MILITARY OPERATIONS ON URBANIZED TERRAIN (MOUT) TRAINING IN SYNTHETIC ENVIRONMENTS USING THE TEAM TARGET ENGAGEMENT SIMULATOR (TTES)

Jeffrey D. Horey, Dr. David H. Fowlkes, Robert S. Reif
Naval Air Warfare Center Training Systems Division
Orlando, FL

Abstract

This paper presents a system description and training capability evaluation results for the Team Target Engagement Simulator (TTES), a virtual environment team training system. The TTES is a research and development effort designed to provide Military Operations on Urbanized Terrain (MOUT) training for deployed rifle squads. A training capability evaluation of the system was conducted at the Marine Corps Base Quantico Combat Village in early May 1995. System effectiveness, simulator sickness, range estimation and limited performance results are presented.

Participants in the evaluation consisted of infantry Marines, many with recent MOUT experience. Participant critiques indicated that the system has considerable potential for training MOUT skills. System features related to controlling movement within the environment and the perceptual aspects of the environment itself were rated effective for MOUT training. Range estimations indicated distances appear, on average, about 47% greater than in the real world. No simulator sickness problems were detected during the evaluation.

ABOUT THE AUTHORS

Jeffrey Horey is a psychologist with the Naval Air Warfare Center Training Systems Division. He holds a Master of Philosophy from the George Washington University in Industrial/Organizational Psychology. He has worked in human factor and training effectiveness evaluation and currently works in small caliber weapons training development.

David Fowlkes is a psychologist with the Naval Air Warfare Center Training Systems Division. He holds a Ph.D. from the University of Georgia in Biopsychology. He currently works in training system research and development.

Robert Reif is an engineer with the Naval Air Warfare Center Training Systems Division. He holds a degree in electrical engineering from the University of Central Florida and has been working in research and development since 1986.

Military Operations on Urbanized Terrain (MOUT) Training in Synthetic Environments Using the Team Target Engagement Simulator (TTES)

Jeffrey D. Horey, David H. Fowlkes, Robert S. Reif
Naval Air Warfare Center Training Systems Division
Orlando, FL

INTRODUCTION

The TTES is an advanced research and development effort at the Naval Air Warfare Center Training Systems Division funded by the United States Marine Corps. The TTES is designed to allow deployed rifle teams to participate in simulated force-on-force training engagements in Military Operations on Urbanized Terrain (MOUT) through interaction with a virtual environment. The system allows multiple trainees to traverse a combat village and practice appropriate threat identification, cover, communication, and engagement skills to complement classroom and other training. Trainee stations, computer controlled hostiles and neutral nodes are connected via Distributed Interactive Simulation (DIS).

The success of a DIS network ultimately depends on the training effectiveness of the individual systems within the network. A training capability evaluation estimates the degree to which a system can support the attainment of training objectives. Such an evaluation should identify strengths as well as weaknesses or problems with the system. Estimating training capability is the first step toward establishing system training effectiveness.

The TTES was demonstrated to infantry Marines for utilization and evaluation. The results of this evaluation are presented as evidence of the TTES training capability. Additional data on the accuracy of the virtual environment representation and potential simulator sickness are also presented. Finally, implications for future improvements in the TTES and implications for other virtual environment trainers are discussed.

System Description

TTES provides the capability to traverse a combat town environment, control direction of gaze, interact with other squad members, and use the M16-A2 to engage hostiles and neutrals. Each of the two current TTES trainee stations has a large screen (70 X 50 degrees field of view), relatively high resolution visual display. The host computer for each TTES station is a Silicon Graphics Incorporated Onyx Reality Engine2, while a personal computer is used to host the computer controlled hostiles. The two TTES stations and computer controlled hostiles node are connected via DIS. The simulated environment is the Quantico Combat Training Village (QCTV) consisting of 16 buildings (1 to 3 stories) on a 1000 ft X 2000 ft piece of land.

Trainee movement within the virtual environment is controlled with a combination of foot pad and head tracker. The foot pad has one pressure sensitive pad located under the heel (backward movement) and one under the ball of the foot (forward movement). Turning of the head while moving causes a change in direction of movement and the amount of foot pressure applied controls speed over terrain.

Movement direction is controlled by direction of gaze. Looking off to the left or right edge of the screen causes the world to rotate to the right or left and, effectively, changes trainee view and direction. The two trainees can talk to each other via microphones and headphones, and see each other on their respective visual displays. Team members are graphically depicted including position (standing, kneeling, and prone) and weapon firing condition.

