td>4.4</td>
<td>0.05</td>
<td>0.95</td>
</tr>
<tr>
<td>Physical</td>
<td>1.9</td>
<td>1.7</td>
<td>1.2</td>
<td>3.2</td>
<td>0.05</td>
</tr>
<tr>
<td>Temporal</td>
<td>2</td>
<td>2.8</td>
<td>2.3</td>
<td>1.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Performance</td>
<td>3</td>
<td>3.4</td>
<td>2.9</td>
<td>0.8</td>
<td>0.45</td>
</tr>
<tr>
<td>Effort</td>
<td>4</td>
<td>4.4</td>
<td>3.4</td>
<td>2.27</td>
<td>0.11</td>
</tr>
<tr>
<td>Frustration</td>
<td>2.95</td>
<td>2.4</td>
<td>2</td>
<td>2.63</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>Simulator Sickness</strong></td>
<td>29.7</td>
<td>29.92</td>
<td>23.75</td>
<td>0.34</td>
<td>0.71</td>
</tr>
<tr>
<td>Nausea</td>
<td>26.8</td>
<td>30.1</td>
<td>14.3</td>
<td>1.55</td>
<td>0.22</td>
</tr>
<tr>
<td>Oculomotor</td>
<td>22.4</td>
<td>29.9</td>
<td>19.7</td>
<td>0.81</td>
<td>0.45</td>
</tr>
<tr>
<td>Disorientation</td>
<td>50.4</td>
<td>43.8</td>
<td>31.3</td>
<td>0.71</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 4 Overview of all the ANOVA results for FOV without pooling.
4.3 Graphics

T-tests were performed to determine if there were any significant differences between participants viewing the simulation in stereo or mono and if there were significant differences for wearing shutter glasses or not.

4.3.1 Stereo vs. Mono

Presence scores were not significantly different between the stereo and mono conditions. However, analyzing each item separately yielded items on the questionnaire that were significant. The ability to move in the environment, the ability to search and the ability to examine objects were all statistically significantly higher in the mono condition. Statistically higher for the stereo condition were SSQ sub scales disorientation \( t(37) = -1.86, p = .05 \) (Figure 20) and oculomotor discomfort \( t(37) = -1.83, p = .05 \) (Figure 19).
Figure 19 Stereo vs. Mono scores on the oculomotor simulator sickness sub-scale. (populations significantly different)
Figure 20 Stereo vs. Mono scores on the disorientation simulator sickness sub-scale. (populations significantly different)
Scores on the memory test were not significantly impacted by stereo and mono manipulations (Figure 21).

Figure 21 Stereo vs. Mono scores for memory (no significant difference)
4.3.2 Glasses vs. No Glasses

Temporal workload was significantly higher for participants wearing glasses, with glasses participants scoring 3.1 and no glasses scoring 2.0, $t(38) = 2.48, p = .01$ (Figure 22).

![Figure 22 Glasses vs. No Glasses scores for Temporal Workload (populations significantly different)]
Scores on the memory test were not significantly impacted by the presence or absence of shutter glasses (Figure 23).

Figure 23 Glasses vs. No Glasses scores for memory (no significant difference)
CHAPTER 5 SUMMARY AND DISCUSSION

5.1 Analysis

The hypothesis that the highest level of immersion in the experiment will yield the highest scores on a performance-based memory test and the secondary goal to determine which factors (presence, situation awareness (SA), simulator sickness (SS) and workload (WL)) influence performance were partially supported. Increasing the FOV from one wall to three walls had a small positive effect on presence; however, increasing the number of walls to four lowered presence ratings. Stereo did not have a positive effect on presence, possibly due to the increased SS that the stereo condition caused. At no point did any of the independent variables significantly affect participant's scores on memory, so there cannot be the conclusion from this experiment that increasing immersion increases a user’s memory of the simulation. The data indicate that there can be a positive influence of increasing the field of view in the simulation, but that it may also be possible that that amount of screen can overload the user when four walls were used.

This research does not rule out, however, the potential benefits of using immersive technology that allow a user to perform command and control functions from an egocentric viewpoint. It is also possible that a difference could be found if the field of view was decreased more for another condition, e.g. using a desktop computer display. The results found may be specific for the ranges of field of view used and not generalizable to smaller displays.
It appears that the use of stereo for this particular type of application is not beneficial (i.e. obtaining task-important information is possible from a great distance); the only statistically significant differences between the conditions favored the use of a mono projection. The increase in SS caused by stereo may have led to the decrease in the three elements of presence, and as those results were not mirrored by the glasses condition, the loss of presence on the effects of wearing shutter glasses cannot be blamed.

