U.S. Army Research Institute
for the Behavioral and Social Sciences

Research Report 1786

Situation Awareness in a Virtual Environment: Description of a Subjective Assessment Scale

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14. ABSTRACT *(Maximum 200 words)*:

The Mission Awareness Rating Scale (MARS), a subjective situation awareness (SA) rating scale designed to assess SA content and SA workload, was tested in a series of virtual environment exercises. Sixteen enlisted soldiers, working in teams of four soldiers each, completed four urban combat missions in a virtual night environment designed to simulate the experience of working with night vision goggles - NVG (PVS-7Bs) and aiming lights. In each scenario, a different approach for simulating this NVG environment was used. After each scenario was completed, each soldier completed the MARS instrument. This yielded estimates of the SA level and workload involved in four dimensions of SA – perception, understanding, projection, and knowing what decision to make. The results indicated that MARS significantly and robustly discriminated among the different approaches, and these SA estimates were congruent with general estimates of SA content and workload while operating at night in the real world, and with the soldier's subjective rankings of the four simulated NVG environments. While promising, MARS must be validated against objective SA measures, both in the virtual environment and in the field environment. However, MARS seems to hold promise as a relatively unobtrusive and effective SA measure.

15. SUBJECT TERMS Situation awareness (SA), decision-making, virtual reality, simulations, SA measures, team SA, individual SA, shared SA, small unit leadership, workload

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FOREWORD

The rapid increase in operational tempo and the influx of sophisticated information technology systems into the Army place huge demands on the information processing capabilities of soldiers and their leaders. Establishing and enhancing situation awareness (SA) is necessary to help these warfighters deal effectively with the information demands of the modern battlefield.

As these trends continue and the Army moves toward the Objective Force, psychometrically sound measures of SA are vitally needed to evaluate the impact new systems have on SA and decision-making. Many existing SA measures are too obtrusive to use in field exercises and other training events that test new systems. The current research focused on testing the Mission Awareness Rating Scale (MARS), a subjective measure of SA designed to quickly and unobtrusively estimate SA through self-ratings.

The data reported here were collected in conjunction with one of a series of experiments designed to investigate new ways to apply virtual environment technology in training dismounted infantry soldiers and small unit leaders. These experiments are part of an ongoing four year Science and Technology Objective (STO) initiative entitled *Virtual Environments for Dismounted Soldier Simulation, Training, and Mission Rehearsal.* The STO is a collaborative effort involving the U.S. Army Research Institute for the Behavioral and Social Sciences, the U.S. Army Research Laboratory, and the U.S. Army Simulation, Training, and Instrumentation Command.

This research represents one of several approaches to measuring SA that are being developed and validated by ARI. The goal is to provide researchers and trainers a relatively simple and useable tool for measuring SA in a variety of settings. The results were briefed to the Department of Behavioral Sciences and Leadership, U.S. Military Academy, 25 February 2002.

MICHAEL G. RUMSEY
Acting Technical Director

SITUATION AWARENESS IN A VIRTUAL ENVIRONMENT: DESCRIPTION OF A SUBJECTIVE ASSESSMENT SCALE

EXECUTIVE SUMMARY

Research Requirement:

This research is part of an ongoing effort by the U.S. Army Research Institute for the Behavioral and Social Sciences, Infantry Forces Research Unit, Fort Benning, Georgia, to develop psychometrically sound measures of situation awareness (SA). In particular, there is a need for SA measures that are easy and practical to administer yet provide useful SA information to researchers and trainers.

Procedure:

Sixteen Fort Benning enlisted soldiers were assigned to one of four 4-man fire teams. Each fire team completed four night urban combat missions in a virtual reality simulator located at the Land Warrior Test Bed at Fort Benning. In each of the four missions, a different method for simulating night vision goggle effects was used. After each mission, each soldier completed the Mission Awareness Rating Scale (MARS), an instrument designed to assess the subjective SA and workload experienced during a given mission.

Findings:

The results indicated that MARS discriminated among the four methods for simulating night vision goggle environments. Moreover, the night simulation method identified by MARS as being most similar to real night operations was also identified as such through interviews with the soldiers involved in the experiment. This also corresponded with their ratings of the difficulty of maintaining SA and workload demands based on their own experience in actual night operations.

Utilization of Findings:

The results suggest that MARS has promise for providing quick and relatively unobtrusive measures of SA. Such a measure is of particular utility in field training exercises, where more obtrusive SA measures commonly used during simulations would be viewed as overly disruptive.

SITUATION AWARENESS IN A VIRTUAL ENVIRONMENT: DESCRIPTION OF A SUBJECTIVE ASSESSMENT SCALE

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SITUATION AWARENESS IN A VIRTUAL ENVIRONMENT: DESCRIPTION OF A SUBJECTIVE ASSESSMENT SCALE

Introduction

Situation awareness (SA) is a construct that links a variety of cognitive processes, such as perception, memory, and schemas, to decision-making and ultimately task performance. High levels of SA are viewed as necessary, but not sufficient, for effective decision-making and performance. Historically, SA has been of most interest in technologically advanced domains, such as aviation, where a complex physical environment, highly sophisticated information and command and control systems, and task demands interact to challenge the human operator's ability to manage cognitive workload and make quick, effective decisions. For similar reasons, the Army is increasingly interested in SA as it integrates digital technologies into its ground forces.

Endsley (1988) defined situation awareness (SA) as "...the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future." Implicit in this definition is the notion that SA consists of three levels. Level 1, *perception*, involves the accurate identification of key features of a situation. Understanding what these elements mean, or *comprehension*, defines Level 2 SA. Level 3 SA, *prediction*, involves the ability to use lower levels of SA to make accurate projections about what is likely to occur in the near future in a given situation. Situation awareness is viewed as a useful construct in improving decision-making and performance in a variety of domains (Endsley, Holder, Leibrecht, Garland, Wampler, & Matthews, 2000).