A demilitarized and instrumented (ultra-sonic tracking system) M16-A2 is used and number of rounds are tracked, requiring magazine changes. The sound of the weapon firing provides some localization cues. Computer controlled hostiles use visual and audio cues to locate trainees, and can kill and be killed. Hostiles may engage trainees or seek cover.

Training Capability Evaluation Objectives

In order to assess the training capability of the system, four different aspects of system performance were included in the evaluation. The first area of consideration was the potential simulator sickness that may occur through the use of the system. Simulator sickness can greatly reduce the perceived and actual impact of training systems.

Another valid concern of synthetic environment training is the appearance of the virtual world to the participants. Distances in synthetic environments can be perceived as different from those that they represent, possibly due to visual acuity problems of the synthetic environment (Hamilton, Johnson, Coker and Wightman, 1994). Given the critical nature of the TTES training, estimation of the accuracy of the perceptual representations should be conducted.

A third area of capability interest is the training system characteristics and features as perceived by subject matter experts (SME's). Training system evaluations often rely on subjective ratings from subject matter experts to determine their capability and effectiveness. Detailed system characteristics evaluation contributes to system development and often identifies strengths and weaknesses not perceived by the development team.

Finally, a training capability evaluation should attempt to examine the extent to which learning takes place in the system. By measuring the performance of participants in the evaluation, estimation of the actual training that takes place can serve as an indicator of training capability.

METHOD

A TTES Training Capability Evaluation was conducted during 2-5 May 1995 at the Marine Corps Quantico Combat Training Village (QCTV). Thirteen infantry Marines from the 1st Squad 3rd Platoon of the 2nd BN, 2nd Marine Division participated in the evaluation. Participants ranged in rank from Private First Class to Sergeant and varied in experience with MOUT assignments. Several had actual MOUT combat experience in Haiti and all had extensive training in MOUT exercises and were familiar with the Quantico Combat Training Village. All participants were in excellent physical health and all were male.

Participants were given a brief general introduction to the evaluation. They were then administered a pre-simulator sickness symptom checklist before any exposure to the TTES. The Simulator Sickness Questionnaire (SSQ) (Lane & Kennedy, 1988) consists of a symptom checklist, administered prior to exposure to the simulator and after exposure. Respondents indicate on a four-point scale (none, slight, moderate, severe) the presence of the symptom. Significant increases in symptom levels between the two administrations signals possible simulator sickness problems. Twenty-eight symptoms plus an "other" category appear on the checklist, including headache, boredom, eye strain, stomach awareness, vertigo, etc.

Each of the thirteen participants was then given a thorough introduction to the TTES system through written and verbal instructions, and each was allowed to familiarize themselves with the TTES during a 10 minute try-out period. During this orientation period they were instructed to shoot and reload their weapon and to move in open terrain and within buildings in order to become familiar with the coordination of the head tracker and foot pedal.

Following the orientation period, participants were provided with a QCTV map to use during the three scenarios. They were then given instructions for successful completion of the scenario, which included engaging hostiles when encountered. Each scenario required movement to and clearing of the outside of one building, and subsequent movement to a final building which was to be cleared on the ground floor only. Each trial differed with respect to hostile location, starting point of the participant, and intermediate and final destinations. Computer controlled hostiles (CCH) were placed strategically throughout the village and would engage the participants where appropriate.

A single observer recorded performance ratings while the participants completed the scenarios. These ratings reflected identifiable behaviors related to movement through the village and situation awareness during the exercise. Upon completion of all three scenarios, participants provided distance estimations within the virtual environment and then outside in the combat village. Locating the virtual Combat Training Village at the actual Combat Training Village presented a unique opportunity for examining range issues of the synthetic environment. Participants estimated six ranges (3 from observer to object, 3 between two objects) within the TTES and then were asked to "step outside" and estimate the same ranges in the village itself.

Immediately following the distance estimation portion, participants completed the post test simulator sickness questionnaire. Finally, participants completed the TTES effectiveness questionnaire. A 40-item effectiveness questionnaire was administered with sections focusing on the effectiveness of the foot pedal, head tracker, visual system, sound system, weapon and miscellaneous features. Nine open ended questions on training value of the system were included to elicit a full range of comments from participants.

RESULTS

The evaluation was impacted by a failure of one of the system computers during initiation of the evaluation. As a result, participants were run individually through the scenarios rather than in two person teams. This reduced many of the subject behaviors available for evaluation. Team communication and coordination of movement were eliminated from the evaluation along with any other measure normally associated with the performance of teams. The following section presents results of simulator sickness, range estimation, system effectiveness and participant performance.

