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THESIS

EMERGENT LEADERSHIP ON COLLABORATIVE TASKS IN DISTRIBUTED VIRTUAL ENVIRONMENTS

by

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September 2001

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Several Department of Defense agencies are currently investigating the use of distributed collaborative virtual environments (CVE) for the training of small dismounted infantry teams. If these systems are to be successful, they will have to do more than simply allow the team members to execute a task. In addition to assuring that training in the CVE transfers to the real task, we will also have to ensure that aspects of team organization also transfer. In particular, we are investigating whether or not predicted emergent leadership, as measured by standardized personality tests, holds within a CVE or if aspects of the interface interfere.

For a given "real-world" task domain a leader can be predicted based on personality traits of the individuals within the group. The interface utilized with a CVE may adversely affect these traits. In other words, predictive measures of leadership in the real world may not hold in a CVE.

The study reported here will use this predictability to identify the expected leader within a group and determine how the CVE interface affects the ability of the predicted individual to emerge as the leader. It is theorized that the limitations of CVE interfaces (field of view, realism, etc.) will negatively impact the transfer of leadership personality traits into the virtual environment, but not to a degree that the limitation cannot be overcome. These limitations may impact the group dynamics and the emergent leader may not necessarily be the predicted leader by personality traits.

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EMERGENT LEADERSHIP ON COLLABORATIVE TASKS IN DISTRIBUTED VIRTUAL ENVIRONMENTS

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ABSTRACT

Several Department of Defense agencies are currently investigating the use of distributed collaborative virtual environments (CVE) for the training of small dismounted infantry teams. If these systems are to be successful, they will have to do more than simply allow the team members to execute a task. In addition to assuring that essential training in the CVE transfers to the real task, we will also have to ensure that aspects of team organization also transfer. In particular, we are investigating whether or not predicted emergent leadership, as measured by standardized personality tests, holds within a CVE or if aspects of the interface interfere.

For a given "real-world" task domain a leader can be predicted based on personality traits of the individuals within the group. The interface utilized with a CVE may adversely affect these traits. In other words, predictive measures of leadership in the real world may not hold in a CVE.

The study reported here will use this predictability to identify the expected emergent leader within a group and determine how the CVE interface affects the ability of the predicted individual to emerge as the leader. It is theorized that the limitations of CVE interfaces (field of view, realism, etc.) will negatively impact the transfer of leadership personality traits into the virtual environment, but not to a degree that the limitation cannot be overcome. These limitations may impact the group dynamics and the emergent leader may not necessarily be the predicted leader by personality traits.

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I. INTRODUCTION

A. MOTIVATION

In today's fast-paced world more people are relying on technology to bring them together, rather than actually gathering in a common location. Recent technologies, like high-speed Internet access virtual reality (VR), have opened new avenues for social interactions and collaboration efforts between remote locations. We see corporate executives using audio and video conferencing instead of travel. Network cameras are populating homes to keep families close. The military is using shared VR systems for training in lieu of costly real-world exercises. Collaborative Virtual Environments (CVE) are being used at research and design institutions. These technologies are changing the way people communicate, interact, and may be altering how we socialize.

All of these technologies have led to significant research in how groups interact within a virtual environment (VE). Some of this research indicates that the interface, or immersion level, users have when working in a distributed VE (i.e. people are not co-located) can play a major role in how they interact. One example suggests that the user with the most immersive interface will emerge as the leader of the group when no leader is appointed. (Slater, Sadagic, Usoh, & Schroeder, 2000) This result may have been revealed because of the way VE interfaces affect a user's level of immersion and presence within the VE. Presence and immersion are recognized as tightly coupled concepts that cannot always be well defined or measured. Slater, and others, suggest that presence is a psychophysical property that is user dependent and immersion is technological. (Slater & Wilbur, 1997) For example, the immersive qualities of a VE are tied to physical elements of the system like field of view; whereas, presence may be tied to how realistic the images appear to the user. Previous group interaction research conducted by Slater focused on the interaction of group members conducting a collaboration task using different interfaces and thus different immersion levels. This study also focused on distributed group collaboration when users have different immersion levels to readdress Slater's research and to extend the dynamics of personality and group dynamics.

The dynamics involved during group collaboration work often have a significant effect on the outcome of the work produced. The movie, "12 Angry Men" (Lumet, 1957), is a striking example of how a person's personality, and how they communicate, can impact a group's collaboration effort. The film does a good job of demonstrating the dynamics of group deliberations during a jury trial, the personality conflicts, the joint effort, and the functioning of several minds working together to find the truth. Taking a reverse perspective, it is easily seen how the dynamics of a group can impact any single participant. This social dynamic is often termed the "Abilene Paradox." This condition exists when the members of a group succumb to a common goal that is contrary to each individual's goal. As an example, imagine the result when one member of a group makes a suggestion they assume is the goal of the other group members, but different than their own desires. Now, the other group members assume the suggested goal meets the person's desires and they each agree to the suggestion. They agree even though the goal is not their own personal desire. The result is a group that works to achieve a goal that no single member desires.

There are many other factors involved in the dynamics of a group beyond those mentioned above. As an example, some research indicates that an attribute like gender can have an impact on group dynamics (Kimble & McNeese, 1987). It gets more complicated when variations on these factors are considered: group gender mix, leader gender, etc. Given the complexities of group dynamics and the amount of research that exists, shouldn't equal consideration be given to the complexities of group dynamics in virtual environments? Specific attention must be paid to groups that collaborate within a shared virtual environment when the participants are not co-located.

B. OBJECTIVE

This study was designed to whittle away at some of the unknown qualities of collaboration within distributed virtual environments. To this end, the study looked specifically at the relationship between system interface, personality traits, and emergent leadership within a distributed collaborative virtual environment.

It is widely known in social psychology circles that certain personality trait combinations are associated with emergent leadership in group interactions. These trait

combinations are highly dependent on the task domain. For instance, the traits required for emergent leadership within a social domain may not be the same as those within a particular work domain. Emergent leadership traits vary across different task domains, but are constant within that task domain. For a given domain, a leader can be predicted based on personality traits of the individuals within the group. To illustrate, if a group member exhibits traits associated with high verbalization and directive skills, they can be predicted with confidence to emerge as the leader of a group containing members with lower trait scores in those areas. This assumes the traits exhibited are associated with the task domain. (Schultz, 1990; Kimble & McNeese, 1987; Knowlton & McGee, 1994)

This study used this predictability to identify the expected leader within a group and then test the effect of the CVE interface on the ability of the selected individual to emerge as the leader. It was theorized that the limitations of CVE interfaces (field of view, degree of realism, etc.) would negatively impact the transfer of leadership personality traits into the virtual environment, but not to a degree that these limitations could not be overcome. These limitations may impact the group dynamics and the emergent leader may not necessarily be the predicted leader by personality trait.

C. APPROACH

To achieve this objective this study took the approach of designing a CVE that allowed a group to conduct a collaboration task that they were familiar with. The task used was a navigation task within a natural terrain domain. Specifically, the participants were required to search, navigate, identify, and locate four targets within a virtual model of a natural outdoor scene.

The virtual model replicated a section of land at the former Fort Ord military installation in Seaside, California. This model was used because it provided the ability to replicate as closely as possible a real world scene so that comparisons could be made with future work between group collaboration within a CVE and the "real-world" setting. Each participant completed a questionnaire to define two main characteristics associated with this study: personality and task expertise. A personality profile of the individual was recorded along with the individual's self-rating of their expertise on the task. These two criteria were used to group the individuals for the study. Specifically, the groups

were arranged so that one participant could be predicted to emerge as the leader if the same task was conducted in the real world.

During and after the experiment the participants were evaluated regarding the role they played within the group. Measures were taken to evaluate who in the group emerged as the leader. The emergent leader participant's leadership and personality trait scores were analyzed for correlations with ratings of CVE interface devices to develop results.

II. BACKGROUND

A. THE FIVE FACTOR MODEL OF PERSONALITY

Several different personality measurement scales can be used to explain an individual's personality. Some of the most popular are the Minnesota Multiphasic Personality Inventory (MMPI), the Myers-Briggs Type Indicator (MBTI), and the Five-Factor Model (FFM). Each tool has its own advantages/disadvantages and proponents. This study used a variation of the FFM called the NEO Five-Factor Inventory (NEO-FFI). The NEO-FFI is actually a reduced version of the revised NEO Personality Inventory (NEO PI-R), which has its roots in the FFM.

The "FFM originated in initial works by Fiske (1949), Norman (1963), and Tuppes and Christal (1963), who produced a highly stable structure with five factors" (Salgado, 1997, p. 30). While most models are derived from theoretical perspectives, the FFM has a theoretically neutral position (Widiger, 1997). The NEO PI-R is a widely accepted measure of personality developed by Costa and McCrae, and assesses personality in terms of Neuroticism, Extraversion, Openness, Agreeableness, and Conscientiousness. The five personality factors are described in the following way:

> People who score high on NEUROTICISM typically report negative emotions such as worry, insecurity, self-consciousness, and tempermentalness (McCrae & Costa, 1987) whereas people with low Neuroticism are calm, self-confident, and cool (Salgado, 1997).
>
> EXTRAVERSION is the factor that describes people who are rated by their peers as "sociable, fun-loving, affectionate, friendly, and talkative" (McCrae & Costa, 1987, p. 87) versus "reserved, timid, and quiet" (Salgado, 1997, p. 30).
>
> The final factor in this model is OPENNESS. Adjectives from lexical studies that describe this factor include "original, imaginative, broad interests, and daring" (McCrae & Costa, 1987, p. 87). "Openness defines individuals who are creative, curious, and cultured versus practical with narrow interests." (Salgado, 1997, p. 30)

> People high in AGREEABLENESS are forgiving, lenient, sympathetic, agreeable, and softhearted, according to peer ratings (McCrae & Costa, 1987). Peers describe those low in Agreeableness in more negative terms: ruthless, uncooperative, suspicious, and stingy.
>
> Peers describe people high in CONSCIENTIOUSNESS as careful, well organized, punctual, ambitious, and persevering (McCrae & Costa, 1987). Conscientiousness includes both proactive (hardworking, ambitious) and inhibitive (dutiful, scrupulous) aspects (McCrae & Costa, 1989).

These personality measurement tools are important because they can be used to closely predict which individual should emerge as the leader for a given group collaboration task.

B. PERSONALITY MEASURES

Some personality measurement techniques are more objective while others are subjective and prone to bias. A goal for this study was to use a technique that is standardized, and that also has high reliability, and validity. These attributes tend to define the best assessment techniques. Standardization, reliability, and validity ensure consistency for administration, consistency of results, and accuracy of measurement. The NEO-FFI has these qualities. As an example, Salgado (1997) while evaluating the validity and consistency of various personality measures for predicting job performance in the European community confirmed that tests based on the Five-factor Model provide consistent results across both North American and European communities. The NEO PI-R was among the tests used and the NEO-FFI is fully based on the NEO PI-R. McCrae and Costa (1987) also compared the NEO PI-R measures between self-reports and peer ratings and found statistically significant validation of the measures.

A primary method for assessment is the self-report inventory method. The self-report method asks people to report on themselves by answering questions about their feelings and behavior in a variety of situations. The person taking the survey must indicate how closely each item describes their own traits or how much they agree with each item. The standardized administration, scoring, and evaluation of the NEO-FFI allows for effective self-reporting.

As indicated above, the MBTI and MMPI are alternatives for personality assessment. The MBTI requires several hours to administer and evaluate and requires a trained psychological professional to interpret the scores. The MMPI determines personality traits of hypochondriasis, depression, hysteria, psychopathic deviate, masculinity-feminity, paranoia, psychasthenia, schizophrenia, hypomania, and social introversion. The MMPI is primarily used by clinical psychologists as a diagnostic tool for assessing personality disorders, but is also utilized as a vocational tool. Like the MBTI, the MMPI is extremely long to administer and require special training to interpret the results.

The NEO-FFI, on the other hand, is easy to administer and interpret. The entire process can take less than 60 minutes per individual. It has been validated and used in previous research at the Naval Postgraduate School. For these reasons, the NEO-FFI fits the requirements of this study well.

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III. APPARATUS

A. NEO-FFI

This study required an assessment tool that has high reliability and validity ratings, while also being easy to administer, easy to complete with minimal time requirements, and easy to interpret. The NEO PI-R, the predominant measure of the five-factor model of personality, was chosen for inventorying an individual's personality since it meets all the above criteria. (Widiger, 1997) The NEO PI-R consists of 240 statements to which a person indicates their degree of agreement on a 5-point scale. The NEO PI-R is often referred to as a lexical five-factor model since it attempts to define personality in natural language terms.