The main performance metric was memory, and the data reveal several important correlations that could attribute to better memory retention of the VE. As predicted, memory is strongly correlated to situation awareness and negatively correlated to workload, specifically the sub-scale frustration. Despite memory being significantly correlated with SA and SA significantly correlated with presence, there was almost no correlation between memory and presence. Although results did not show differences in memory through experimental conditions, correlations have been identified that indicate how different factors relate to memory retention in an immersive command and control application. By improving these factors, such as increasing SA and decreasing SS, it could be expected that users would retain more information from the VE.

Several studies have indicated that larger fields of view improve memory and spatial tasks (Slater et al, 1996, Tan et al, 2003, and Czerwinski et al, 2003), but this experiment did not find that result. Increasing the field of view has also been shown to increase presence (Prothero & Hoffman, 1995) and increase simulator sickness (Seay et al, 2001), neither of which were results replicated in this experiment. Memory and presence are positively correlated in this experiment, which is the same result found by Lin et al 2002. However,
this experiment did not find the result to be significant nor significantly correlated to FOV as Lin et al found.

Stereo graphics did produce some simulator sickness that was statistically significant, as could be expected based on other research (Mollenhauer, 2004).

Overall, the increase in immersion unexpectedly had little impact, but situation awareness was significantly correlated to memory, a long held belief (Ma & Kaber, 2007).

The results from this experiment add to the understanding of the attributes that are related to memory performance in command and control; high SA, low WL frustration, and higher hours playing video games. Also critical to understanding the entire picture is that SS is significantly negatively correlated with SA and positively with WL, while presence is significantly positively correlated to SA. This experiment also revealed that certain differences between the levels of immersion may not have effects to memory.

5.2 User Feedback

This research was part of an iterative process to create a viable method for the future visualization of the battlefield and management of UAVs, thus there was an attempt to collect some usability information from participants to make future versions better and to assist with interpreting the results of the other measures.

By sorting participants’ comments, there were several themes that occurred frequently. The first was the control scheme used: the two analog stick controller was a very familiar method of interaction for most of the participants, but the mapping of the directions was not what many of them had learned to expect in a 3D environment (e.g. first-person shooters and flight simulators). This interfered with their ability to navigate and may have decreased their level of presence.
Another common frustration that participants noted was that the simulation moved too slowly and that it was hard to determine what was occurring because of this. This was a problem within the experiment because it likely caused people to become bored and not pay attention as much as they should, or possibly divert attention because they had a misconception about the amount of activity that was actually occurring.

A final request brought up by many participants was that the icons include more information, such as a squadron consisting of three planes would be marked with a '3' and missiles would be graphically linked to the entity that fired them. Some participants felt that the amount of information available to them was somewhat sparse and felt they would have performed better with more information associated with the iconography and a method to log information that they deemed important.

5.3 Implications

5.3.1 Command and Control Visualization

User feedback provided helpful insight for what pieces of information users needed to adequately understand their environment. Other research has highlighted the importance of salience in entities versus realism (Dragon) and this research affirms that notion because users commented that numerical values would have been beneficial for keeping track of UAV aggregates.

This experiment only lasted approximately fifteen minutes and numerous participants indicated varying levels of eye and body fatigue from standing in the CAVE and holding the controller. In actual military usage, users would be engaged for longer periods of time, thus attention needs to be paid toward reducing the physical workload.

Many users had difficulty focusing on important things that occurred in the environment. It would be helpful to investigate methods to guide users’ attention to changes that they might miss because the environment is so large. This would be extremely critical in
a battle scenario in which many pieces of information are changing constantly. It may also be important to devise additional cues as to the speed at which the units are traveling, because many participants did not accurately gauge the high speeds of the units. Small scale and potentially misleading graphical representation of the units can make it appear as though units are moving very slowly when they are traveling hundreds of miles per hour. It is also clear that even with a command and control visualization that is highly intuitive, there will need to be thorough instruction given before people can adequately use the system (e.g. some participants had difficulty understanding what the relevant information was)

5.3.2 Virtual Reality

The use of shutter glasses and stereo graphics did not improve memory scores and yielded some negative effects in this research. Researchers need to be careful using stereo graphics and make sure that they are actually beneficial in their domain. This was possibly due to entities in this environment being represented as being far away from the user and therefore stereo as a cue was not as essential as if users were examining virtual entities up close. It is also possible that the mere use of stereo impeded participants because shutter glasses may have not been synched perfectly with the display, resulting in a ghosted image.