Simulator Sickness

Average exposure time to the system was approximately 50 minutes. Differences between pre and post scores are used because there were no "other than healthy" subjects (Lane & Kennedy, 1988). Total difference scores (post - pre) for each of the 29 symptoms for the 13 participants are presented (Table 1). Positive difference scores indicate the symptom increased in magnitude from pre to post TTES exposure, while negative scores indicate the opposite. For a total of 377 difference scores (13 subjects X 29 questions), there was a change in only 26 cases. Results of the SSQ reveal no incidence of simulator sickness present from the 13 participants in the evaluation.

Table 1

Total Difference Score for Simulator Sickness Symptoms for the TTES

Symptom	Difference	Symptom	Difference
General Discomfort	1	Dizziness with Eyes Open	1
Fatigue	(-1)	Dizziness with eyes closed	0
Boredom	(-4)	Drowsiness	(-3)
Vertigo	0	Headache	(-2)
Visual Flashbacks	0	Eye Strain	1
Faintness	0	Difficulty Focusing	1
Aware of Breathing	1	Salivation Increased	0
Stomach Awareness	0	Salivation Decrease	0
Loss of Appetite	1	Sweating	4
Increase Appetite	0	Nausea	0
Desire to Move Bowels	0	Difficulty Concentrating	0
Confusion	0	Mental Depression	0
Burping	0	Fullness of the Head	0
Vomiting	0	Blurred Vision	0
Other	0		

The key categories for simulator sickness are normally those associated with visual distortion (blurred vision, flashbacks, etc.) or stomach awareness and nausea. No significant reports were made in these categories, nor any of the others. In fact, only one "moderate" or "above" rating was recorded by any of the participants, and this was for increased appetite as a result of using the system. The only symptom that even slightly increased across administrations was that of sweating, and if anything, this is a positive sign for the system indicating that trainees do experience some stress similar to that which might occur in the real world.

None of the differences in symptoms would be considered significant based on scoring provided by Lane and Kennedy, 1988. Some symptoms actually appear to have dissipated in the simulator, namely boredom, drowsiness, fatigue and oddly, headaches.

Overall these results show no indication that simulator sickness symptoms would result from using the TTES. However, simulator sickness is usually reported by a small percentage of the general population and additional data should be collected whenever there is opportunity.

Range Estimations

Participants were asked to judge distances in the

TTES combat village and the real combat village to test for correspondence of range estimation of the two environments. Average estimates for the six ranges appear in Table 2.

Table 2

Average Range Estimations and Standard Deviations for TTES Participants (in meters)

Range	Actual Distance	Estimated MOUT	Sd	Estimated TTES	Sd	Ratio TTES/MOUT
1	25.6	22.5	4.1	31.1	4.6	1.38
2	21.3	22.5	3.3	31.1	8.0	1.38
3	50.0	53.5	8.5	83.5	19.0	1.56
4	7.4	9.8	1.4	12.7	2.0	1.29
5	10.0	12.9	1.6	23.8	4.0	1.84
6	15.5	26.1	4.6	35.5	6.2	1.36

According to these data, range estimates in the TTES, on average, are always exaggerated over those in the actual village. The ratios of TTES to real world are shown in the last column of this table. These ratios correspond to an average overestimation in distance of 47% in the virtual world compared with the real world. Ranges 1 through 3 were from the observer to a separate point, while ranges 4 through 6 were estimations of distances between two points. The average TTES to MOUT ratio for ranges 1-3 is 1.41 and for ranges 4-6 is 1.50. No analysis of variance estimates were run on these means due to the nature of the data.

TTES Effectiveness Ratings

Results of the TTES effectiveness questionnaire are broken down by the major system features of foot pedal, head/helmet tracker, visual system, sound system, weapon and miscellaneous. Effectiveness ratings are presented first for each category and open ended question comments are then presented. Effectiveness ratings are based on the following five point scale:

5 Very Effective
4 Somewhat Effective
3 No Opinion
2 Somewhat Ineffective
1 Very Ineffective

Foot Pedal

Five items dealing with use of the foot pedal were included in the questionnaire specifically related to forward movement, backward movement, movement within buildings, movement over terrain and controlling speed. The average rating given across these five categories for the 13 participants was 4.1, equivalent to slightly better than "somewhat effective." The average effectiveness ratings appear in Table 3.