Buziak (2000, p. 24) states that "substantial research exists regarding NEO PI-R reliability and validity. Most importantly, the NEO PI-R has demonstrated consistent convergent and discriminant validity, as well as indicating how alternate models can be understood from the perspective of the five factor model." He goes on to note that many studies on personality measurement, including the MBTI, have used the NEO PI-R as a comparison to find overlaps because of the consistency in results. The use of the NEO PI-R for comparison is due to the high correlation with the five factor model, which does not rely on a particular theory of personality. (McCrae & Costa, 1987)

The NEO Five Factor Inventory (NEO-FFI) is a 60-question subset of the full 240-question NEO PI-R. The NEO PI-R's additional length allows for more precise measurement and better false answer detection while the shorter length of the NEO-FFI required less time to administer. The authors of the NEO PI-R do not envision any significant changes in the near future; thus, it is a logical conclusion that there will be no major revisions planned for the NEO-FFI and it can be used with confidence. (McCrae & Costa, 1992)

B. TASK EXPERTISE

Establishing a profile of the individual personalities alone was not sufficient for this study of emergent leadership. As indicated above, specific personality traits are often effective within certain task domains. Since this study used a land navigation

exercise for the collaborative task, In addition, each individual's expertise and experience within this task domain was profiled. As part of developing these profiles, a land navigation background questionnaire was developed and utilized.

The questionnaire defined broad categories of expertise levels within the land navigation domain. By using a profile of each individual, the groups could be formed so that no single individual had a significant advantage on the task based solely on their land navigation expertise. This was important in order to ensure personality traits were the underlying force behind any emergent leadership. Expertise of a group leader plays an important role in land navigation tasks because the leader is looked upon for guidance and training (Stine, 2000).

C. VIRTUAL ENVIRONMENT MODEL

A distributed collaborative virtual environment was developed to support the collaborative task for this study. The distributed nature of the CVE presented a significant human factors issue in the experiments conducted by Slater (2000). To support this endeavor, the virtual model was represented on three high-end graphics computers over a Local Area Network (LAN). Each computer interface provided a different degeree of immersion similar to the Slater experiments. The individual immersive interfaces utilized a CAVE (CAVE Automatic Virtual Environment – originally developed at University of Illinois, Chicago) interface, a system with three large-screen monitors, and a standard computer monitor. All other interface tools, such as input devices, were kept identical.

1. Virtual Model Description

The shared virtual environment was created using Multigen-Paradigm Creator. The entire model was built to scale with overall dimensions of approximately 1000 by 500 meters. Terrain elevation was developed in accordance with local topographic maps having contours every ten feet. A satellite image of the area was overlaid on the terrain map and helped to establish paths within the environment. Photographs of objects and vegetation were taken of the represented area and converted to objects and placed in the virtual model. Figure 1 shows a sample view of the virtual model, as the user would have experienced it. The end result of the model was an environment where the user, while

moving, experienced parallax and obscured visibility due to vegetation. Additionally, they could identify key landscape features, terrain elevation changes, and paths.

Figure 1. Virtual Model as Seen by User.

2. High-Immersion Station

The workstation used by the participants that provided the highest level of immersion was implemented using a CAVE-like interface. It was composed of three (3) large rear projection displays each having an 81-inch diagonal measurement as depicted in Figure 2. The displays were connected together at a near seamless 45 degrees and almost completely filled the user's normal field of view. The virtual model was rendered in real-time via Multigen-Paradigm's Vega software. The view point for each display was rendered using three 45-degree frustrums set at 45-degree offsets, which together presented a 135-degree graphical field of view.

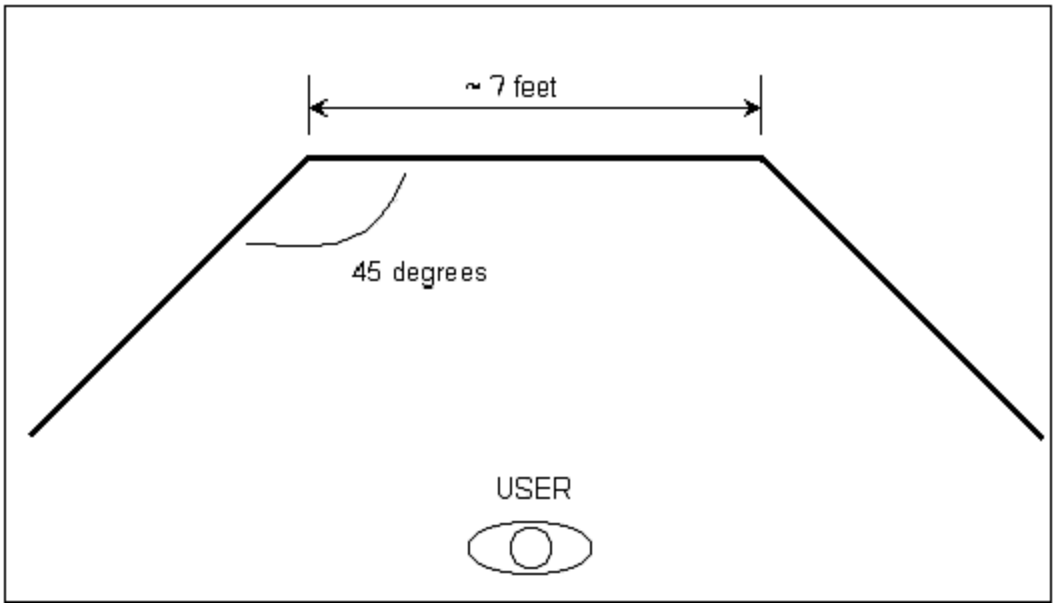


Figure 2. High-Immersive Display Layout.

Each display projector was driven by a dedicated high-end personal computer (PC). The computers utilized the Vega software feature that allows one "master" computer to distribute scene rendering to multiple "slave" computers. All three computers were linked via a high-speed gigabit network and the master controlled the display synchronization. Table 1 shows the hardware configuration for each computer.

Operating System	Windows 2000 (SP2)
Computer Processor	Dual Intel Pentium III, 1Ghz
Memory	2 Gigabytes
Graphics Adapter	Nvidia GeForce 3
Frames per Second	Greater than 25

Table 1. High-Immersion Workstation PC Configuration.

3. Mid-Immersion Station

The mid-level immersive station was rendered using the same software configuration as the high-immersion station; however, at this station the computer and display device were significantly different. This station utilized a single PC with multiple graphics adapters to render the scene to a single Panoram PV230 DSK display that integrates three (3) 15-inch high-definition LCD displays. The PV230 display provided the user with a high quality semi-immersive display of the virtual environment. Table 2 shows the hardware configuration for the PC rendering to the PV230 display.

4. Low-Immersion Station

The low-level immersive station was rendered using an Intergraph computer with multiple graphics adapters, but only one display device actually rendered the virtual model. Rather than display three separate frustrums, this station only rendered a single 45-degree frustrum sent to a single 21-inch display monitor. This configuration provided the user with a significantly reduced graphical and physical field of view. Table 2 shows the hardware configuration for the PC.

Station	Mid-Immersion Station	Low-Immersion Station
Operating System	Windows 2000 (SP2)	Windows NT
Computer Processor	Dual Intel Pentium II, 800 Mhz	Dual Intel Pentium II, 450 Mhz
Memory	512 Megabytes	512 Megabytes
Graphics Adapter	Three 3Dlabs Oxygen GVX1	Wildcat 2000
Frames per Second	Approximately 10	Approximately 20

Table 2. Mid- and Low-Immersion Workstation PC Configurations.

All other features of the user interface at each station were kept the same. Each participant sat at the workstation and used a keyboard and mouse to manipulate the virtual scene. Each model was rendered on the display at a high resolution of 1024 by

768 pixels. Additional information on hardware and software configuration is located in Appendix A.

D. USER REPRESENTATION AND CONTROLS

As is normal for distributed collaborative environments, the participant human-human interaction methods are severely limited compared to real world interactions. Slater's experiment essentially limited the human interaction to voice communications. In comparison, this study used voice communication augmented with a "life-like" avatar with a limited set of controls including a form of pointing. These limitations impact group collaboration effectiveness because people usually use other methods of communicating ideas and desires, such as touch, facial gestures, and body language.

1. Voice Communication

Voice communication between the participants was handled by "voice-over-IP". Each user was provided an audio headset with an attached boom microphone. Additionally, each headset had controls to adjust audio level and microphone mute. A freely available software product, "Team Sound" by RedWired Software, connected each user to a dedicated server. To reduce network traffic and keep communication as natural as possible, all transmissions were controlled by a voice-activated feature of the software. For clarity, a minimal compression algorithm was used. Slight transmission delays were noted by users, although all easily adapted.

2. Avatar Control and Movement

Each user interacted with the virtual model via an avatar generated by Boston Dynamics DI-Guy software. This software provided a realistic representation of each user as a "soldier" carrying a weapon. The avatar motions and actions were controlled by keyboard commands. Each user could command their avatar to "turn left/right," "stand," "walk," "walk backward," "run," "kneel," "lay down," and "aim rifle." Figure 3 shows these various states. By commanding the avatar to "turn left/right," "stand," "walk," "walk backward," or "run" the user was able to navigate through the virtual environment. The "kneel" and "lay down" actions were available to allow the user to change the height of their viewpoint. Changing view height was helpful to the user in areas where they wanted to see under the low branches of trees.

Since this experiment required the participants to navigate together, the capability of each user to be able to point at objects was deemed necessary. The “aim rifle” feature met this requirement by allowing the user to point their rifle in a given direction. It should be noted that this is a common way to point under a dismounted infantry military exercise context.

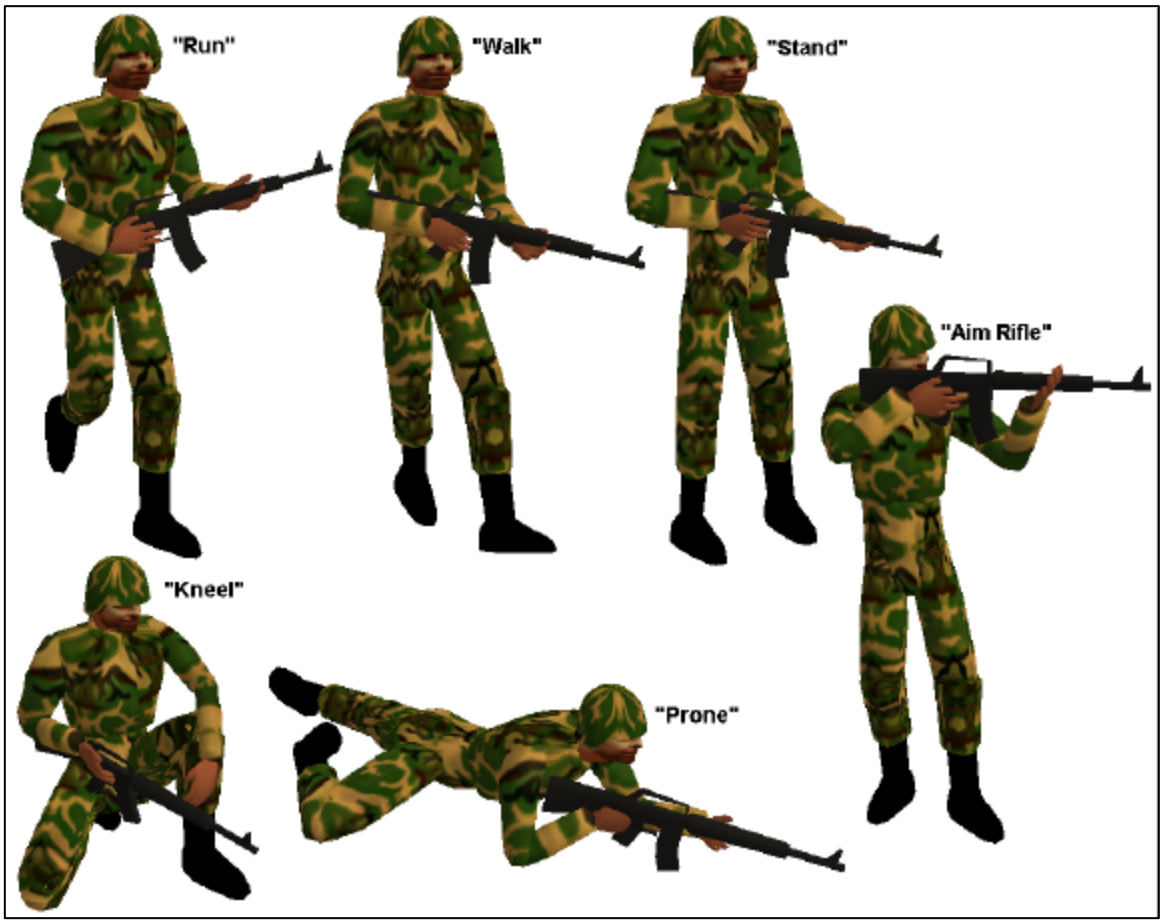


Figure 3. Avatar States.