This research found important positive correlations between memory, situation awareness and presence. These factors were negatively correlated with simulator sickness and workload, which were positively correlated with one another. This further highlights the importance of reducing the negative impacts of workload and simulator sickness for optimal performance. Future research is needed to identify what exactly is driving these factors since this research did not find that the level of immersion is responsible.

A positive correlation between hours of video game experience and memory is an interesting result for the future as virtual reality systems become more prevalent methods for visualization. This result may indicate that people who play more video games may perform
better in virtual reality. More research is needed to determine if it is the video game playing that creates this correlation, or if it is something else about those individuals.

Some participants did not notice semantically significant events during the simulation (e.g. missiles firing), which indicates a need for more assistance for users to identify salient changes in the environment. A VR application driven by real-time data likely requires training and other user assistance for guiding their attention toward relevant data and events.

This research also highlights the need to carefully establish how an application will benefit from different elements of immersion. The most pragmatic approach to understanding the specific scenario in this experiment appeared to be maintaining a distant overview of the VE; unit placement and activity allowed one 10’x10’ display wall to be sufficient for participants to view all of the relevant information with good resolution and detail (Figure 24). This approach may have negated a genuine need for stereoscopic graphics and extremely large fields of view.

Figure 24 Representative images of the entire scenario. This demonstrates that a large field of view was not necessary for this specific simulation because all activity was easily viewed the entire time.
5.4 Limitations

The reason there was little difference in memory across the different conditions could be due to insufficient information presented to the participants (i.e. there would have been greater statistical power if there had been a greater number of things to remember). Or, the scores may reflect the average number of correct responses that would be remembered at any level of immersion because there was relatively little happening during the simulation. Many participants became noticeably disengaged from the task after several minutes and would periodically fly to regions of the VE that had no activity at all just to explore. This lack of engagement could also account for no difference in presence scores. The lack of engagement could also have been due to the limited amount of interaction participants had with the environment in this more observation-based task.

There were large differences between the fields of view in the conditions, but every condition was a large field of view by comparison to a traditional display. Including smaller displays in the experiment, similar to previous research (e.g. Slater et al 1996), may have indicated more about the effects of FOV.

None of the participants had experience with VEs, which could have impacted a number of the results, such as similar levels of presence across conditions and higher simulator sickness scores.

5.5 Future Research

To increase the chances of identifying differences between the conditions it would be valuable to include more units, more activity, and more action spread throughout the environment in future experiments, not only to uncover differences in the necessary field of view needed to interpret the scenario accurately, but also more closely replicate real world situations. Limiting the area that participants could explore would also help keep them focused on the relevant content. Including head-tracking or even eye-tracking would also be
a useful tool for monitoring a participant’s focus was on the relevant content. Head and eye-tracking would also be useful as a measure of which events and icons drew attention.

It would be valuable to run the experiment again with much smaller displays than the smallest display size of 10'x10' to identify whether there are differences in field of view when the range is larger. Most current displays are much smaller than the smallest used in this experiment; comparing CAVE conditions to traditional displays would help determine the value of immersive technology for command and control.

There also remains the need to compare three-dimensional to two-dimensional command and control visualizations. It is likely the case that each has advantages and disadvantages, and it would be valuable to identify how to integrate the visualizations.

Providing participants with training or using a within subjects design could increase the sensitivity of finding statistically significant differences. Future experiments would incorporate more quantitative measures of performance than memory to better gauge the utility of immersive VR. Giving participants a mission to complete with specific goals, e.g., maintain appropriate fuel levels, avoid enemy units, locate and destroy targets, would provide more complete information on how VR can be used for command and control.

Lastly, an advantage of CAVE VR over other types of VR such as HMD is the ability to collaborate because of the shared space, so it would be valuable to study the effects of multiple participants simultaneously engaging in a mission.

Participants in the current research maintained the role of manager, but later iterations of Battlespace will allow users to pilot individual UAVs. A great deal of research needs to be done to ensure safe transitions between modes and to explore how to keep relevant information available to the pilot while in flight.

Net-centric operations demand that every aspect of command and control communicate effectively with each other in order to create the most comprehensive battle space. The Virtual Battlespace could play an important role in maintaining high situation
awareness and information validity between numerous platforms. Future work will network the CAVE with other platforms such as multi-touch table interfaces, other CAVEs, PC’s and mobile devices.
APPENDIX

Presence Questionnaire

Post experiment questionnaire
Please read the questions carefully and circle the appropriate number from 1 to 7.