Until recently, however, very little formal attention had been given to SA for infantry forces. In 1998, the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) hosted a workshop designed to establish dialogue between researchers and infantry warfighters, identify requirements for future training, leader development, and soldier research in the SA domain, and to establish SA requirements and performance measures for infantry combatants and teams (Graham, 1999). A fundamental recommendation stemming from the workshop was the need to develop psychometrically sound measures of SA. Reliable and valid SA measures are critical for evaluating the impact of new technology on performance and designing information technology systems to enhance SA, decision-making, and ultimately soldier performance.

Endsley et al. (2000) reviewed SA measurement approaches, and evaluated them for applicability to the infantry environment. According to Endsley et al., SA measurement approaches can be divided into four types: Process indices, direct measures, behavioral measures, and performance measures. Process measures include eye movements, communications, and verbalizations. Direct measures include objective measures such as on-line probes and "freeze" probes, and subjective measures based on self and observer ratings. Behavioral measures involve inferring SA from specific behaviors on specific subtasks, such as "time to make a response (verbal or non-verbal) to some event, and correct or incorrect SA as identified from soldier verbalizations and appropriateness of a given behavior for a particular situation" (Endsley et al., 2000, p. 80). Performance measures are based on tactical performance during missions and/or exercises.

Each type of SA measure has strengths and weaknesses and may provide different sorts of information. For example, direct subjective SA measures have an advantage of assessing a subject's personal level of SA, are easily administered, and are relatively unobtrusive to collect. However, soldiers may not know what information they are unaware of and their judgments may be influenced by self-assessments of their own or their unit's performance. Similarly, direct objective SA measures, such as the situation awareness global assessment technique (SAGAT, see Endsley, 1995), have the advantages of providing objective, unbiased estimates of SA, but are relatively obtrusive and require considerable prior analyses to develop valid measurement protocols. However, given that different SA measurement approaches may provide different types of information or be more acceptable in certain situations, a measurement strategy utilizing multiple SA approaches is desirable.

Based on Endsley et al.'s (2000) analysis, Strater, Endsley, Pleban, and Matthews (2001) developed three SA measures specifically designed to measure SA among infantry small unit leaders, and tested them during platoon level missions in a virtual environment. In this study, experienced and inexperienced platoon leaders led three squad leaders and computer generated forces through four missions in a virtual environment focusing on military operations in urbanized terrain (MOUT). The first measure was a SAGAT protocol modified to reflect SA requirements for infantry platoon leaders in MOUT missions. The second, the Situation Awareness Behaviorally Anchored Rating Scale (SABARS), was a direct subjective measure utilizing expert-observers to rate the platoon leaders on behaviors linked to SA in this context. The last measure developed was the Participant Situation Awareness Questionnaire (PSAQ), a subjective SA measure.

The SAGAT procedure involved periodically freezing action during the virtual MOUT scenarios, and then administering probe questions to the platoon leaders. These questions were based on a SA requirements analysis completed previously (Matthews, Pleban, Endsley, & Strater, 2000). Based on this requirements analysis, a list of 21 queries were generated that indexed information critical to SA for small unit leaders in missions of this type. These queries corresponded to the three levels of SA defined by Endsley (1988). In the virtual environment, unlike the real world, the "ground truth" (i.e., the actual status of these factors, which can be verified in virtual simulations and carefully conducted field experiments) of the situation is known. Participants whose responses match the ground-truth criteria, therefore, presumably possess higher SA than those whose responses fail to correspond to ground-truth, thus providing an objective index of the individual's level of SA. Results showed that the

SAGAT procedure differentiated SA as a function of the experience level of the platoon leaders. It also was sensitive to the type of scenario or mission. More experienced platoon leaders showed better SA for enemy information such as location and strength, while less experienced platoon leaders focused their attention more on the status of their own forces.

The SABARS also showed promise for measuring SA. Based on the SA requirements analysis described above (Matthews et al., 2000), 27 behaviors and actions linked to SA in MOUT missions were identified. Observer/controllers (O/Cs) closely watched each platoon leader work through the four missions. The O/Cs then rated the platoon leaders on a five-point scale with respect to how well they performed these actions. Like SAGAT, the SABARS data differentiated SA as a function of the experience level of the platoon leaders. Specifically, experienced platoon leaders were more likely to gather relevant information, follow procedures, and to focus on the big picture more than less experienced platoon leaders.

The PSAQ, which consisted of three questions dealing with workload, performance, and awareness of the situation as it evolved, showed the least promise for measuring SA. No significant effects were found for experience level, scenario, or the interaction between these two variables (Strater et al., 2001, p. 26).

The importance of the Strater et al. (2001) experiment is that it represented the first systematic attempt to assess SA for typical infantry operations. Both SAGAT and SABARS showed promise for measuring SA and for use as a tool in estimating the impact of new technology or operational procedures on small leader SA. These measures may also provide a basis for evaluating strategies designed to enhance SA. Further testing of both of these measurement approaches in other mission types and in field training exercises are necessary to fully evaluate their psychometric properties and potential utility in SA research, development, and training.

Because SAGAT is a direct objective measure of SA, it might seem to be the preferred method for measuring SA. In simulations and other tightly controlled settings it may indeed represent the most desirable approach. However, much of the training in the Army is done in the field, and Army leaders and trainers often are reluctant to interrupt the flow of an exercise to allow measures of what they may view as elusive psychological constructs. In these settings, the SABARS or a similar approach might be more desirable to the extent that it is less obtrusive. However, SABARS is labor intensive in the sense that O/Cs or other highly experienced personnel must be dedicated to observing a particular leader over the course of an exercise in order to provide meaningful ratings of SA related behaviors.