The only other control the participants had available was mouse control of viewpoint. The intent was to allow the user to be able to look around without changing their direction of movement. This emulates the notion of walking and turning your head to see something to your side. The mouse motions were translated into viewpoint changes in azimuth and elevation.

There were two negative artifacts of the avatar that were introduced as a result of software limitations. The first being that the transitions between avatar states were not smooth. For instance, when a user commanded the avatar to "aim rifle" the action occurred immediately rather than affording a smooth transition of raising the rifle. The second artifact was that each user could not see their own avatar, with the exception of their rifle. Although seeing their own rifle was helpful, especially when trying to realign view direction with movement direction, it provided very little proprioceptive feedback.

All of the character states of each user were transmitted to the other participants and the representative avatar would change state. Overall this provided a more realistic expression of each user than Slater's study, although still a "far-cry" from what people experience in real-world collaboration.

IV. METHODOLOGY

A. EVALUATING PARTICIPANT PERSONALITY

As mentioned above, this research required profiling each participant's personality. These profiles were used to form collaboration groups for the experiment task. Specifically, each group required one, and only one, individual with personality traits that would predict that this person would emerge as the group leader. The NEO-FFI provided the framework for profiling the potential participant personalities. In addition to forming groups based on personality, each participant's expertise on the experiment task was also profiled.

1. Survey Implementation

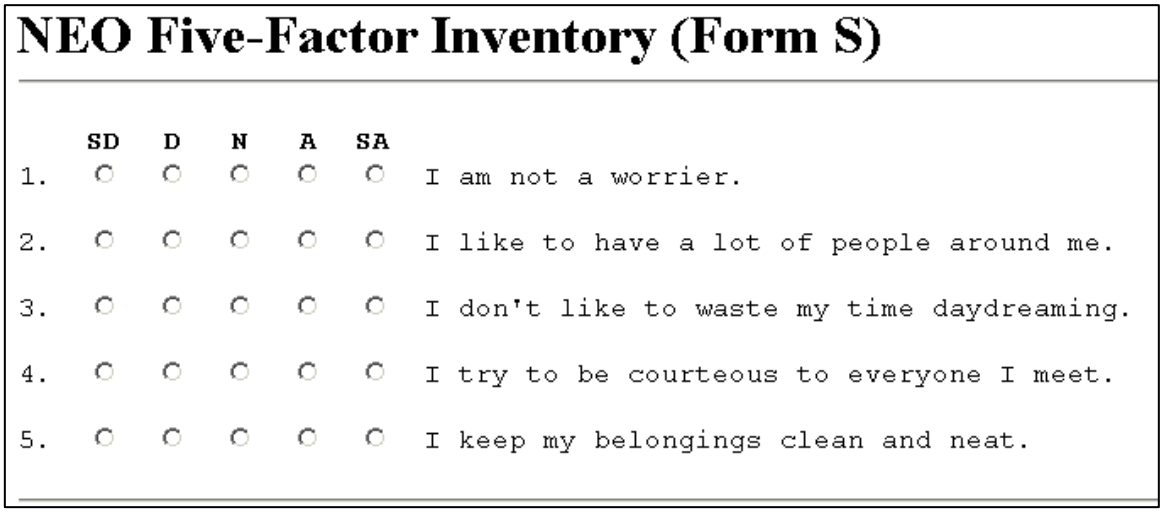
The questionnaires for profiling personality and expertise were combined into one document. This helped to limit the number of separate documents the participants were required to complete. Although the profiling was conducted using one document, the questions were divided into separate sections so that the participant noticed the shift in question domains.

NEO-FFI personality surveys from Psychological Assessment Resources, Inc. were used for documenting each individual's personality traits. Because this study required participants that possessed specific personality traits, a large pool of perspective participants was needed. To meet this objective, the NEO-FFI survey was additionally converted to hypertext documents and made available via a secure web site. Care was taken in developing the web-based documents to ensure respondents understood how to complete the survey and their rights to privacy. For those individuals who did not desire to complete the personality survey via the web, information was provided on how to complete the questionnaires using the normal paper documents.

2. Survey Documents

Each of the survey implementations presented the instructions and questions in exactly the same wording and format. Figures 4 and 5 provide examples of each of the survey implementations. The only notable difference between the implementations was in the recording format. The hypertext document provided "radio buttons" adjacent to

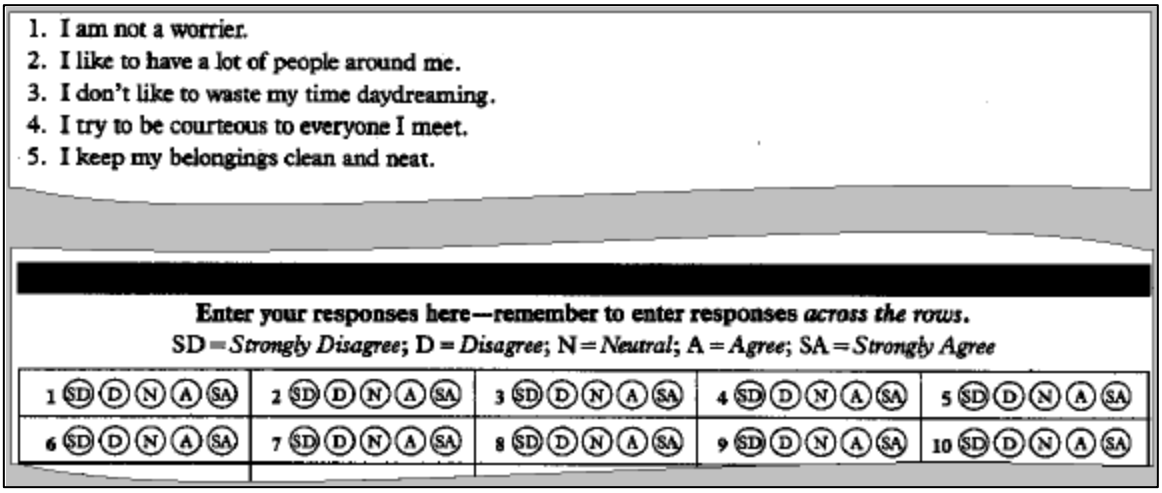
the questions and responses were automatically recorded to an electronic database. The traditional paper documents had a page for questions and a separate page for recording the answers to the questions. The electronic database automatically keyed each user with a unique identification number. This number was used throughout the experiment to anonymously record information about each participant. Responses recorded via traditional paper documents were manually entered, by the principle investigator, into the electronic database, and a unique identification number was assigned.



NEO Five-Factor Inventory (Form S)

	SD	D	N	A	SA	
1.	○	○	○	○	○	I am not a worrier.
2.	○	○	○	○	○	I like to have a lot of people around me.
3.	○	○	○	○	○	I don't like to waste my time daydreaming.
4.	○	○	○	○	○	I try to be courteous to everyone I meet.
5.	○	○	○	○	○	I keep my belongings clean and neat.

Figure 4. Question Format from Web-based Survey.



1. I am not a worrier.
2. I like to have a lot of people around me.
3. I don't like to waste my time daydreaming.
4. I try to be courteous to everyone I meet.
5. I keep my belongings clean and neat.

Enter your responses here—remember to enter responses *across the rows*.

SD = *Strongly Disagree*; D = *Disagree*; N = *Neutral*; A = *Agree*; SA = *Strongly Agree*

1 SD D N A SA	2 SD D N A SA	3 SD D N A SA	4 SD D N A SA	5 SD D N A SA
6 SD D N A SA	7 SD D N A SA	8 SD D N A SA	9 SD D N A SA	10 SD D N A SA

Figure 5. Question Format from Paper-based Survey. After Ref. (McCrae & Costa, 1992).

All the questions on the survey required the respondent to make a decision on whether they agreed with a particular statement on a scale from “Strongly Disagree” to “Strongly Agree”. The NEO-FFI converts these answers to a numeric value used for scoring the various personality traits. It was these numeric values that were recorded in the database for later analysis.

3. Survey Responses

After completing the survey, each participant was advised they would be contacted to coordinate any further participation. This allowed time for the coordinator to review the surveys and establish the groups for the experiment. All communication after completing the survey was handled via email.

A total of 67 people initiated the survey, but only 56 completed all required information and questions. The 56 respondents were all staff or students at the Naval Postgraduate School in Monterey, California. All respondents were over the age of 21; 4 of the 56 respondents were female.

4. Emergent Leadership Personality Traits

The traits associated with emergent leadership for this study were related to the required navigation and communication tasks. The experiment focused primarily on communication over navigation. Previous research conducted for the Office of Naval Research (ONR), indicated that certain personality traits are more useful for certain tasks. That research divided tasks into broad categories: realistic, investigative, artistic, social, enterprising, and conventional. For this study, the required navigational and communicational tasks fit into the realistic and social domains - primarily the social domain. Based on the research for ONR, group performance for the assigned task should improve when the members of the group have traits that are high in conscientiousness and agreeableness. (Hogan, Raza, Sampson, Miller, & Salas, 1989)

A number of studies have compared leadership and personality. In 1994, Hogan, Curphy, and Hogan, conducted an in-depth analysis of these studies and concluded emergent leadership is a specialized niche within the leadership domain that develops in small groups when no appointed leader exists. The result of the analysis Hogan, et al.

(1994) conducted on emergent leadership shows a correlation between emergent leadership and personality traits. Specifically, that the personality traits of high surgency (sociability, social presence, etc.), conscientiousness, and emotional stability are correlated to emergent leaders. These traits closely map to high scores in extraversion and conscientiousness, and a low score in neuroticism on the NEO-FFI personality assessment, respectively. By combining these two results, this study anticipated that extraverted, conscientious, and emotionally stable people would emerge as leaders in a group that was made up of members that did not possess these traits.

The NEO-FFI divides the scale for each of the five traits into categories: Very Low, Low, Average, High, and Very High. This study considered the terms "low" and "high" in previous research to equate to Low/Very Low, and High/Very High, respectively. Of the pool of 56 respondents, only 7 met the personality characteristic of "emergent leader"; specifically, high or very high scores in extraversion and conscientiousness, and a low or very low score in neuroticism. To provide a larger pool of potential leaders, another pass was taken through the database to find all the people that did not meet the personality characteristics, but differed only by an "average" score in one of the evaluated traits. For example, someone with an "average" score on extraversion, high score on conscientiousness, and low score on neuroticism would not have been among the original 7, but would have been included in the second pass. This second pass increased the "potential leader" pool by 12 people.

5. Other Group Member Personalities

Once the list of potential leaders had been generated, another pass was taken through the list of respondents to find prospective group members. On this pass the primary consideration was to identify those individuals that had personality traits opposite of those selected for the "emergent leader" pool. Specifically, the goal was to select people that had personality traits with the following characteristics: low extraversion, low conscientiousness, and high neuroticism. This pass provided only a handful of potential group members, which was not sufficient for this study.

To broaden the list of potential group members who had personality traits opposite of the traits possessed by the predicted group leaders, a list was generated that

contained only people with average or lower extraversion scores. Extraversion is the trait with the highest correlation to emergent leadership (Hogan, Curphy, & Hogan, 1994). This provided a pool of 22 people that could be used as group members to be paired with the predicted leaders. Given the two lists, predicted leaders and followers, groups were formed based on the available schedules of the potential participants. A "best effort" was made to keep the group members task expertise at a common level so that any emergent leader would be based solely on personality attributes. Additionally, the groups were gender homogenous to alleviate any gender biasing.

B. COLLABORATION TASK

Each group was assigned a task that was designed to maximize collaboration among the group members. A land-navigation task was devised to achieve this objective. Land navigation was selected because the Naval Postgraduate School has conducted a series of studies involving cognitive modeling of group behaviors within real and virtual navigation tasks. Previous research had also indicated that while conducting small group navigation exercises, the members of the group were very involved in collaborating when they were disoriented. (Boswell, 2000) This provided a nice venue for developing a navigation task that purposely placed the participants in a disoriented state. In this way, extensive collaboration could be assured.