1. How much were you able to control events?

   1  2  3  4  5  6  7
   NOT MODERATELY WELL
   WELL

2. How responsive was the environment to actions that you initiated (or performed)?

   1  2  3  4  5  6  7
   NOT RESPONSIVE MODERATELY RESPONSIVE
   RESPONSIVE

3. How natural did your interactions with the environment seem?

   1  2  3  4  5  6  7
   NOT NATURAL MODERATELY NATURAL
   NATURAL

4. How completely were all of your senses engaged?

   1  2  3  4  5  6  7
   NOT ENGAGED MODERATELY ENGAGED
   ENGAGED

5. How much did the visual aspects of the environment involve you?

   1  2  3  4  5  6  7
   NOT MUCH MODERATELY MUCH
   MUCH

6. How much did the auditory aspects of the environment involve you?

   1  2  3  4  5  6  7
   NOT MUCH MODERATELY MUCH
   MUCH

7. How natural was the mechanism which controlled movement through the environment?

   1  2  3  4  5  6  7
   NOT NATURAL MODERATELY NATURAL
   NATURAL
8. How aware were you of events occurring in the real world around you?

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9. How aware were you of your display and control devices?

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10. How compelling was your sense of objects moving through space?

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11. How inconsistent or disconnected was the information coming from your various senses?

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12. How much did your experiences in the virtual environment seem consistent with your real-world experiences?

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13. Were you able to anticipate what would happen next in response to the actions you performed?

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14. How completely were you able to actively survey or search the environment using vision?

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15. How well could you identify sounds?

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16. How well could you localize sounds?

1 2 3 4 5 6 7
NOT WELL MODERATELY WELL VERY WELL

17. How well could you actively survey or search the environment using touch?

1 2 3 4 5 6 7
NOT WELL MODERATELY WELL VERY WELL

18. How compelling was your sense of moving around inside the virtual environment?

1 2 3 4 5 6 7
NOT COMPPELLING MODERATELY COMPPELLING VERY COMPPELLING

19. How closely were you able to examine objects?

1 2 3 4 5 6 7
NOT CLOSELY MODERATELY CLOSELY VERY CLOSELY

20. How well could you examine objects from multiple viewpoints?

1 2 3 4 5 6 7
NOT WELL MODERATELY WELL VERY WELL

21. How well could you move or manipulate objects in the virtual environment?

1 2 3 4 5 6 7
NOT WELL MODERATELY WELL VERY WELL

22. To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?

1 2 3 4 5 6 7
NOT DISORIENTED MODERATELY DISORIENTED VERY DISORIENTED
23. How involved were you in the virtual environment experience?

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24. How distracting was the control mechanism?

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25. How much delay did you experience between your actions and expected outcomes?

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26. How quickly did you adjust to the virtual environment experience?

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27. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

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28. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

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29. How much did the control devices interfere with performance of assigned tasks or other activities?

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30. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

1 2 3 4 5 6 7
NOT WELL MODERATELY WELL VERY WELL

31. Did you learn new techniques that enabled you to improve your performance?

1 2 3 4 5 6 7
NOT MUCH MODERATELY MUCH VERY MUCH

32. Were you involved in the experimental task to the extent that you lost track of time?

1 2 3 4 5 6 7
NOT MUCH MODERATELY MUCH VERY MUCH
Immersive Tendency Questionnaire

Pre experiment questionnaire
Please read the questions carefully and circle the appropriate number from 1 to 7.

1. Do you ever get extremely involved in projects that are assigned to you by your boss or your instructor, to the exclusion of other tasks?
   NOT
   OFTEN

2. How easily can you switch your attention from the task in which you are currently involved to a new task?
   NOT
   EASILY

3. How frequently do you get emotionally involved (angry, sad, or happy) in the news stories that you read or hear?
   NOT
   FREQUENTLY

4. How well do you feel today?
   NOT
   WELL

5. Do you easily become deeply involved in movies or TV dramas?
   NOT
   EASILY
6. Do you ever become so involved in a television program or book that people have problems getting your attention?

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7. How mentally alert do you feel at the present time?

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<td>ALERT</td>
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<td>ALERT</td>
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</table>

8. Do you ever become so involved in a movie that you are not aware of things happening around you?

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<td>VERY</td>
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</table>

9. How frequently do you find yourself closely identifying with the characters in a story line?

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<tbody>
<tr>
<td>NOT</td>
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</table>

10. Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?