Thus, in some instances a subjective SA assessment procedure may prove useful. In Strater et al. (2001) the subjective measure, the PSAQ, did not provide useful assessments of SA. However, numerous other direct, subjective SA measures exist and have been used in a variety of domains (see Endsley et al., 2000). More recently, McGuinness and Foy (2000) reported the development of a subjective SA measure that can be easily tailored to a variety of settings or domains. McGuinnes and Foy refer to this instrument as the Crew Awareness Rating Scale (CARS). The CARS consists of two sets of four questions. The first three questions of each set correspond to the three levels of SA defined by Endsley (1988), i.e., perception, comprehension, and projection. The fourth question of each set deals with how well the respondent identifies goals for the situation he or she is in. Moreover, the first set of four questions pertain to assessing SA content, for example, how well the respondent thinks he or she understands the situation. The second set of questions addresses workload, for example, how much mental effort is required to achieve understanding in a given situation. The assessment of workload is an important aspect of SA. There could be situations, for instance, in which a person has high levels of SA, but most of their attentional capacity is required to achieve that level of SA. This would leave little mental workspace left to allocate to other, perhaps equally critical, processes. This sort of subjective measure could prove very useful in evaluating the impact of new technologies on SA and mission performance.

The purpose of the current study was to adapt CARS for application to small unit leaders in the Infantry. The revised CARS was tested during a virtual MOUT experiment initially designed to evaluate the use of virtual environments for night operations training. Specific focus was directed to the night capabilities currently available on selected simulation systems. The capabilities evaluated in this research included night vision goggles (Nags, specifically the PVS-7B) with aiming lights. Two simulated NVG software systems were evaluated; one system was developed by Reality by Design (RBD) and the other by AcuSoft (AS). These systems were compared to actual PVS-7Bs that were worn under simulated unaided night conditions. Previous testing showed that using actual PVS-7Bs under these conditions generated very realistic images.

Because the focus of infantry operations is on team conducted missions, the modified CARS is referred to in this report as the Mission Awareness Rating Scale (MARS). If MARS is in fact sensitive to SA content and SA workload, then any differences that exist among technologies for simulating night environments should be reflected in MARS ratings to the extent that they (1) affect the user's ability to perceive elements important in the situation, (2) understand the meaning of those elements, and (3) make predictions based on that understanding about what is likely to occur in the near future. It is hypothesized that poorer image fidelity should either decrement SA content and/or increase cognitive workload demands needed to sustain good SA.

Method

Overview

Four-man infantry teams conducted four night missions in an immersive virtual urban environment. Scenarios were generally the same, differing only in starting location, reconnaissance objectives, and sequencing of the appearance of civilians, enemy forces, vehicles, aircraft, etc. Each mission was conducted under one of four different night conditions. Two conditions simulated night vision goggles (NVGs, specifically PVS-7Bs) and aiming lights but used different software approaches to create their effects. Two additional conditions simulated an unaided night environment, where soldiers wore actual NVGs with the lens cap off (to approximate real-world images under good illumination), or with lens cap on (to approximate real-world images under bad illumination). [Note: The lens cap contains a tiny pinhole at the center that greatly restricts the amount of light that can pass through the system.]. A retired non-commissioned officer, who role played the squad leader, offered minimal guidance during the scenarios and provided immediate feedback following the completion of each scenario during the after action reviews. ARI researchers served as additional observers and data collectors.

Participants

Subjects were sixteen enlisted and non-commissioned officers from Fort Benning, Georgia. The average age of the soldiers was 25 years, 11 months. Average time in service was 75.2 months, with a range of 17 – 174 months. Nine soldiers were Airborne qualified and two had successfully completed Ranger school. Seven soldiers had completed the Primary Leader Development Course and four had completed the Basic Non-Commissioned Officer Course.

Soldiers had trained at the McKenna MOUT site at Fort Benning an average of eight times since basic training (range 0 – 50 times). Only one soldier had ever operated a virtual individual combatant simulator such as the type employed at the Land Warrior Test Bed (LWTB). The majority of soldiers had some experience with military simulation systems. Four soldiers had trained using Simulation Networking (SIMNET) and/or the Close Combat Tactical Trainer. All soldiers had previous experience with NVGs and aiming lights.

Instruments

Biographical Information Questionnaire. The Biographical Information Questionnaire (Appendix A) is a multiple choice/short answer paper-and-pencil instrument designed to document the prior military training, experience, and vision status of each subject, as well as their experience with computers and simulations.

Virtual Environment Night Operations Comparison Questionnaire. At the end of the experiment the Virtual Environment Night Operations Comparison Questionnaire was administered (Appendix B). Soldiers rank ordered the different night conditions based on how well each environment was able to accurately simulate the experience of working under night conditions. Rankings could range from 1 (Very realistic simulation of night conditions) to 4 (Very poor simulation of night conditions). In addition, the soldiers responded to a series of open-ended questions that were presented orally in individual interviews with ARI researchers. Questions addressed the following issues:

- Rationale for ranking a particular night condition as the best (most realistic) or worst (least realistic)
- What was liked the most/least about these night simulations
- Whether wearing NVGs increased the realism of the simulation
- How virtual night environments could be incorporated in training

Pre-Mission Awareness Rating Scale (Pre-MARS). Pre-MARS (Appendix C) is an eight question instrument based on the Crew Awareness Rating Scale (CARS) described in depth by McGuinnes and Foy (2000). The instrument consists of four questions designed to assess the ability of soldiers to perceive, comprehend, project, and how to best achieve mission goals during night missions, based on their experience with such missions. Four additional questions address the same dimensions (perceive, comprehend, project, and how to achieve mission goals) but ask the respondent how much mental effort (i.e., workload) is needed to perform these functions during night operations. The Pre-MARS instrument, therefore, required the participants to estimate, based on their past experiences with night missions, their level of SA and amount of workload required to achieve that level of SA.