1. Task Objective

The general task objective was to search for targets or markers within the virtual environment, and when located, plot those locations on a map. During the experiment in-brief, each participant was provided guidance on this objective. An explanation of the collaborative and navigational tools was presented and the group as a whole had an opportunity to experience how to navigate and communicate within a practice environment. Prior to entering into the experimental environment, each participant was again advised that the goal of the group was to work together to identify the location and orientation of the group as a whole and to develop and implement a strategy for locating targets. Each participant was provided an outline map of the environment for marking purposes. It was left up to the group members to decide what roles, if any, each member would take to solve the problem.

2. Navigation Tools

In all land-navigation tasks specific tools are required to achieve the objective. These tools provide the user the ability to identify current location, orientation to some known reference point, and relative scale of the environment. For this study, several tools were introduced to the users to assist in achieving their objective. As a whole, the group had the following set of tools available:

- Compass
- Overhead color imagery map depicting vegetation and roads
- Terrain contour map with a compass rose identifying North
- Distance traveled in meters indicator
- Photos of key landmarks within the virtual environment
- Map identifying locations of the key landmarks

If any single person had all these tools available they would be able to move through the environment with confidence and be able to effectively identify their location. To ensure that each member of the group was fully involved in collaborating about the navigation task, each member was supplied with only a portion of the tools required to effectively complete the task. In this manner, each member was required to communicate what tools they had available for the task and how they could help solve the problem. The grouping and distribution of the navigation tools is described below in the variable manipulation section.

3. Group Coordination

Given the limited set of tools available to each group member, some level of coordination was required. During the in-brief for the experiment, each participant was provided guidance on what tools were available to the group as a whole, but not who possessed each of the tools. Additionally, the group was instructed that any movements and decisions would need to be made as a group. That is to say, that no one participant was free to roam around the environment alone. These attributes of the task induced

more collaboration among the participants on how to complete the task. It also increased the likelihood of one participant emerging as a leader as final decisions were established.

4. Group Member Anonymity

The study required that participants in any one group not be unduly familiar with each other. Lester (2001) suggests this requirement must be adhered to keep the level of trust between participants to a level of "cognitive-based trust". Without this limitation the participants may have had different interactions due to anticipated actions of others caused by familiarity. Every group was developed through coordination by the principle investigator of each potential participant's schedule. At no time during the recruiting process were any of the participants exposed to whom else may be participating in the experiment. Each group member was briefed individually prior to starting the experiment task and only told that there were two other members of their group.

Anonymity was also provided during the group collaboration by assigning generic names to each of the group members. As all the participants had military experience and they were represented within the CVE as soldiers, traditional military communication callsigns were used for identification purposes. Each member was assigned the callsign of "Echo", "Kilo", or "Tango" throughout the experiment. Each participant was instructed to only use these callsigns for communicating. The callsign was also attached to corresponding avatar for identification purposes.

C. VARIABLE MANIPULATION

The primary purpose of this study was to ascertain the potential effects CVE interfaces can have on emergent leadership. When studying human factors related issues there can be some variables that are difficult if not impossible to control. Some of these variables may not even be recognized as a factor. The formation of the groups as described above was a direct attempt to minimize any confounding factors. This should allow for the only independent variables to be the interface used by participants and the tools used for collaboration.

1. Rotating Interface

The interface was the variable that was expected to have the highest potential impact on emergent leadership within the group. Each participant was exposed to each of the three different levels of immersion into the CVE. If the interface did have an affect on leadership, as suggested by Slater (2000), then the most immersive interface should produce more emergent leaders regardless of whether those people had traits that predict leadership. The other argument was to look at how often a predicted leader emerged as the leader regardless of the interface. By rotating each participant through all of the interfaces, both of these arguments could be studied. Thus, each participant was exposed to each of the three interfaces, or immersion levels, and evaluated for their role, specifically leadership role, while experiencing each interface. Additionally, during the rotation the anonymity of each group member was maintained.

2. Rotating Tool Sets

The tools for navigating were divided into three sets where any one set did not provide enough input to the user to accomplish the task on their own. In this way, each member was required to request assistance from the other members. The three sets of tools were divided in this way:

- Compass, movement counter, and vegetation map
- Compass rose, contour map, and photos of targets
- Key feature location map and photos of key navigation objects

Consideration was given to whether the tool set selection criteria was a dominant factor in who would emerge as the leader. To ensure that one set of tools was not more advantageous to the task and thus set one participant apart by providing a performance advantage, the tools were rotated between the different CVE interfaces. This rotation occurred between groups not between individuals. For example, one group may have tools sets 1, 2, and 3 combined with interfaces 1, 2, and 3 respectively. Each participant in this group was then rotated between each of the combinations. The next group would have tool sets 1, 2, and 3 combined with interfaces 2, 3, and 1 respectively. In this way,

any correlations that exist between interface, tool set, or personality and emergent leadership could be identified.

D. MEASURING EMERGENT LEADERSHIP

There is not always a well-defined method for determining who the leader is within a group. Previous research indicates that verbal communication can be used as an indicator of leadership (Kimble & McNeese, 1987; Slater, et al., 2000). These studies used different methods to quantitatively measure verbalization, but each looked at the amount of talking done by any individual and the nature of the talking.

This study used a similar method to identify who within the group was perceived as the leader. Participants were required to complete a survey after conducting the navigation task using each of the different interfaces. The survey, as represented in Appendix B, consisted of a series of questions that required them to rate each person within the group, including themselves, on various attributes of the collaboration effort. Specifically, they rated each participant on talkativeness, quantity of feedback, quality of feedback, effectiveness of input, and overall involvement. For each rating, the rater was instructed to place a mark on a linear scale from "Low" to "High." These group-peer evaluations were compiled as a subjective measure of who had emerged as the leader within the group for that portion of the experiment. After completing the interim survey, each participant was rotated to the next station to continue the experiment with one of the other CVE interfaces.

After rotating through each immersion level and completing a survey for each trial, the participants completed a second survey (Appendix B) that queried the user on aspects of the overall experiment. This survey included as the last question a rating of each group member on overall leadership. All of these ratings were quantified and used during the analysis to determine who had emerged as the leader during each exercise.

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V. ANALYSIS AND RESULTS

A. EVALUATING EMERGENT LEADERSHIP

Six groups of three people completed the initial personality survey and the CVE task. As indicated earlier, each of the participants evaluated the other people in their group, including themselves, on behaviors correlated with group leadership. These evaluations were subjective in nature and attempts were made to develop objective measures of emergent leadership.

1. Recording Group Participation

To help evaluate the group members for emergent leadership, the actions and behaviors of each participant were recorded on video and audio equipment at the various workstations. It was anticipated that these recordings could be reviewed after each session to produce objective measures for emergent leadership. Specifically, the intent of the recordings was to evaluate each individual for the following objective criteria.

- Amount of time individual spent talking
- Number of orders or suggestions given
- Number of regroup or cooperation statements
- Number of positive group statements given
- Amount of time individual led the group formation within the CVE
- Number of final decision made by individual

These criteria could then be tallied for each individual and entered into a formula for evaluating the individual as the emergent leader. Unfortunately, while reviewing these recordings, it was determined that some of the data was garbled or it was difficult to accurately identify which actions were taken by which participants. It was deemed inappropriate to use these recordings for creating objective measures due to the inability to determine which participant was speaking each utterance. However, the recordings were useful for improving the context of comments made by the participants on their

post-experiment questionnaires and interviews. This information can be applied to future research in small group collaborations.

2. Interim Questionnaires

Each group collaborated to solve the navigation task and within each group different people used different styles for collaboration, such as aggressive, passive, disruptive, etc.. These differences represent the heart of this research effort. Individual personality traits are one factor involved in the exhibition of these differences. Those individuals with personality traits associated with emergent leadership (extraverted, conscientious, etc.) should display those traits in a physical way (i.e. talkativeness) and then emerge as the leader.

a. Scoring

The completed interim questionnaires were converted to a database of scores associated with each participant. Each participant's mark for a given measure was represented as a value from 0 to 10. The raw data is represented in Appendix C. As each group had three members and each survey had five measures, each participant was assigned 15 values for each of the three different CVE interfaces utilized.

3. Post Questionnaires

After completing the task within each of the three CVE interfaces and the associated interim questionnaires, the participants were directed to complete a final survey (Appendix B) to elicit general comments regarding the CVE interfaces and group collaboration. An additional measure was taken for each group member to evaluate the others as to their role as the overall leader of the group. This evaluation was converted to a numeric value in the same fashion as the questions on the interim survey.

B. ANALYSIS OF MEASURED LEADERSHIP SCORES

Two main avenues of approach were taken for analyzing the data collected from the 18 participants. The first approach was to look at the scores in a general way similar to the way Slater (2000) measured the emergent leader in his research. The second approach entailed a statistical correlation of personality, interface, and emergent leadership.

1. General Analysis

In the research conducted by Slater emergent leadership was not the primary focus. It was merely an observation of interest that bore notation. The approach used was to evaluate the mean and standard deviations for the leadership scores of each individual related to the interface they used within the environment. He also analyzed the number of times a particular individual had the highest score amongst the other members of the same group.

Taking this approach, this study summed and averaged each of the values from the interim questionnaires for each participant. The range of summed values for each measurement on the questionnaire was 0 - 30, as there were three people evaluating that characteristic. The values for each characteristic were also added to create a range of possible values from 0 - 150 for any one participant at a particular CVE interface. These scores were then tabulated according to personality traits and interfaces. Specifically, for each individual they were categorized as "predicted leaders" or "non-leaders" according to personality traits and those scores across all interfaces were summed and average. Additionally, the scores across all the individuals at each of the three different immersion workstations were also categorized. The number of times a particular individual's scores, or the scores of the people using a particular interface, was the highest was also recorded. Tables 3 and 4 show the relationship of these scores. Some information can be gained from these tables, but only in an exploratory way.

	Total Score	Avg	Std Dev	Frequency
Leader	1369.5	273.9	26.5	43.0
Non-leader 1	1010.4	202.1	24.1	21.0
Non-leader 2	1203.6	240.7	23.7	26.0

Table 3. Mean, Standard Deviation and Frequency of Highest Score per Personality.

	Total Score	Avg	Std Dev	Frequency
Cave	1565.4	313.1	20.1	30.5
PV230	1507.1	301.4	23.4	24.5
Single	1480.4	296.1	19.3	35.0

Table 4. Mean, Standard Deviation and Frequency of Highest Score per Interface.

2. Statistical Analysis

For a more complete analysis, scores for each participant and each immersion interface were analyzed using analysis of variance (ANOVA). To analyze the effects the interface had on potential emergent leadership, a 1-way ANOVA was conducted with three treatments. The box plot of the data (Figure 6) shows the distribution of the scores for each interface. The results of the statistical ANOVA show an acceptance of the null hypothesis that all the means are equal with a probability of 0.8 (F-test: 2, 51 degrees of freedom). A post-hoc power analysis was conducted to recognize possible Type II errors - acceptance of null hypothesis that was actually false. Using an $a = 0.1$ on 3 treatments with a population of 18 a low power $(1 - b) = 0.39$ was calculated. This indicates there is a high probability that a significant difference between treatments did exist but could not be detected due to low sample size.