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<thead>
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<th>1</th>
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<tbody>
<tr>
<td>NOT</td>
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<td>VERY</td>
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<td>OFTEN</td>
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</tbody>
</table>

11. On average, how many books do you read for enjoyment in a month?

12. What kind of books do you read most frequently?
(CIRCLE ONE ITEM ONLY!)

Spy novels Fantasies Science fiction Adventure
Romance novels Historical novels
Westerns Mysteries Other fiction Biographies
Autobiographies Other non-fiction
13. How physically fit do you feel today?
   1 2 3 4 5 6 7
   NOT MODERATELY VERY
   FIT FIT

14. How good are you at blocking out external distractions when you are involved in something?
   1 2 3 4 5 6 7
   NOT MODERATELY VERY
   GOOD GOOD

15. When watching sports, do you ever become so involved in the game that you react as if you were one of the players?
   1 2 3 4 5 6 7
   NOT MODERATELY VERY
   OFTEN OFTEN

16. Do you ever become so involved in a daydream that you are not aware of things happening around you?
   1 2 3 4 5 6 7
   NOT MODERATELY VERY
   OFTEN OFTEN

17. Do you ever have dreams that are so real that you feel disoriented when you awake?
   1 2 3 4 5 6 7
   NOT MODERATELY VERY
   OFTEN OFTEN

18. When playing sports, do you become so involved in the game that you lose track of time?
   1 2 3 4 5 6 7
   NOT MODERATELY VERY
   OFTEN OFTEN
19. Are you easily disturbed when working on a task?

NOT       MODERATELY       VERY
EASILY     EASILY           EASILY

20. How well do you concentrate on enjoyable activities?

NOT       MODERATELY       VERY
WELL      WELL             WELL

21. How often do you play arcade or video games? (OFTEN should be taken to mean every day or every two days, on average.)

NOT       MODERATELY       VERY
OFTEN     OFTEN            OFTEN

22. How well do you concentrate on disagreeable tasks?

NOT       MODERATELY       VERY
WELL      WELL             WELL

23. Have you ever gotten excited during a chase or fight scene on TV or in the movies?

NOT       MODERATELY       VERY
OFTEN     OFTEN            OFTEN

24. To what extent have you dwelled on personal problems in the last 48 hours?

NOT       MODERATELY       VERY
MUCH      MUCH             MUCH

25. Have you ever gotten scared by something happening on a TV show or in a movie?

NOT       MODERATELY       VERY
OFTEN     OFTEN            OFTEN
26. Have you ever remained apprehensive or fearful long after watching a scary movie?

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<tbody>
<tr>
<td>NOT</td>
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<td>MODERATELY</td>
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27. Do you ever avoid carnival or fairground rides because they are too scary?

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<tbody>
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</table>

28. How frequently do you watch TV soap operas or docu-dramas?

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<tbody>
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<td>NOT</td>
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29. Do you ever become so involved in doing something that you lose all track of time?

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<td>NOT</td>
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</table>
SART

Read each question carefully and circle a number from 1 to 7 (low to high).

**Instability of Situation**

How changeable is the situation? Is the situation highly unstable and likely to change suddenly (high), or is it very stable and straightforward (low)?

<table>
<thead>
<tr>
<th>Low</th>
<th>1</th>
<th>2</th>
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<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>High</th>
</tr>
</thead>
</table>

**Complexity of Situation**

How complicated is the situation? Is it complex with many inter-related components (high) or is it simple and straightforward (low)?

<table>
<thead>
<tr>
<th>Low</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>High</th>
</tr>
</thead>
</table>

**Variability of Situation**

How many variables are changing in the situation? Are there a large number of factors varying (high) or are there very few variables changing (low)?

<table>
<thead>
<tr>
<th>Low</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>High</th>
</tr>
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</table>

**Arousal**

How aroused are you in the situation? Are you alert and ready for activity (high) or do you have a low degree of alertness (low)?

<table>
<thead>
<tr>
<th>Low</th>
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<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>High</th>
</tr>
</thead>
</table>

**Concentration of Attention**

How much are you concentrating on the situation? Are you bringing all your thoughts to bear (high) or is your attention elsewhere (low)?

<table>
<thead>
<tr>
<th>Low</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>High</th>
</tr>
</thead>
</table>
Division of Attention

How much is your attention divided in the situation? Are you concentrating on many aspects of the situation (high) or focused on only one (low)?