Mission Awareness Rating Scale (MARS). The MARS instrument (Appendix D) included the same eight questions as the Pre-MARS instrument. However, instead of basing responses on general past experience with night operations, MARS required the participants to rate their SA content and workload for the virtual scenario they had just completed in the LWTB. Thus, MARS represents a subjective self-assessment of SA and SA-related workload for each of the four specific missions/night environment conditions included in the current experiment.

Night Scenarios

All scenarios were set as if in a small European town. The town was a virtual representation of the McKenna MOUT training site at Fort Benning, Georgia. A military subject matter expert developed four versions of a reconnaissance mission. Missions involved eight to twelve events. Events depicted virtual images of civilians, friendly/enemy soldiers, civilian and military vehicles. Entities were either stationary or moving. These events were scripted to occur at differing times as the soldiers moved to their objective. All missions concluded with a firefight between the test subjects and an opposing force (OPFOR) that was played by live soldiers. Missions differed in the location where the soldiers started, the order of presentation of the various entities, and building location of the OPFOR.

Apparatus

Soldier Visualization Station (SVS). Four full-immersion SVS systems [helmet mounted display – HMD (this feature was not used), weapon, screen] were employed along with three desktop versions. The desktop system was joystick controlled. The four stand-alone systems were linked to the desktops. Technical specifications of the two systems are shown in Table 1. Team members could communicate with each other and to both the team and squad leaders. Only the team leader was allowed to communicate with the squad leader. The four SVS systems were housed in their own enclosures. These enclosures were made of thick black cloth and fastened to a metal frame surrounding the SVSs. They were designed to dampen extraneous sound, reduce light, and minimize distractions from other people moving around the area.

Table 1
Technical Specifications of the SVS and Desktop Systems

System Hardware (Immersive and Desktop)	• Pentium III – 450 MHz microprocessor • 128 Mb RAM • Obsidian 200 – 8440 3D Graphics Card • SoundBlaster AWE 64 Gold Audio Card • Removable 4.55 GB SCSI Hard Drive
Movement Control	• Weapon-mounted thumbswitch • Desktop SVS – Microsoft joystick control
Motion Capture/ Weapon Tracking	• InterSense Mark2 X-Bar Tracking System • Weapon tracking accurate to within ½ of 1°
Visual Display	• 90° x 60° field of view at center of enclosure (varies with position change) • Rear screen projection resolution 1024 x 768 • Desktop SVS resolution 800 x 600
Enclosures	• Aluminum frame over black sound-dampening fabric. (10 x 10 x 12)
Software	• Reality By Design proprietary software

Each subject operated an SVS, while the squad leader and the OPFOR operated the desktop systems. ARI researchers observed events from either the simulation system operator's computer screen depicting a top-down view of McKenna or by looking at the squad leader's screen. The squad leader and the simulation operator systems were adjacent to each other, but away from the SVS systems. The OPFOR systems were located in another room next to the SVSs. The dimensions and other specific details of its layout are described in more detail by Salter, Eakin, & Knerr (1999).

AN/PVS-7B Night Vision Goggle. The A/N (Army/Navy) PVS-7B NVG is a lightweight image intensification, near infrared device that uses ambient light conditions.

It weighs 1.5 pounds and fastens via a harness to the user's head. An eyepiece diopter is provided so the device can be worn without corrective lenses. The PVS-7B is equipped with an infrared light sources and positive control switch that permits close-in viewing (e.g., map reading, close-up work in zero ambient light conditions) under limited illumination. (A feature not used in the current experiment.) An auto gain control insures the right level of illumination regardless of light sources in the field of view. The field of view is 40 degrees with a focus range of six inches to infinity. Two AA batteries power the PVS-7B.

Procedure

Pilot testing. Four individuals with NVG experience were recruited to take part in the pilot testing which lasted approximately one day. These individuals were briefed on the missions and conducted one movement to engagement mission per night condition as a fire team. Any problems with a particular night condition or the NVGs were noted. All procedures including real time data collection using spot report check lists were examined. The squad leader rehearsed his role with the other team members. After the testing was completed, any procedural modifications that were needed were completed.

Soldier training. Four soldiers arrived each morning at the LWTB and were briefed on the objectives of the experiment. They were given a chance to ask any questions concerning their roles in the experiment. They then completed the Biographical Information Questionnaire and the Pre-MARS.

After completing the questionnaires, the soldiers were given a brief introduction to the SVS system and allowed hands-on time (approximately 30 minutes) to familiarize themselves with the key system features (e.g., moving within the SVS area, moving via the thumb switch on the M-4 rifle, engaging targets). In addition, they were shown what various entities looked like in the virtual world (e.g., buildings, furniture, friendly/enemy forces, civilians, vehicles, and aircraft) under simulated NVG conditions.

Experimental procedure. Following the training phase, the soldiers composing the fire team met with the squad leader in the LWTB conference room. The squad leader briefed the mission to the team members who were given a chance to ask questions and then allowed 15-20 minutes to develop their plan. The squad leader emphasized to the team leader that spot reports (to the squad leader) were required immediately following the detection of any event (e.g., civilian walking across the street, burning car, etc.).

The soldiers then proceeded to the simulator bay and to their assigned immersible SVS systems. The squad leader moved to his assigned desktop system co-located with the immersible SVSs. ARI researchers stayed with the squad leader. Each researcher had headphones and was able to hear all message traffic between the team and squad leaders. In addition, they could also observe the actions of the team from the screen of the squad leader's desktop SVS. The OPFOR were already in place in front of their desktop systems in a separate room. After completing system checks on the SVSs and the communication nets, the scenario started.