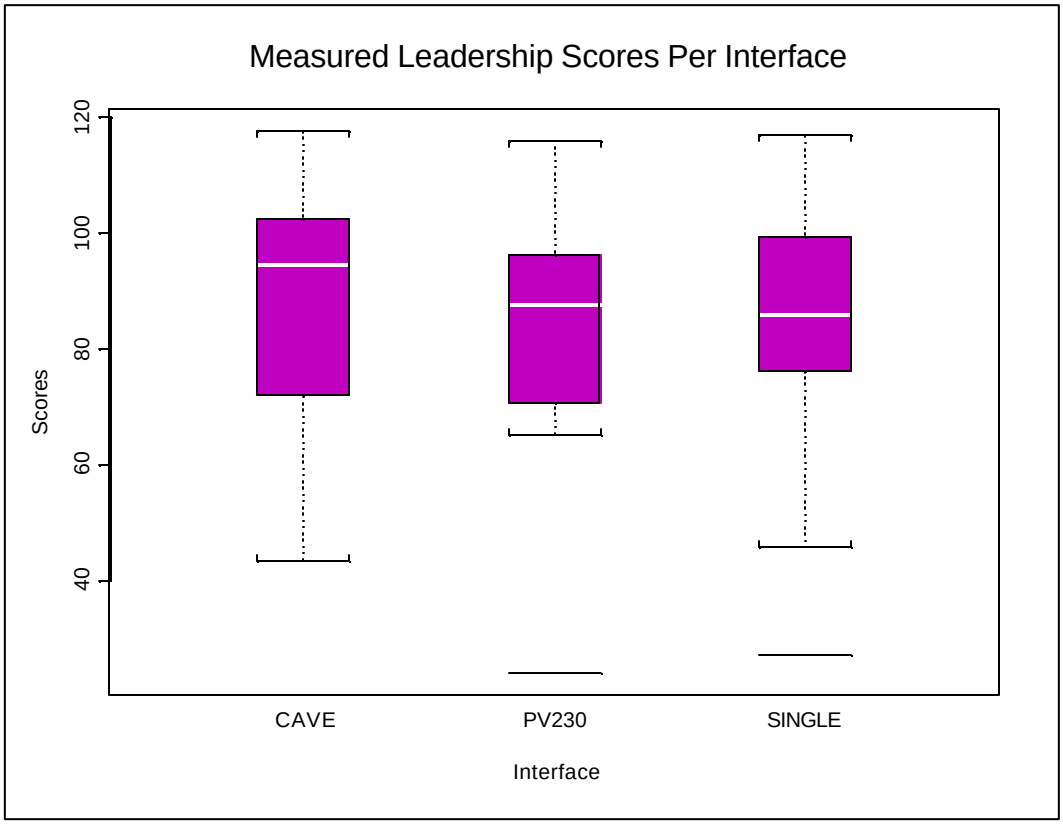

Figure 6. Distribution of Emergent Leadership Scores by Interface.

A slight variation in approach was used for analyzing the effect personality traits have on emergent leadership. Although each participant had different personality traits, there was only a distinction made between the individual that had the traits related to emergent leadership and those that did not have those traits. This distinction required an analysis between two groups, leaders and non-leaders, with different population counts. The paired T-test was inappropriate for this dataset, so a 1-way ANOVA was again used to account for the different populations. Figure 7 shows the distribution of the scores for the two personality categories across all interfaces. The result of this analysis was to reject the null hypothesis that the means were equal. The F-test yields $f = 6.84$ is greater than $\mathbf{F}_{(0.05,\,1,\,52)} = 4.02$ ($p = 0.012$).

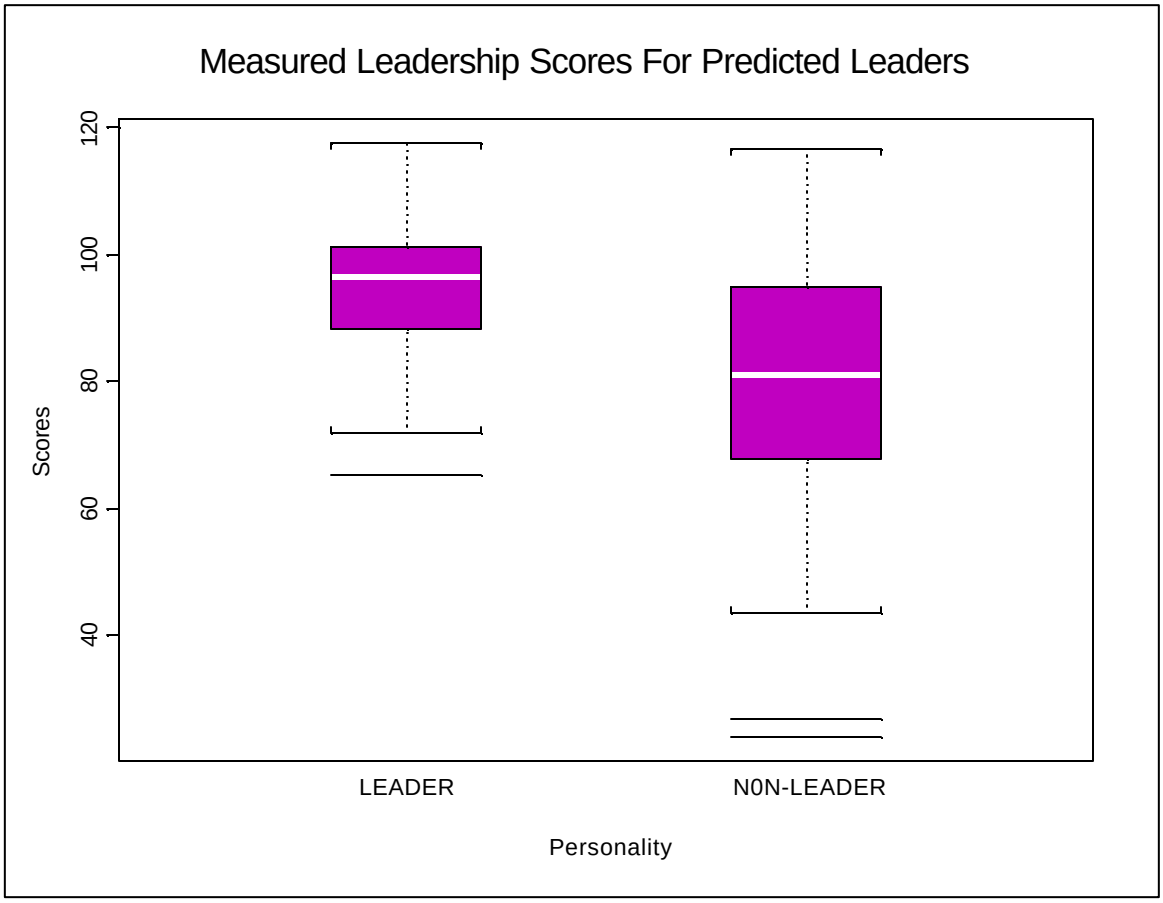

Figure 7. Distribution of Emergent Leadership Scores by Personality Across All Interfaces.

One additional analysis was conducted, but did not produce significant results. Using the data gained from the post questionnaire, which required the participants to rate each other as overall leader, another unbalanced ANOVA was completed. The box plot in Figure 8 shows the distribution of data. The results of this analysis were to not reject the null hypothesis that the means were equal. The F-test yields $f = 4.37$ is not greater than $\mathbf{F}_{(0.05,\,1,\,16)} = 4.49$ ($p = 0.053$).

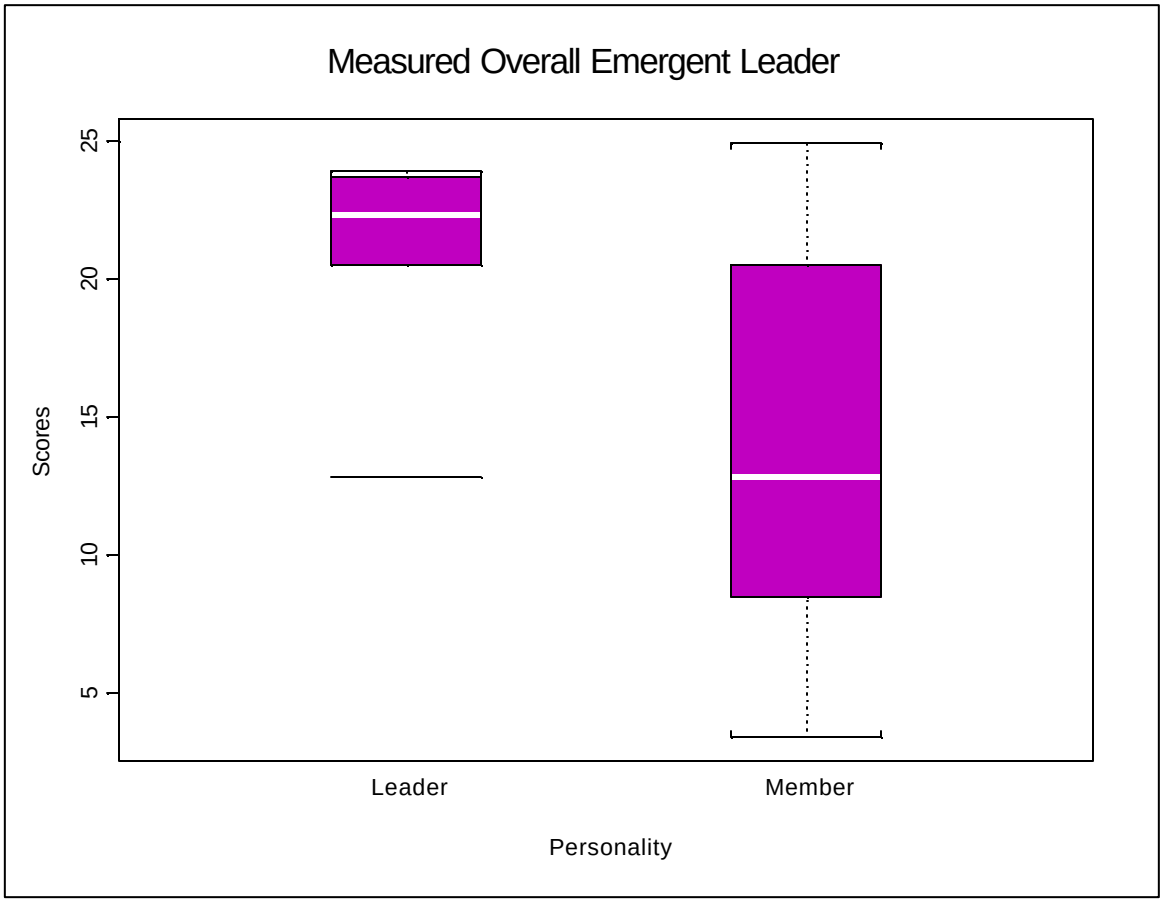

Figure 8. Distribution of Overall Leadership Scores by Personality.

C. ANALYSIS DISCUSSION

The results obtained from looking at the mean and frequency of selection provides some insight into the group collaboration. Table 3 clearly shows that those individuals possessing the "emergent leader" traits scored higher, on average, than the other group members. It is even more noticeable when examining the frequency for people who received the highest leadership characteristics scores. In these cases, the predicted leaders were selected nearly 2 to 1 over the other group members. This result was confirmed through statistical analysis using the unbalanced ANOVA with an almost 99 percent confidence interval. Additionally, results obtained from evaluation of each group member as the "overall leader" reveal similar results. The analysis did not produce a significant result, but this may be due to the small population size. Those results show significance at an alpha level of 0.10, but not at 0.05.

The results regarding interface effects differs from the results obtained in Slater's research. The study reported here found some variation between mean leadership scores and the number of times these participants were selected as leaders, but does not demonstrate any clear relationship between these two variables. The results obtained from the ANOVA indicate the mean leadership scores were equal between the different interfaces.

There are several explanations to account for the differences observed. During Slater's (2000) experiment all the group members were required to collaborate on the task, but one of the participants was instructed to nonchalantly obstruct the view of one of the other participants. This additional duty was also never given to the participant with the most immersive interface (i.e. Head Mounted Device). As this additional duty could potentially detract from the ability of the person to communicate and collaborate, then they would be at a disadvantage. This study did not implement any additional tasks in the manner of Slater's study. So, this could account for some of the difference but not all. Another consideration is the use of the HMD. In general, a HMD will provide a more immersive interface than the CAVE-like interface used in this study. The physical field of view and view orientation attributes of the HMD also produce different interactions with the CVE and the real world. The HMD does not easily allow the user to switch between real and virtual worlds. Hence, the user tends to become more immersed over time. This study required the users to review maps that necessitated switching between real and virtual environments to complete the task. This switching could have reduced the ability of the various interfaces to fully the immerse the participants in the virtual environment. An additional note, the participants in Slater's study were involved in performing the task in the CVE for a greater time period than this study which also may have had an effect on the degree of immersion.

The conclusions to be gained from these analyses are that the interface used with a CVE, or the level of immersion the interface provides to the user, does not appear to significantly affect the emergence of leadership. Further study must be given to this area of collaborative virtual environments in order to explain the differences found between this research and Slater's. A larger sample size might have permitted forming groups based on more extreme scores which might have produced the anticipated results.

Additionally, the personality traits associated with emergent leadership do play a significant role in emergent leadership within collaborative virtual environments.

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V. CONCLUSION AND FUTURE WORK

A. RESTATEMENT OF OBJECTIVE

As technologies like high-speed networks, audio and video conferencing, and virtual reality improve and gain more acceptance, people will be more involved in collaborative work between distant locations. Collaborative virtual environments may play a significant role and we must better understand the implications involved in their use. This is especially important when these systems are used for training to help ensure adverse training effects are avoided.