Low 1 2 3 4 5 6 7 High

Spare Mental Capacity

How much mental capacity do you have to spare in the situation? Do you have sufficient to attend to many variables (high) or nothing to spare at all (low)?

Low 1 2 3 4 5 6 7 High

Information Quantity

How much information have you gained about the situation? Have you received and understood a great deal of knowledge (high) or very little (low)?

Low 1 2 3 4 5 6 7 High

Information Quality

How good is the information you have gained about the situation? Is the knowledge communicated very useful (high) or is it a new situation (low)?

Low 1 2 3 4 5 6 7 High

Familiarity with Situation

How familiar are you with the situation? Do you have a great deal of relevant experiences (high) or is it a new situation (low)?

Low 1 2 3 4 5 6 7 High
Simulator Sickness Questionnaire

Please report the degree to which you experience each of the below symptoms as one of "None", "Slight", "Moderate" and "Severe". Using the scale from "0" (none) to "3" (severe).

<table>
<thead>
<tr>
<th></th>
<th>None</th>
<th>Slight</th>
<th>Moderate</th>
<th>Severe</th>
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</thead>
<tbody>
<tr>
<td>General discomfort</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Fatigue</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Headache</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Eyestrain</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Difficulty focusing</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Increased salivation</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Sweating</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Nausea</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Fullness of head</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>Blurred vision</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Dizzy (eyes open)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Dizzy (eyes closed)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>Vertigo</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>Stomach awareness</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>Burping</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
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**Workload**

Carefully read the description of each item, then go to the next page and circle a number from 1 to 7 (low to high). Feel free to continue to look back to this page to review the descriptions as you answer each item.

<table>
<thead>
<tr>
<th><strong>RATING SCALE DEFINITIONS</strong></th>
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<tbody>
<tr>
<td><strong>Title</strong></td>
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<tr>
<td>MENTAL DEMAND</td>
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<td>PHYSICAL DEMAND</td>
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<td>TEMPORAL DEMAND</td>
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<td>EFFORT</td>
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<td>PERFORMANCE</td>
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<tr>
<td>FRUSTRATION LEVEL</td>
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</table>
Memory Questionnaire

How many red air squadrons were there at the start?

How many blue air squadrons were there at the end?

Which color lost the first squadron?

How many SAM sites are there?

What direction were the blue squadrons coming from relative to the red squadrons (north, east, south, west)?

What city was near the battle?

How many blue squadrons did the SAM sites shoot down?

What direction did the blue squadrons that were shot down come from relative to the SAM sites (north, east, south, west)?

How did the blue squadrons group themselves initially while traveling to the red squadrons?
   A) 2 leading, 4 following
   B) 2 leading, 5 following
   C) 3 leading, 3 following
   D) 5 leading, 2 following

Where did the final blue squadron fly relative to the SAM sites?
   A) north of
   B) between
   C) south of

How many blue squadrons flew into the target at the end of the mission?

Which air unit fires first? (blue/ red)

After hitting the ground target the blue units regroup to what direction of the SAM sites (north, east, south, west)?

How many individual planes were in the largest blue squadron?

How far along in the battle was it when the blue squadrons were shot down? (minutes)
Experiment Questionnaire

Did you notice anything strange about the experiment?

What strategy did you use to determine if a convoy was a threat or not?

Did you notice any kind of pattern in the red air units' flight?

What strategy did you use to move from the swarm to the battlefield?

What strategy did you use to view the battlefield?

Was there anything that helped you a lot to perform your task or remember the scenario?

Was there anything that hindered your performance or made it more difficult to remember the scenario?

What improvements could be made to aid you in understanding and retaining the battlefield?

What features of the virtual environment stood out the most or were most memorable?

How often do you play video games (hours per week)?
REFERENCES


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I would like to thank the Air Force Office of Scientific Research for funding this project and Dr. James Oliver for identifying the need for more human-centered research. Dr. Derrick Parkhurst helped tremendously to guide the design of this experiment and the analysis of the data. Dr. Eric Cooper provided additional expertise with the data analysis.

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I am grateful for the quick actions of Glen Galvin and Kevin Teske, which saved me more than a few times when last minute technical problems threatened to cancel a session. Pam Shill went above and beyond to keep me informed and on schedule during this process. I could always count on Karen Koppenhaver knowing the answer to my questions and letting me know when food was up for grabs. And I appreciate all of the help Beth Hageman and Lynette Sherer provided me during my research; it has been great to work with all of you.

Finally, many thanks to my family for their encouragement, and to my fiancée Amanda for her hours of support and data entry.