Presentation of the four night conditions was balanced using a Latin square design. After each night condition/mission, the squad leader conducted a brief After Action Review. The soldiers then completed the MARS instrument.

This sequence was presented a total of four times. At the conclusion of the experiment, the soldiers completed the first part of the Virtual Environment Night Operations Comparison Questionnaire (rank ordering of night conditions). Individual structured interviews were then conducted based on the remaining items making up the questionnaire.

Four night environment conditions were examined. The first condition ("RBD") was a night scene software projection developed by Reality by Design (RBD), designed to simulate the images soldiers would see while using night vision goggles. In this condition, no image intensification device was worn by the participants. The second condition ("AS") was a night simulation software projection designed by AcuSoft (AS). Like the RBD condition, this software simulated night images without the use of goggles. The third condition ("Caps Off") required participants to wear PVS-7B NVGs with the lens cap off while viewing the unaided night projections (that is, what a soldier would see at night without any image intensification device). This is the manner that NVGs are usually used in the field. The final condition ("Caps-On") involved wearing the PVS-7Bs with the lens cap on while viewing the same unaided projection. The caps allow a minimal amount of light in via a pinhole. This greatly reduced the visibility of the scene.

Results

Pre-MARS. Pre-MARS was designed to provide an estimate of SA during night operations based on the participant's general experience in night operations. Results from the Pre-MARS instrument are summarized in Table 2, which shows the mean and standard deviation for the Pre-MARS SA content and SA workload subscales. A one-way repeated measures analysis of variance (ANOVA) revealed a significant difference among the four subscales for SA content ($F[3,45] = 3.17$, $p < .05$, eta squared = .17), with the most demanding SA component being level 3 SA, *prediction*. To determine which means differed significantly, post hoc analyses were conducted using paired *t* tests, with alpha set at .05, df = 15, and using the Bonferroni correction to account for multiple comparisons. This showed that only the *predict* versus *decide* comparison was significant. Similarly, responses to the SA workload subscales also differed significantly, $F[3,45] = 6.37$, $p < .05$, eta squared = .30. Post hoc comparisons, again using paired *t* tests, showed that *perceive* versus *predict* and *comprehend* versus *predict* were significant.

Table 2
Pre-MARS Ratings of Night Mission SA

	Mean	Standard Deviation	N
SA Content*			
Perceive	1.94	.68	16
Comprehend	1.63	.62	
Predict	2.13	.72	
Decide	1.62	.72	
SA Workload**			
Perceive	1.81	.66	16
Comprehend	1.87	.62	
Predict	2.44	.81	
Decide	2.13	.72	

* $\underline{F}$ (3,45) = 3.17, $\underline{p}$ < .05, eta squared = .17
** $\underline{F}$ (3,45) = 6.37, $\underline{p}$ < .05, eta squared = .30

<u>MARS</u>. Table 3 shows the means and standard deviations for MARS SA content subscales for each of the treatment conditions, Caps Off, Caps On, RBD, and AS. For SA content, the participants rated the Caps On condition as being the most difficult for all four subscales. Moreover, comparing within the Caps On condition across the subscales, the most difficult tasks were *perception* followed closely by *prediction*. For the SA content subscales, the least demanding ways of simulating NVG-like images in a virtual environment were RBD and AS for all four subscales. The Caps Off condition fell intermediate in difficulty for all four subscales, with mean ratings similar to those from the Pre-MARS scale.

Four one way repeated measures ANOVAs were conducted for each SA content subscale. The ANOVAs were statistically significant with large eta squares. Post-hoc comparisons within each level of SA content were performed using paired *t* tests with alpha set at .05 and 14 degrees of freedom. Using the Bonferroni correction to adjust for multiple comparisons, all pair-wise comparisons for level 1 SA (*perceive*), with the exception of RBD versus AS, were significant. For level 2 SA (*comprehend*), all pair-wise comparisons were significant except for Caps Off versus RBD, and RBD versus AS. Among level 3 SA (*prediction*) comparisons, the following were statistically significant: Caps On versus Caps-Off, Caps On versus AS, and Caps On versus RBD. No other pair-wise comparisons were significant for level 3 SA. Finally, for the *decide* questions under SA content, three comparisons were statistically significant: Caps Off versus AS, Caps On versus AS, and Caps On versus RBD.

Table 3

Means and Standard Deviations for MARS SA Content Subscales for Each Night Simulation Condition

	SA Content											
	Perceive[1]			Comprehend[2]			Predict[3]			Decide[4]		
	M	SD	N	M	SD	N	M	SD	N	M	SD	N
Caps On	2.73	.88	15	2.27	.70	15	2.47	.83	15	2.13	.64	15
Caps Off	1.80	.77	15	1.60	.63	15	1.87	.64	15	1.80	.68	15
RBD	1.13	.35	15	1.20	.41	15	1.53	.52	15	1.27	.46	15
AS	1.13	.35	15	1.20	.41	15	1.60	.74	15	1.20	.41	15

[1] $F\ (3, 42) = 27.36$, $p < .01$, eta squared = .66

[2] $F\ (3, 42) = 15.06$, $p < .01$, eta squared = .52

[3] $F\ (3, 42) = 10.48$, $p < .01$, eta squared = .43

[4] $F\ (3, 42) = 10.36$, $p < .01$, eta squared = .42

For the SA workload scales a similar pattern emerged. Repeated measures ANOVAs revealed significant differences in rated difficulty among the four ways of simulating NVG image effects across all four subscales, with the Caps On condition being rated the most difficult for each subscale. With that condition, the most difficult tasks were *prediction*, followed closely by *perception*. Again, the easiest conditions for all four subscales were RBD and AS. The Caps Off ratings again fell between the Caps On and RBD/AS ratings, and were similar to those obtained from Pre-MARS ratings of SA workload for night operations in the real world. Eta squared values were also robust for these comparisons, indicating a strong relationship between workload subscales and treatment condition. These data are summarized in Table 4.