This study was designed to whittle away at some of the unknown quantities of collaboration within distributed virtual environments. To this end, the study looked specifically at the relationship between system interface, personality traits, and emergent leadership within a collaborative virtual environment. By using the predictability personality traits provide for detecting emergent leadership, this research evaluated who emerged as the leader during small group collaboration and compared this with who was the predicted leader based on personality traits. As each group member was exposed to three different interfaces each with a different level of immersion, any effects the varied interface provided to the users should have been uncovered. It was theorized, based on previous research (Slater, et al., 2000), that the limitations of low-end interfaces would negatively impact the transfer of leadership personality traits within the virtual environment, but not to such a degree that the limitations could not be overcome.

B. CONCLUSIONS

Two main conclusions were formed based on the results of the experiment. The first of these conclusions is directly related to emergent leadership personality traits and the applicability of these traits within virtual environments. The conclusion states:

- The personality traits associated with emergent leadership do play a significant role in emergent leadership within collaborative virtual environments.

The second conclusion actually argues against the conclusions generated in previous research by Slater (2000) at University College, London. Slater's results indicated that

the interface is a major contributing factor to emergent leadership, but the results of this research conclude:

- The interface to a CVE, or the level of immersion the interface presents to the user, may not significantly affect the emergence of leadership.

There may be several possible explanations for the difference in conclusions, and one significant point is that Slater's research did not take the dynamics of personality into account while studying the group interaction.

C. FUTURE WORK

One point is clear when looking at the results of this research, Slater's, and others like it, is that further research is needed to fully understand the effects virtual environment technologies have on group collaboration. Specific attention must be paid to groups that collaborate within a shared virtual environment when the participants are not co-located.

Many factors are involved in the dynamics of group interactions in addition to personality. This research took precautions to ensure the participants within each group remained anonymous and were gender homogenous. Other research indicates that attributes, whether simple or complex, can have an impact on group dynamics and gender is among these attributes (Kimble & McNeese, 1987). Group dynamics become more complicated when several factors are considered: group gender mix, leader gender, etc. Future research should consider gender and other attributes of group dynamics and how different CVE interfaces affect the roles people take within groups. Below is a partial list of topics for future work.

- Emergent leadership in groups with a gender mix
- Measuring leadership qualities in groups with appointed leaders
- Effects different interfaces have on training leadership within small groups
- Evaluating effects CVE interfaces have on things other than leadership (aggression, stress resolution, situational awareness, etc.)

- CVE interface effects within domains other than land navigation or reconnaissance (personnel management, academic research, training, etc.)
- Comparison between real and virtual world group dynamics for similar tasks
- Qualities required of a CVE to support effective collaboration

The United States military is deeply involved in researching the use of virtual environment technologies for training individuals and teams. Virtual environments are a logical choice for some training platforms due to the costs and dangers involved in some of the training requirements. Before these training systems are implemented for field use, a thorough understanding of the effects different CVE interfaces provide must be achieved. With a good understanding of these effects the best systems can be employed to produce positive training transfer for individuals and groups.

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APPENDIX A. VIRTUAL MODEL IMPLEMENTATION

A. HARDWARE CONFIGURATION

This appendix provides the detailed information on how the hardware and software was configured to support this research.

1. High-Immersion Workstation

During the planning stage of this research special consideration was given to the hardware requirements for this workstation. The research conducted by Slater utilized a Head-Mounted Display (HMD) for the high-immersion workstation. For similarity purposes, a HMD type system was desired, but the collaborative task made using a HMD impractical. The task required the user to interact with "real-world" tools like maps in order to achieve the objectives. The resolution capabilities of current HMD technologies are not sufficient to support detailed map displays. Thus, a CAVE-like system was utilized to provide a highly immersive interface to the user.

a. Display Hardware

The display system utilized a Multi-Angle Virtual Environment (MAVE) developed from previous research at NPS (Figure 9). The MAVE consisted of three large polarization-preserving rear-projection screens that were each 7 feet wide and 6 feet high. Each of these screens was raised above the floor 22 inches to provide a more natural viewing angle to a participant in a standing posture. For this experiment the participants were provided an elevated stool to reduce fatigue and facilitate an eye position approximating a standing posture. The three displays were placed at 45 degree angles to each other and produced a physical field of view of approximately 135 degrees when the user was at the optimal viewing distance from the center display of approximately 6 feet. Each display had a dedicated VRex VR2210 polarized stereo LCD projector that projected the image onto the screens via two reflecting mirrors. The three displays existed within a small room with sound absorbent surfaces and no external distraction. Overall this provided a highly immersive environment for the experiment participants.

Figure 9. User at High-Immersion Workstation.

b. Computer Hardware

This workstation required the highest level of computational power. This was achieved by building three machines dedicated to rendering the CVE images to the three projectors. Each machine was produced from commercial off-the-shelf products as indicated in Table 1. The graphical rendering synchronization between the machines was controlled by software over a dedicated high-speed 1000 Megahertz. Overall, the computer configuration smoothly reproduced the CVE with average frame rates greater than 25 frames per second at a resolution of 1024 by 768 pixels.

2. Mid-Immersion Workstation

The basic requirements for this workstation were to provide the user an interface to the CVE that was more immersive than a single-screen display and less than that of the high-immersion workstation.

a. Display Hardware

The display system utilized a specialized panoramic display (PV230) developed by Panoram Technologies (Figure 10). The display consisted of three mid-sized flat panel LCD screens connected together at approximately 25 degree angles. The

seams between each display were approximately 11 millimeters and produced little distraction when the user's focal point transitioned between the displays. Each individual display had a 15 inch diagonal measurement and all combined provided a 36 inch wide by 9 inch high viewing area. Overall this provided a pleasing, high quality display with a wide field of view, but not as immersive a display as the high-immersion workstation.

Figure 10. User at Mid-Immersion Workstation.

b. Computer Hardware

This workstation utilized a high-end Dell personal computer augmented to support multiple displays as indicated in Table 2. Due to the complexities of the virtual model, the computer configuration reproduced the CVE with a disappointing average frame rate of approximately 10 frames per second at a resolution of 1024 by 768 pixels. Although this frame rate could have been improved by reducing the image resolution, it was considered more important to ensure each workstation had identical pixel resolutions. The frame rate difference was noticeable, but participant post-experiment comments regarding frame rate did not reveal any significant display problems. It is theorized the slow movement associated with "walking" in the CVE allowed the users to

cope with the low frame rate. The difference in frame rate was most noticeable while changing view azimuth or elevation.

3. Low-Immersion Workstation

The basic requirement for this workstation was to provide the user an interface to the CVE that had few immersive qualities, as found in typical personal computer systems.

a. Display Hardware

The display system utilized a single 21 inch diagonal monitor as part of a multiple display system; the additional displays were not utilized for the experiment. Although the diagonal measurement of this display was greater than the mid-immersion workstation, the total viewing area was less and covered a much smaller physical field of view. Overall, this interface provided the least capability to immerse the participant in the CVE.

Figure 11. User at Low-Immersion Workstation.

b. Computer Hardware

This workstation utilized a high-end Intergraph TDZ 2000 personal computer augmented to support multiple displays as indicated in Table 2. Overall, the computer configuration reproduced the CVE with an average frame rate of approximately 20 frames per second at a resolution of 1024 by 768 pixels.

B. SOFTWARE CONFIGURATION

All the CVE workstations utilized the same software with minor variations to support the different interface requirements. The real-time simulation software utilized for the CVE was Multigen-Paradigm's Vega software. Several modules were attached to the software kernel to support the requirements of the experiment. The list below identifies the main modules of concern and their use requirement.

- "DI-Guy" for avatar implementation
- "DIS/HLA" for network protocol support
- "Symbology" for implementation of a compass and distance display
- "Distributed Vega" for multi-machine multi-pipe scene rendering

All the modules were available at every workstation, but the symbology and distributed Vega modules were only activated on the computer systems that required that implementation. Specifically, the Distributed Vega module was only activated for the high-immersion workstation and Symbology was only implemented for users that had the compass as part of their tool set.

One complication that occurred during this experiment was that not all the modules functioned together properly. An exorbitant amount of time was spent configuring the software to adequately support effective user control and display of an avatar within the networked virtual environment. The DIS module makes sharing environments and virtual objects across networks very simple to implement. Additionally, the DI-Guy module is a great way to introduce humanoid objects into a CVE, but they were designed for scripted behaviors. Another complication was that the DI-Guy is represented within the Vega software as a special kind of object. As a special object, the avatar is not sent across networks by the DIS module in the same way as other

objects. In essence, these peculiarities of the software complicated the development process. The next sections document some of the solutions implemented to support this research. Specifically, the code implementation to allow a user to control an avatar and then represent the state of that avatar at the receiving workstations will be described.

1. Avatar Control

The DI-Guy software module was developed to support the introduction of humanoid objects with realistic human behaviors into real-time simulations. These objectives have been met quite effectively, but are done using pre-scripted behaviors and movement paths. There are hooks available to allow software to dynamically control the actions of the avatar, but when these are utilized the realism of the behaviors and actions is reduced.

The requirements of this study included the ability of the user to point at objects or in a given direction. To support this, the avatar required direct user control and all the group members needed to see the pointing behavior. Control was achieved through keyboard actions that translated to a change of avatar "state". The code fragment below (Figure 12) illustrates how those keyboard commands were utilized. When a keyboard event was captured the event information was parsed to determine which key was pressed and then the appropriate avatar state was set and that state was transmitted over the network to the workstations. An additional adjustment was also made to the viewing height of the user dependent on whether the avatar state changed from standing to kneeling.

```
.
.
.

switch(keyPressed) {

   //******* the following key events are for DI-Guy motions ******
   case VGWIN_UPARROW: //character walk (property value = 6)
   case VGWIN_PAD8:
      //****** change avatar state
      vgDIGuyAction (vgCharHandle, SOLDIER_WALK);
      //****** adjust observer view point
      chgObsOffsetAlt(SOLDIER_WALK);
      //****** send State change info to DIS
      sendState(SOLDIER_WALK);
      break;

   case VGWIN_PAD9: //character jog (property value = 11)
   case 'r':
   case 'R':
      //****** change avatar state
      vgDIGuyAction (vgCharHandle, SOLDIER_JOG);
      //****** adjust observer view point
      chgObsOffsetAlt(SOLDIER_JOG);
      //****** send State change info to DIS
      sendState(SOLDIER_JOG);
      break;
.
.
.
```

Figure 12. Code to Control DI-Guy Avatar State.

The pre-scripted behaviors for which the DI-Guy object was designed utilized transitions between states to achieve the realistic human actions when switching avatar states. For instance, if the avatar switched from running to standing, then the script would actually adjust the avatar from a running state to a walking state and then a standing state. This created a visually realistic state transition. When sending state information about the avatar over the network these intermediate states must be sent as well. For simplicity reasons, these intermediate states were not transmitted which could cause the avatar on the receiving workstation to get stuck in a particular state. To remedy this feature, the state transitions were disabled and the avatar immediately changed state. This created some jerky actions when transitioning between certain avatar states.

2. Sending and Receiving Avatar State Information

The DIS network module was designed to automatically send state and positional information about objects to all the nodes in the shared CVE. Unfortunately, the DI-Guy

is treated as a special type of object and this information is not captured and sent properly when the avatar is under user control. Thus, the state information of the avatar was manually sent to the other nodes on the network. This was implemented via a separate multicast channel established between all the workstations. Sending the information was simple and straightforward; the complications occurred on the receive side.

Each workstation had an established identification number within the CVE and this number attached to the avatar state information that was sent to the other workstations. Upon receipt, the receiving node would parse the network packet for the station identification and then locate the associated avatar that needed to be adjusted. Typically, this locating of the associated avatar would be a trivial search for the object name and assigning a pointer, but because of the special nature of the DI-Guy objects this was complicated. The DI-Guy objects that represent another workstation user are dynamically created and destroyed during the simulation, and each time this happens a new name is assigned to the object. Thus, the name of the object is never known. To get around this problem, each user's avatar was assigned a specific name and that name was linked to the workstation identification number. Then, the receiving workstation could identify each avatar by the link between the name and the number.

3. Adjusting Avatar Position

Another compatibility problem between the modules appeared in relation to the position of the avatar on the receiving station. The DIS module automatically reported the position information of an object within the CVE. For DI-Guy objects, the module does not send the position information of the avatar, but sends the position of another object that represents the avatar. When the positional information is received at a workstation the DIS module automatically decodes the information and sets the position of another object that represents the avatar rather than the avatar itself. This representative object exists because of the special nature of DI-Guy. The action states and behaviors associated with the DI-Guy avatar tend to make the avatar position on the receiving station shift in relation to the representative object position. To fix this problem the avatar object position needs to be periodically adjusted back to the position of the representative object. Figure 13 shows the function used to make this adjustment.

This drift and adjustment occur for every instance of networked DI-Guys, so the function simply adjusts all the inbound avatar positions.

```
void diGuyCorrection() {
   vgDIGuy *d = NULL;
   float x=0.0f, y=0.0f, z=0.0f;
   bdiCharacterHandle bdiChar = NULL;

   //loop through all the DIS DI-Guys and
   //find the active DIS DIGuy entities
   for (int index = 0; index < MAX_DIS_DIGUYS; index++) {
      //check if array holder has a valid DIS entity
      if (disDIGuyNames[index] != NULL) {
         //try to find the associated DIGuy
         if ((d = vgFindDIGuy(disDIGuyNames[index])) != NULL) {

            //get the associated BDI Handle
            bdiChar = vgGetDIGuyCharacterHandle(d);

            //teleport to 0,0,0
            diguy_teleport(bdiChar, &x, &y, &z);

         }//end if
      }//end if
   }//end for loop
}//end diGuyCorrection
```

Figure 13. Code to Adjust DI-Guy Avatar Position.

There were many adjustments made to the experiment model to create controllable avatars that could be used by the participants in a way that was conducive to the navigation task. Although not all the problems were fixed, the participants did not report an inability to achieve the task objectives based on avatar control and representation. Most users enjoyed the experience and found the pointing, along with other features, important to achieving the objectives.

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APPENDIX B. EXPERIMENT FORMS

A. GENERAL

The forms in this appendix appear in the same format utilized for the experiment and do not follow the standard thesis formats utilized in the chapters of this document. The appendix consists of six documents: Privacy Act Statement, Participant Consent Form, Minimal Risk Consent Statement, In-brief Statement, Interim Questionnaire, and the Post Questionnaire.

1. Privacy Act Statement

The following page represents the Privacy Act Statement presented to each participant. Each participant was required to read and sign this document prior to participating in the experiment.

PRIVACY ACT STATMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
PRIVACY ACT STATEMENT

1. Authority: Naval Instruction

2. Purpose: Personality information will be collected to enhance knowledge, and to develop tests, procedures, and equipment to improve the development of Distributed Collaborative Virtual Environments.

3. Use: Personality information will be used for statistical analysis by the Departments of the Navy and Defense, and other U.S. Government agencies, provided this use is compatible with the purpose for which the information was collected. Use of the information may be granted to legitimate non-government agencies or individuals by the Naval Postgraduate School in accordance with the provisions of the Freedom of Information Act.

4. Disclosure/Confidentiality:

   a. I have been assured that my privacy will be safeguarded. I will be assigned a control or code number, which thereafter will be the only identifying entry on any of the research records. The Principal Investigator will maintain the cross-reference between name and control number. It will be decoded only when beneficial to me or if some circumstances, which is not apparent at this time, would make it clear that decoding would enhance the value of the research data. In all cases, the provisions of the Privacy Act Statement will be honored.

   b. I understand that a record of the information contained in this Consent Statement or derived from the experiment described herein will be retained permanently at the Naval Postgraduate School or by higher authority. I voluntarily agree to its disclosure to agencies or individuals indicated in paragraph 3 and I have been informed that failure to agree to such disclosure may negate the purpose for which the experiment was conducted.

   c. I also understand that disclosure of the requested information, including my Social Security Number, is voluntary.

_____

Signature of Volunteer Name, Grade/Rank (if applicable) DOB SSN Date

_____

Signature of Principal Investigator Date

2. Participant Consent Form

The following page represents the Participant Consent Form presented to each participant. Each participant was required to read and sign this document prior to participating in the experiment.

PARTICIPANT CONSENT FORM

1. **Introduction.** You are invited to participate in a study of group interactions within virtual environments. With information gathered from you and other participants, we hope to discover insight on communication techniques used while collaborating within a virtual environment during dismounted navigation of natural terrain. We ask you to read and sign this form indicating that you agree to be in the study. Please ask any questions you may have before signing.

2. **Background Information.** The Naval Postgraduate School NPSNET Research Group is conducting this study.

3. **Procedures.** If you agree to participate in this study, the researcher will explain the tasks in detail. There will be two sessions: a) 30 minute pretest phase and b) 60 minute training and execution phases, during which you will be expected to accomplish a number of tasks related to navigating a natural terrain environment.

4. **Risks and Benefits.** This research involves no risks or discomforts greater then those encountered in ordinary computer usage. The benefits to the participants are gaining techniques for enhancing spatial knowledge of unfamiliar environments and contributing to current research in human-computer interaction.

5. **Compensation.** No tangible reward will be given. A copy of the results will be available to you at the conclusion of the experiment.

6. **Confidentiality.** The records of this study will be kept confidential. No information will be publicly accessible which could identify you as a participant.

7. **Voluntary Nature of the Study.** If you agree to participate, you are free to withdraw from the study at any time without prejudice. You will be provided a copy of this form for your records.

8. **Points of Contact.** If you have any further questions or comments after the completion of the study, you may contact the research supervisor, Dr. Rudolph P. Darken (831) 656-4072, darken@nps.navy.mil.

9. **Statement of Consent.** I have read the above information. I have asked all questions and have had my questions answered. I agree to participate in this study.

_____

Signature of Volunteer Date

_____

Signature of Principal Investigator Date

3. Minimal Risk Consent Statement

The following page represents the Minimal Risk Consent Statement presented to each participant. Each participant was required to read and sign this document prior to participating in the experiment.

MINIMAL RISK CONSENT STATEMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
MINIMAL RISK CONSENT STATEMENT

Participant: VOLUNTARY CONSENT TO BE A RESEARCH PARTICIPANT IN: Virtual Environment Interface Effects on Collaboration

1. I have read, understand and been provided "Information for Participants" that provides the details of the below acknowledgments.

2. I understand that this project involves research. An explanation of the purposes of the research, a description of procedures to be used, identification of experimental procedures, and the extended duration of my participation have been provided to me.

3. I understand that this project does not involve more than minimal risk. I have been informed of any reasonably foreseeable risks or discomforts to me.

4. I have been informed of any benefits to me or to others that may reasonably be expected from the research.

5. I have signed a statement describing the extent to which confidentiality of records identifying me will be maintained.

6. I have been informed of any compensation and/or medical treatments available if injury occurs and is so, what they consist of, or where further information may be obtained.

7. I understand that my participation in this project is voluntary, refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled. I also understand that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.

8. I understand that the individual to contact should I need answers to pertinent questions about the research is Krist Norlander, Principal Investigator, and about my rights as a research participant or concerning a research related injury is the Modeling Virtual Environments and Simulation Chairman. A full and responsive discussion of the elements of this project and my consent has taken place.

Medical Monitor: Flight Surgeon, Naval Postgraduate School

_____

Signature of Volunteer Date

_____

Signature of Principal Investigator Date

4. In-brief Statement

The following page represents the In-brief Statement presented to each participant. Each participant was required to read this document prior to commencing the experiment.

Collaboration In-Brief

You, as a participant in this experiment, have been assigned to a small collaboration group consisting of three (3) persons. Your assignment to this group was predicated on the results obtained from the personality questionnaire completed in the first stage of the experiment.

Experiment Focus:
The focus of the experiment is on collaboration interaction within a small group. For data collection purposes your participation will be recorded on video.

Objective:
Your objective in this experiment is to work with the other participants in your group to search, identify, and locate as many targets as possible within the time period allotted. This task is similar to a military reconnaissance mission.

Tools:
Each person in your group has a different set of tools available to assist in achieving your goal. The tools available to any one participant are not enough to effectively solve the problem. The best results will be achieved through collaboration with the other group members. It will be advantageous to the group for each member to be aware of the tools the other members have available.

Collaboration:
You can talk to the other participants via the audio headset provided. This headset includes a voice-activated microphone that supports full-duplex network communication.

In addition to the headset, each person in your group will be represented by an avatar (computer generated soldier). The other participants will see your avatar and you will be able to see theirs. Your avatar has a limited set of interactions that will represent what you are doing in the virtual environment. The avatar can "stand", "walk", "run", and "aim a rifle". The avatar state of "aiming your rifle" will be used to show the other participants that you are pointing in a given direction.

Requirements:
Throughout the experiment you will be required to identify the other group members by one of the following names: "Echo", "Kilo", "Tango". Even if you think you know another group member via voice recognition, you are required not to address that person by their real name.

The only other requirement is that all members of the group must remain together and agree on the actions of the group. Each member will have a diagram for marking the position of the targets located and identified.

Experiment Sequence:
You will participate in three (3) 15-minute reconnaissance sessions. After each session, you will be required to complete a short series of questions about the roles each member undertook within the virtual environment and then rotate to a new interaction station.

Practice:
When you are ready, you will be provided a five (5) minute period to become familiar with the navigation procedures within the virtual environment. A short task list will be provided to assist in familiarization.

Please, ask any questions you have prior to starting the experiment. During the experiment, the Principle Investigator will monitor the audio channel and be available to answer a limited set of questions.

5. Interim Questionnaire

The following page represents the Participant Interim-Questionnaire presented to each participant during the experiment. Each participant was required to complete this survey after completing the navigation task at each workstation.

Participant ID: _____ Callsign: _____ Run # ____

Participant Interim Questionnaire

Please, answer the following questions as honestly as possible. Your responses will be utilized to better understand the interactions of each member of this collaboration group exercise. All questions should be answered referencing the collaboration experience you just completed. Mark your responses on the scale by placing an "X" at the appropriate level.

Least |---------|---------|---------|---------|---------|---X---|---------|---------|---------|---------| Most

Identify how much of the overall talking was done by each group member (including yourself).

ECHO Least |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| Most

KILO Least |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| Most

TANGO Least |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| Most

Identify the amount of verbal feedback (response to another member) that was provided by each group member (including yourself).

ECHO Least |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| Most

KILO Least |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| Most

TANGO Least |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| Most

Identify the quality ("helpfulness") of the verbal feedback that was provided by each group member (including yourself).

ECHO Low |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| High

KILO Low |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| High

TANGO Low |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| High

Identify the amount of input that was provided by each group member (including yourself) that appeared effective at achieving the objectives (communicating, finding targets, and positioning targets on maps).

ECHO Least |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| Most

KILO Least |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| Most

TANGO Least |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| Most

Identify the amount of overall involvement by each group member in discussions and decisions.

ECHO Least |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| Most

KILO Least |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| Most

TANGO Least |---------|---------|---------|---------|---------|---------|---------|---------|---------|---------| Most

6. Post Questionnaire

The following page presents the Participant Post-Questionnaire presented to each participant after completing the experiment. Each participant was required to complete this survey after completing the navigation tasks at all of the three workstations.

Participant ID: _____

Participant Post Questionnaire

Please, answer the following questions as fully and honestly as possible. Your responses will be utilized to improve future research in Distributed Collaboration. When answering a question regarding interface, each interface should be identified by the following terms:

CAVE	-	Large 3 screen display
PV230	-	Small 3 screen display
Single	-	Small single screen display

1. Which interface provided you the most enjoyable experience? Why?

2. What was your preferred interface? Why?

3. Which, if any, of the interfaces did you feel interfered the most with your ability to meet the objectives (communicate, navigate, locate and identify targets)?