Table 4

Means and Standard Deviations for MARS SA Workload Subscales for Each Night Simulation Condition

	SA Workload											
	Perceive[1]			Comprehend[2]			Predict[3]			Decide[4]		
	M	SD	N	M	SD	N	M	SD	N	M	SD	N
Caps On	2.73	.80	15	2.47	.52	15	2.80	.68	15	2.27	.80	15
Caps Off	2.00	1.00	15	1.67	.82	15	2.00	.76	15	2.07	.70	15
RBD	1.40	.51	15	1.13	.35	15	1.53	.64	15	1.33	.62	15
AS	1.40	.51	15	1.40	.63	15	1.53	.74	15	1.47	.64	15
		.63										

[1] $F\ (3, 42) = 12.83$, $p < .01$, eta squared = .48

[2] $F\ (3, 42) = 24.40$, $p < .01$, eta squared = .64

[3] $F\ (3, 42) = 14.58$, $p < .01$, eta squared =.51

[4] $F\ (3, 42) = 9.59$, $p < .01$, eta squared = .41

Pair-wise *t* tests were again used for the four SA Workload scales as a post-hoc procedure to locate which means within comparisons were statistically significant. With alpha set at .05, 14 degrees of freedom, and using the Bonferroni correction, only two comparisons were found to be significant for the *perceive* scale: Caps-On versus AS, and Caps-On versus RBD. For the *comprehend* and *predict* scales there were three significant comparisons: Caps off versus Caps on, Caps On versus AS, and Caps On versus RBD. Finally, for the *decide* scale, significant differences were found between Caps versus AS, Caps Off versus RBD, Caps On versus AS, and Caps On versus RBD.

MARS subscale intercorrelations. Conceptually, there should be a high positive correlation among the MARS subscales. For example, good level 2 SA should be dependent upon achieving high level 1 SA. Appendix E shows the MARS subscale intercorrelations for the Caps Off, Caps On, RBD, and AS conditions, respectively. These tables reveal large and statistically significant ($p < .05$) correlations between subscales for all but the RBD condition. For that condition, only 6 of the 28 possible correlations were statistically significant.

Subjective data. The soldiers participating in the experiment were asked to rank order (from best to worst) how well each method was able to accurately simulate the experience of working under night conditions. Forty percent of the soldiers rated the Caps Off condition as most similar to actual night conditions, followed by Caps On and RBD (27% each). Only one soldier rated AS as the most realistic condition. Two conditions were identified as being the poorest approximation of night conditions, with 53% of the soldiers rating the AS condition as the worst approach, followed closely by 47% who rated the Caps On as the worst.

Discussion

The main experimental question addressed was whether MARS would discriminate among four approaches to simulating night vision goggle image effects. The results indicate that it did detect differences both in the SA content and SA workload as a function of the simulation procedure. The MARS instrument also may provide insight on which method most closely simulates NVG images seen under real world conditions using PVS-7Bs. For example, the Caps Off condition emerged with ratings on all subscales that were closest in value to those obtained from the Pre-MARS instrument. One of the conditions – Caps On – was consistently rated as more demanding than actual night operations. Two others, the RBD and the AS conditions, were uniformly rated as easier than actual night operations. The question of which night simulation is most "realistic" is complicated, with many image and fidelity issues involved, but SA as indexed by MARS may represent one component used to judge the realism of these night environments.

The second line of evidence supporting this conclusion was in the comparison of MARS responses with feedback given to the experimenters by the soldiers at the conclusion of the experiment. Forty percent of the soldiers rated the Caps Off condition as the most realistic NVG environment. In contrast, none reported this condition as being the worst.

Thus, it appears that MARS discriminated among these four treatment conditions. It could be questioned, however, what exactly it is that MARS measures. In order to demonstrate that MARS actually measures SA, per se, it will be necessary to compare MARS responses against a more objective and better validated SA measure. Probably the best of these measures is SAGAT. In contrast to MARS, which relies on subjective and general ratings of SA content and SA workload, SAGAT involves specific questions on SA related information, such as the location of friendly and enemy troops, status of ammunition, fuel, and supplies, etc. These responses are compared to "ground truth." To establish that MARS is measuring SA, and not some other process, it will be necessary to simultaneously collect MARS and SAGAT data, using the latter as the validation criterion.

With the exception of the RBD condition, the MARS subscales generally showed large and positive inter-correlations. According to Endsley et al. (2000) model of infantry SA, this would be expected to be the case. It would be difficult, according to this model, to have high level 3 SA (projection) if lower levels of SA were not also at a high level. The failure to find high inter-correlations among the MARS subscales for the RBD condition may reflect some sort of "floor" effect. Both SA content and workload were rated as relatively easy to obtain under that condition, and this could have resulted in a case where good higher-order SA might not depend on good lower level SA. The AS condition had similar SA content and workload ratings as the RBD condition, however, yet showed relatively large subscale inter-correlations. So it is possible that some other unique aspect of the RBD condition affected the ratings for that condition.

The importance of developing a psychometrically sound subjective SA measurement approach that could be used in a variety of Army field settings is that more objective approaches, like SAGAT, are viewed as too obtrusive to be used in field exercises. Infantry teams operate in a fluid and dynamic way, and Army trainers are concerned that stopping action – even if for only a few minutes – will detract from the realism of the training. However, some method for assessing SA during these types of exercises is necessary for a number of reasons. First, new technologies designed to improve communication and enhance information flow may actually detract from SA by causing overload. Second, there needs to be a way of assessing new training strategies on SA. Finally, because good decision-making hinges on good SA, techniques and approaches designed to improve SA itself must be evaluated. While some of these objectives can be accomplished in virtual environments or very carefully controlled and conducted field training, much of this will be conducted in settings where SAGAT or similar procedures would be found unacceptable.