4. If applicable, how did the interface identified in above (question 3) interfere?

5. Which, if any, of the interfaces made you feel "less a part" of the group? Why?

6. Did you experience difficulties verbally communicating yourself over the networked communication system?

7. If applicable, describe the verbal communication conflicts experienced? Why?

8. Did you find the "pointing" capability useful to group interaction? Why or why not?

9. Overall, which group member would you identify as the leader? Why?

ECHO Least |----------|----------|----------|----------|----------|----------|----------|----------|----------|----------| Most

KILO Least |----------|----------|----------|----------|----------|----------|----------|----------|----------|----------| Most

TANGO Least |----------|----------|----------|----------|----------|----------|----------|----------|----------|----------| Most

APPENDIX C. RAW DATA

A. GROUP 1 – INTERIM- AND POST-QUESTIONNAIRE SCORES

Participant ID	16			53			59		
Emergent Leader Traits	No			Yes			No		
Run #	1	2	3	1	2	3	1	2	3
Workstation Interface	Cave	Single	PV230	PV230	Cave	Single	Single	PV230	Cave
Tool Set	A	B	C	C	A	B	B	C	A
Amount of Talking									
16	5.5	1.6	9.4	9.5	9.5	7.5	5.5	3.4	7.5
53	2.6	4.4	5.5	6.5	6.5	5.5	5.4	6.5	6.4
59	2.4	2.4	3.5	6.5	5.6	4.5	4.6	6.4	4.5
Feedback Quantity									
16	3.4	2.5	9.5	3.5	9.5	5.5	3.5	2.5	3.4
53	3.6	4.5	5.5	4.5	5.6	5.5	6.5	6.4	5.5
59	1.5	1.5	2.5	7.5	6.4	4.5	6.5	6.5	5.4
Feedback Quality									
16	3.5	4.4	8.3	8.5	9.3	7.6	4.4	5.4	6.6
53	0.5	4.5	5.5	0.5	6.5	6.4	0.5	6.5	6.4
59	0.5	1.5	1.5	7.5	6.4	4.5	4.5	7.4	4.5
Effective Input									
16	6.5	5.7	8.5	8.6	6.4	6.3	6.5	7.5	5.4
53	2.4	4.5	5.5	6.4	5.5	5.5	5.6	6.4	5.5
59	0.5	1.5	2.5	4.5	5.5	4.5	4.5	5.5	4.5
Overall Involvment									
16	5.6	1.5	8.4	8.6	7.6	7.6	5.6	3.5	5.5
53	3.4	4.5	5.5	6.4	5.5	5.5	6.4	5.5	5.5
59	1.5	0.6	4.5	7.3	5.4	5.5	6.5	7.5	5.5

Overall Leader	16	53	59
16	5.6	8.4	5.5
53	3.5	6.4	7.4
59	2.5	8.6	7.5

Toolset	Elements
A	Compass and Satellite Image
B	Key Feature Location with Photos
C	Compass Rose and Contour Map

B. GROUP 2 – INTERIM- AND POST-QUESTIONNAIRE SCORES

Participant ID	54			40			34		
Emergent Leader Traits	Yes			No			No		
Run #	1	2	3	1	2	3	1	2	3
Workstation Interface	Cave	PV230	Single	PV230	Single	Cave	Single	Cave	PV230
Tool Set	C	A	B	A	B	C	B	C	A
Amount of Talking									
54	4.6	5.0	5.0	4.6	5.0	5.0	4.6	5.0	5.0
40	5.6	6.6	7.4	6.6	8.5	8.4	7.4	7.5	7.4
34	5.0	8.0	8.0	7.0	8.0	8.0	3.0	8.0	4.0
Feedback Quantity									
54	4.7	5.0	5.0	4.7	5.0	5.0	4.7	5.0	5.0
40	5.4	7.4	7.5	5.4	8.5	8.4	5.4	7.3	7.4
34	7.0	8.0	8.0	7.0	8.0	8.0	6.0	7.0	8.0
Feedback Quality									
54	5.1	5.0	5.0	2.9	5.0	5.0	2.7	5.0	5.0
40	6.5	6.5	7.5	6.5	7.5	8.5	6.5	8.4	7.3
34	7.0	8.0	8.0	7.0	8.0	7.0	7.0	8.0	7.0
Effective Input									
54	3.6	5.0	5.0	2.6	5.0	5.0	3.8	5.0	5.0
40	4.4	6.3	4.5	4.4	8.5	4.5	4.4	7.4	4.5
34	9.0	9.0	7.0	9.0	9.0	7.0	9.0	8.0	7.0
Overall Involvment									
54	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
40	6.5	7.4	7.5	6.5	8.4	7.5	6.5	7.4	7.5
34	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0

Overall Leader	54	40	34
54	5.0	5.0	5.0
40	5.50	6.50	7.50
34	10.00	9.00	8.00

Toolset	Elements
A	Compass and Satellite Image
B	Key Feature Location with Photos
C	Compass Rose and Contour Map

C. GROUP 3 – INTERIM- AND POST-QUESTIONNAIRE SCORES

Participant ID	35			91			41		
Emergent Leader Traits	No			Yes			No		
Run #	1	2	3	1	2	3	1	2	3
Workstation Interface	Cave	Single	PV230	PV230	Cave	Single	Single	PV230	Cave
Tool Set	B	A	C	C	B	A	A	C	B
Amount of Talking									
35	4.4	5.3	4.5	7.5	8.4	7.5	2.5	0.6	6.4
91	4.4	4.5	4.5	6.2	4.5	5.3	2.3	0.0	6.4
41	5.5	6.5	3.5	9.3	9.5	6.5	2.3	5.6	7.6
Feedback Quantity									
35	7.4	7.5	4.5	3.5	7.5	6.5	6.5	0.4	7.4
91	7.2	4.5	5.5	1.6	4.5	4.5	3.4	0.0	6.5
41	4.3	5.5	4.6	3.5	4.5	5.5	6.5	6.3	6.7
Feedback Quality									
35	7.4	7.6	4.4	5.4	6.5	6.5	1.4	0.5	8.4
91	8.5	4.5	4.5	8.5	4.5	6.5	2.5	0.0	6.5
41	6.5	5.5	4.5	7.3	7.4	7.6	3.5	3.5	7.7
Effective Input									
35	5.5	7.5	5.6	6.6	6.5	5.5	1.5	0.5	8.5
91	5.5	4.5	4.5	7.5	4.5	6.5	2.5	0.0	6.5
41	8.5	5.5	3.5	6.5	8.3	7.6	3.5	2.5	8.4
Overall Involvment									
35	5.4	7.5	5.4	7.5	7.6	7.6	1.4	0.5	5.4
91	7.5	4.5	6.6	7.5	4.5	6.5	3.5	0.0	5.5
41	7.3	6.5	4.5	8.4	7.5	6.5	3.4	3.5	8.3

Overall Leader	35	91	41
35	5.3	7.4	3.4
91	0.0	6.5	0.0
41	0.0	10.0	0.0

Toolset	Elements
A	Compass and Satellite Image
B	Key Feature Location with Photos
C	Compass Rose and Contour Map

D. GROUP 4 – INTERIM- AND POST-QUESTIONNAIRE SCORES

Participant ID	74			81			65		
Emergent Leader Traits	No			No			Yes		
Run #	1	2	3	1	2	3	1	2	3
Workstation Interface	Cave	Single	PV230	PV230	Cave	Single	Single	PV230	Cave
Tool Set	A	C	B	B	A	C	C	B	A
Amount of Talking									
74	0.5	0.5	3.5	8.5	9.5	9.3	8.5	9.5	9.3
81	2.5	1.4	1.0	8.0	6.8	9.0	6.0	7.6	7.5
65	4.4	2.5	3.4	9.5	8.3	7.6	7.5	8.2	8.5
Feedback Quantity									
74	2.5	3.5	9.5	7.4	5.5	9.4	7.4	5.5	9.4
81	2.6	2.1	2.5	4.8	7.5	7.7	6.8	7.5	7.7
65	6.3	1.4	4.4	7.4	7.4	7.4	7.4	7.5	7.4
Feedback Quality									
74	6.5	0.4	7.5	7.5	9.4	7.5	7.5	9.4	7.5
81	2.8	6.5	7.7	7.4	7.3	7.7	8.3	9.4	8.6
65	2.5	0.5	5.4	2.5	5.3	6.5	2.4	5.3	6.4
Effective Input									
74	7.5	0.6	7.5	7.5	5.5	6.4	7.5	5.5	6.4
81	1.9	3.6	3.3	8.0	8.3	7.6	8.2	7.3	7.5
65	3.4	0.6	4.6	4.4	5.6	6.4	4.4	7.3	6.3
Overall Involvment									
74	0.5	0.5	2.4	9.4	9.5	9.4	9.4	9.5	9.4
81	3.4	0.4	0.3	9.8	6.5	7.3	8.3	7.9	7.2
65	3.5	2.4	4.5	8.5	7.5	7.5	6.5	8.5	8.4

Overall Leader	74	81	65
74	0.6	9.4	8.5
81	0.4	8.0	6.7
65	4.3	7.5	8.5

Toolset	Elements
A	Compass and Satellite Image
B	Key Feature Location with Photos
C	Compass Rose and Contour Map

E. GROUP 5 – INTERIM- AND POST-QUESTIONNAIRE SCORES

Participant ID	92			85			77		
Emergent Leader Traits	No			No			Yes		
Run #	1	2	3	1	2	3	1	2	3
Workstation Interface	Cave	Single	PV230	PV230	Cave	Single	Single	PV230	Cave
Tool Set	C	B	A	A	C	B	B	A	C
Amount of Talking									
92	5.5	4.0	2.0	5.5	4.0	2.9	5.5	4.0	3.1
85	7.5	6.5	6.4	3.5	6.5	7.5	6.5	6.5	5.6
77	4.8	5.4	5.2	3.6	5.4	5.2	6.4	5.0	5.8
Feedback Quantity									
92	5.0	2.0	3.1	5.0	2.9	3.0	5.0	3.1	3.1
85	6.4	6.5	4.6	6.5	2.4	7.5	6.6	5.4	5.6
77	4.8	5.9	5.7	4.8	5.0	5.8	4.9	5.0	5.2
Feedback Quality									
92	1.0	1.0	3.0	1.0	1.0	3.0	1.0	1.0	3.1
85	7.5	3.5	7.3	6.5	3.5	8.6	5.5	3.5	5.5
77	5.8	5.8	5.4	5.8	4.5	5.3	5.8	4.1	5.7
Effective Input									
92	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	3.0
85	5.5	4.5	6.3	2.6	4.5	7.6	5.5	4.5	5.5
77	5.1	5.3	5.8	5.0	4.8	5.8	5.0	4.2	5.8
Overall Involvment									
92	5.0	3.0	2.0	5.0	3.9	2.9	5.0	4.0	3.1
85	6.6	7.5	6.4	6.5	7.6	7.5	6.6	7.6	6.4
77	5.0	5.2	5.5	5.0	5.2	4.6	5.7	5.3	5.3

Overall Leader	92	85	77
92	3.0	3.0	3.0
85	4.5	4.5	4.5
77	5.3	5.2	5.3

Toolset	Elements
A	Compass and Satellite Image
B	Key Feature Location with Photos
C	Compass Rose and Contour Map

F. GROUP 6 – INTERIM- AND POST-QUESTIONNAIRE SCORES

Participant ID	52			64			48		
Emergent Leader Traits	No			Yes			No		
Run #	1	2	3	1	2	3	1	2	3
Workstation Interface	Cave	Single	PV230	PV230	Cave	Single	Single	PV230	Cave
Tool Set	B	A	C	C	B	A	A	C	B
Amount of Talking									
52	2.0	4.7	4.6	3.3	5.4	6.5	5.2	4.5	4.5
64	3.0	3.0	4.0	8.0	10.0	9.0	8.0	8.0	9.0
48	5.0	4.0	6.0	6.0	6.0	6.0	7.0	5.0	6.0
Feedback Quantity									
52	2.8	6.2	5.8	3.5	4.6	3.8	3.5	6.4	4.2
64	4.0	5.0	5.0	8.0	7.0	8.0	7.0	8.0	8.0
48	5.0	5.0	6.0	7.0	5.0	6.0	6.0	5.0	6.0
Feedback Quality									
52	3.3	7.3	5.7	4.7	4.7	4.3	4.8	6.6	6.5
64	3.0	6.0	4.0	6.0	6.0	10.0	8.0	6.0	9.9
48	6.0	5.0	6.0	6.0	5.0	6.0	6.0	5.0	6.0
Effective Input									
52	5.1	5.9	5.6	5.9	4.6	6.9	5.1	7.0	6.1
64	3.0	5.0	5.0	6.0	9.0	9.0	7.0	7.0	9.0
48	6.0	5.0	6.0	6.0	6.0	6.0	6.0	5.0	6.0
Overall Involvment									
52	3.2	6.0	5.5	5.1	4.5	7.2	5.1	6.7	6.3
64	3.0	3.0	3.9	8.0	10.0	8.9	8.0	8.0	8.9
48	6.0	5.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0

Overall Leader	52	64	48
52	4.9	5.2	6.7
64	3.0	10.0	9.0
48	5.0	6.0	5.0

Toolset	Elements
A	Compass and Satellite Image
B	Key Feature Location with Photos
C	Compass Rose and Contour Map

G. PARTICIPANT PERSONALITY TRAIT SCORES

For privacy concerns, the data received from each participant was not published with this document. For future research requiring the use of this data, the Principle Investigator, LT Krist Norlander, USNR, or the Thesis Advisor, Dr. Rudolph P. Darken, should be contacted at The MOVES Institute, Naval Postgraduate School, Monterey, California for official release of this information.

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