In conclusion, MARS represents a potentially useful instrument for use in assessing subjective SA. The instrument could be used to assess the impact of new information technologies on SA content and SA workload, and thus help determine if these technologies actually facilitate or inhibit decision-making and performance. Future research efforts should center on validating MARS against more objective direct measures of SA, such as SAGAT, and evaluating its usability and psychometric properties in the field environment.

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Appendix A

Biographical Information Questionnaire

Biographical Information Questionnaire

Name________________________ Unit_________ Date_________

Please fill in the blank or mark or circle the appropriate response.

1. What is your age? _____ Years _____Months

2. MOS _________

3. Rank ________

4. Time in service Years _____ Months _____

5. What is your current (or most recent) duty position? _______________
How long in this position? _______

6. What Army training courses have you completed? Check all that apply.

_____ PLDC _____BNCOC _____ANCOC _____ Airborne

_____BFV Leader Course _____ Ranger _____Air Assault

_____Other (please specify)______________________________

7. How susceptible to motion or car sickness do you feel you are?

1	2	3	4	5	6	7
not susceptible			moderately susceptible			highly susceptible

8. Do you have normal 20/20 vision **without glasses**? ____Yes ___No

9. Do you have 20/20 vision **with contact lenses or glasses**? ____Yes ____No
____NA

10. Are you color blind? _____Yes _____No

11. Are you _____right handed? _____left handed?

12. How many hours per week do you play 'virtual reality' type games? _____ hours per week

13. How often have you trained at the McKenna MOUT site (not including demos)? _____ times

14. Have you ever been in a Virtual Individual Combatant (VIC) simulator at the Land Warrior Test Bed before?

_____Yes _____No

If YES, which one(s)? (Describe if you cannot remember the name)

15. Have you had any <u>other</u> experience with military computer simulations?

_____Yes _____No

If yes, please describe briefly or give the names of the simulators.

Appendix B

Virtual Environment Night Operations Comparison Questionnaire

Virtual Environment Night Operations Comparison Questionnaire

Name:____________________ Date:__________ VE Comparison

1. Rank order the virtual night environments from 1-4, based on **how well** each was able to **accurately simulate** the experience of **working under night conditions**. **(Note. Use each number – 1, 2, 3, 4 only once in your rankings)**.

1 = **Best** (Very realistic simulation of night conditions)
4 = **Worst** (Very poor simulation of night conditions)

_____PVS-7B Good Illumination
_____PVS-7B Bad Illumination
_____RBD NVG
_____AS NVG

Structured Interview Questions

2. Why did you select the _____ system as the best?

3. Why did you select the_____ system as the worst?

4. What did you like most about these night simulations? Why?

5. What did you like least about these night simulations? Why?

6. Did wearing NVGs (PVS-7Bs) increase the realism of the simulation? If so, how?

7. How would you incorporate virtual night environments in your training?

Appendix C

Pre-Mission Awareness Rating Scale (Pre-MARS)

Name ______________ Date ______________

Position (check one) ____ Team Leader _____ Team Member

Night Operations Situation Awareness Questionnaire

The following four questions deal with your ability to perceive and understand important aspects of a situation during night operations in the *REAL WORLD* while using NVG (& aiming light) or other equipment you routinely use:

1. Please rate your ability to ***identify*** mission-critical cues at night.

    ___ very easy – able to identify all cues
    ___ fairly easy – can identify most cues
    ___ somewhat difficult – many cues hard to identify
    ___ very difficult – have substantial problems identifying most cues

2. How well can you ***understand*** what is happening at night?

    ___ very well – can always understand the situation
    ___ fairly well – can understood most aspects of the situation
    ___ somewhat poorly – often have difficulty understanding the situation
    ___ very poorly – the situation usually does not make sense to me

3. How well can you ***predict*** what is about to occur next at night?

    ___ very well – can predict with accuracy what is about to occur
    ___ fairly well – can make accurate predictions most of the time
    ___ somewhat poor – misunderstand the situation much of the time
    ___ very poor – usually unable to predict what is about to occur

4. How aware are you of ***how to best achieve*** your goals at night?

    ___ very aware – know how to achieve goals at all times
    ___ fairly aware – know most of the time how to achieve mission goals
    ___ somewhat unaware – am not aware of how to achieve some goals
    ___ very unaware – generally unaware of how to achieve goals

The last four questions ask how *difficult* it is for you to detect and understand important cues present at night in the REAL WORLD.

5. How difficult – in terms of mental effort required - is it for you to ***identify*** or detect mission-critical cues at night?

___ very easy – can identify relevant cues with little effort
___ fairly easy – can identify relevant cues, but some effort required
___ somewhat difficult - some effort is required to identify most cues
___ very difficult – substantial effort is required to identify relevant cues

6. How difficult – in terms of mental effort – is it to ***understand*** what is going on at night?

___ very easy – understand what goes on with little effort
___ fairly easy – understand events with only moderate effort
___ somewhat difficult – hard to comprehend some aspects of situation
___ very difficult – hard to understand most or all aspects of situation

7. How difficult – in terms of mental effort – is it to ***predict*** what is about to happen at night?

___ very easy – little or no effort needed
___ fairly easy – moderate effort required
___ somewhat difficult – many projections require substantial effort
___ very difficult – substantial effort required on most or all projections

8. How difficult – in terms of mental effort – is it to decide on ***how to best achieve*** mission goals at night?

___ very easy – little or no effort needed
___ fairly easy – moderate effort required
___ somewhat difficult – substantial effort needed on some decisions
___ very difficult – most or all decisions require substantial effort

Appendix D

Mission Awareness Rating Scale (MARS)

Name ______________ Date ______________

Position (check one) ____ Team Leader _____ Team Member

Treatment Condition: __ PVS-7/GI ___ PVS-7/BI ___ RBS/NVG ___ ASW/NVG

Mission Awareness Rating Scale (MARS)

Instructions. Please answer the following questions about the exercise you just completed. Your answers to these questions are important in helping us evaluate the effectiveness of this training exercise. Check the response that best applies to your experience.

The first four questions deal with your *ability* to detect and understand important cues present during the exercise.

1. Please rate your ability to ***identify*** mission-critical cues in this exercise.

    ___ very easy – able to identify all cues
    ___ fairly easy – could identify most cues
    ___ somewhat difficult – many cues hard to identify
    ___ very difficult – had substantial problems identifying most cues

2. How well did you ***understand*** what was going on during the exercise?

    ___ very well – fully understood the situation as it unfolded
    ___ fairly well - understood most aspects of the situation
    ___ somewhat poorly – had difficulty understanding much of the situation
    ___ very poorly – the situation did not make sense to me

3. How well could you ***predict*** what was about to occur next in the exercise?

    ___ very well – could predict with accuracy what was about to occur
    ___ fairly well – could make accurate predictions most of the time
    ___ somewhat poor – misunderstood the situation much of the time
    ___ very poor – unable to predict what was about to occur

4. How aware were you of ***how to best achieve*** your goals during this exercise?

    ___ very aware – knew how to achieve goals at all times
    ___ fairly aware – knew most of the time how to achieve mission goals
    ___ somewhat unaware – was not aware of how to achieve some goals
    ___ very unaware – generally unaware of how to achieve goals

The last four questions ask how *difficult* it was for you to detect and understand important cues present during the exercise.

5. How difficult – in terms of mental effort required - was it for you to ***identify*** or detect mission-critical cues in the exercise?

___ very easy – could identify relevant cues with little effort
___ fairly easy – could identify relevant cues, but some effort required
___ somewhat difficult - some effort was required to identify most cues
___ very difficult – substantial effort required to identify relevant cues

6. How difficult – in terms of mental effort – was it to ***understand*** what was going on during the exercise?

___ very easy – understood what was going on with little effort
___ fairly easy – understood events with only moderate effort
___ somewhat difficult – hard to comprehend some aspects of situation
___ very difficult – hard to understand most or all aspects of situation

7. How difficult – in terms of mental effort – was it to ***predict*** what was about to happen during the exercise?

___ very easy – little or no effort needed
___ fairly easy – moderate effort required
___ somewhat difficult – many projections required substantial effort
___ very difficult – substantial effort required on most or all projections

8. How difficult – in terms of mental effort – was it to decide on ***how to best achieve*** mission goals during this exercise?

___ very easy – little or no effort needed
___ fairly easy – moderate effort required
___ somewhat difficult – substantial effort needed on some decisions
___ very difficult – most or all decisions required substantial effort

Appendix E

MARS Subscale Correlation Matrices

Caps Off Condition

	Content/ Perceive	Content/ Comprehend	Content/ Project	Content/ Decide	Workload/ Perceive	Workload/ Comprehend	Workload/ Project	Workload/ Decide
Content/ Perceive		.700**	.663**	.600*	.553*	.678**	.610*	.550*
Content/ Comprehend			.741**	.635*	.678**	.692**	.598*	.706**
Content/ Project				.429	.558*	.592*	.591*	.656**
Content/ Decide					.634*	.647**	.559*	.631*
Workload/ Perceive						.875**	.850**	.710**
Workload/ Comprehend							.694**	.663**
Workload/ Project								.671**
Workload/ Decide								

* $p < .05$
**$p < .01$

Caps On Condition

	Content/ Perceive	Content/ Comprehend	Content/ Project	Content/ Decide	Workload/ Perceive	Workload/ Comprehend	Workload/ Project	Workload/ Decide
Content/ Perceive								
Content/ Comprehend	.698**							
Content/ Project	.487	.629**						
Content/ Decide	.447	.394	.413					
Workload/ Perceive	.908**	.646**	.536*	.492				
Workload/ Comprehend	.624**	.429	.629**	.657**	.687**			
Workload/ Project	.531*	.571*	.689**	.394	.584*	.524*		
Workload/ Decide	.616*	.504*	.555*	.626**	.678**	.546**	.630**	

* $p < .05$
**$p < .01$

RBD Condition

Workload/ Decide	Workload/ Project	Workload/ Comprehend	Workload/ Perceive	Content/ Decide	Content/ Project	Content/ Comprehend	Content/ Perceive	
								Content/ Perceive
							.218	Content/ Comprehend
						.218	.333	Content/ Project
					.323	.234	-.255	Content/ Decide
				.035	.683**	-.149	.098	Workload/ Perceive
			.289	.367	.424	.092	-.182	Workload/ Comprehend
		.345	.556*	.706**	.608*	-.059	-.039	Workload/ Project
	.620*	.234	.162	.703**	.342	-.120	-.236	Workload/ Decide

* p < .05
**p < .01

AS Condition

	Content/ Perceive	Content/ Comprehend	Content/ Project	Content/ Decide	Workload/ Perceive	Workload/ Comprehend	Workload/ Project	Workload/ Decide
Content/ Perceive		.784**	.771**	.784**	.706**	.706**	.801**	.338
Content/ Comprehend			.515*	.583*	.764**	.764**	.789**	.431
Content/ Project				.749**	.521*	.521*	.678**	.424**
Content/ Decide					.491	.491	.557*	.162
Workload/ Perceive						.821**	.729**	.565*
Workload/ Comprehend							.881**	.741**
Workload/ Project								.641*
Workload/ Decide								

* $p < .05$
**$p < .01$