Table 3

Average Effectiveness Ratings and Standard Deviations for Foot Pedal Items

ITEM	RATING	Sd
Forward Movement	3.6	1.2
Backward Movement	4.4	.65
Movement w/in Buildings	4.2	.60
Movement over Terrain	4.0	1.3
Speed Control	4.2	.8
Average	4.1	

Head Tracker

Six Items concerning use of the head tracker as a control mechanism were included in the questionnaire. These items consisted of controlling direction of gaze outside buildings, controlling direction of gaze inside buildings, allowing real time vision, looking around building corners, looking around vehicles, and looking up and down stairs. Average effectiveness scores for head tracker items was 4.2, indicating again, slightly better than "somewhat effective" ratings. The individual item averages appear in Table 4.

Table 4
Average Effectiveness Ratings and Satndard Deviations for Head Tracker Items

ITEM	RATING	Sd
Direction of Gaze (Outside)	4.7	.63
Direction of Gaze (Inside)	4.5	.78
Real Time vision	3.6	1.1
Looking around Corners	4.5	.88
Looking around Vehicles	4.0	1.0
Looking up/down stairs	3.8	1.2
Average	4.2	

Visual System

The visual system represents the major sensory interface with the trainee. Thirteen items reflecting visual system effectiveness were evaluated. The average effectiveness score across these categories was 4.6, indicating high effectiveness for these items. The individual feature effectiveness ratings are provided in Table 5.

Table 5
Average Effectiveness Ratings and Standard Deviations for Visual System Items

ITEM	RATING	Sd	ITEM	RATING	Sd
Realistic Terrain	4.9	.3	Range Estimation (outdoors)	3.8	.9
Realistic Building Exteriors	5.0	0	Range Estimation (indoors)	4.2	.73
Realistic Building Interiors	4.9	.3	Depth Perception	4.5	.52
Realistic Hostiles	4.7	.5	Determining Location	4.2	.93
Movement over Terrain	4.7	.85	Overall Visual Content	4.9	.28
Movement inside Buildings	4.6	.65	Overall Scene Resolution	4.9	.3
Move up/down Stairs	4.2	.9			
Average	4.6				

Sound

Evaluation of the sound system consisted of two items related to the ability to properly identify sounds and the ability to properly locate sounds. Identifying the appropriate sound was given a 4.7 average rating (Sd=.6), near "very effective" on the rating scale. Locating sound was given an average rating of 3.4 (Sd=1.1), indicating additional work may need to be done to improve location detection. However, it should be noted that sound localization in urban environments is somewhat poor due to human perceptual limitations and building/echo effects.

Weapon Handling

Three items relating to weapon handling were included in the questionnaire concerning feel of the M16-A2, functionality of the weapon and accuracy. Weapon feel was rated 4.8 (Sd=.8) indicating a high effectiveness rating. Functionality was also rated "very effective" overall with a 4.8 rating (Sd=.4). Weapon accuracy, however, was given only a 2.8 rating (Sd=1.5), indicating considerable room for improvement. Current technological limitations have hampered efforts to accurately model M16-A2 ballistics.

Miscellaneous

Participants were queried on the ability of the system to provide a sense of balance while traversing the environment to which they responded with a rating of 4.2 (Sd=.73), or above "somewhat effective." They were also asked to respond to an item on their ability to communicate. This item has little meaning at this time however, as only one system was on-line and there was no one else with whom to communicate.

Open Ended Responses

Eight open ended items were included in the evaluation questionnaire dealing with features that distracted from training realism or additional components that were required. Participants were also asked to identify additional training applications for the TTES. Seventy suggestions were provided by the participants and these responses generally could be categorized into TTES hardware, tactical software, sound system, visual system, movement control devices, and weapon area system improvements.

Thirteen of the responses (18%) dealt with TTES hardware improvements, with ten of those related to eliminating helmet cords and weapon cords to make control of the environment and weapon handling less cumbersome. Tangling of cords and cord repositioning created undue distraction from the exercises. Additional suggestions were made for more stations and wrap around visual screens.

Fifteen suggestions (21%) were made for improving aspects of the tactical software. Five of these dealt with improving hostile behavior to make their reaction faster and more realistic. Three suggestions were made for displaying blood or other graphical effects on hostiles when shot. Other suggestions for improving the realism of the environment included adding building names, more neutrals and a less "sterile" looking environment.
The sound system was only identified in three suggestions (4%) as requiring improvement, and each of these was related to localization of sounds. The visual system was identified in nine comments (13%) with the majority (7) concerning gaze improvements to allow more real time gaze and less restriction in direction.

Nine suggestions (13%) for improving movement control mechanisms were made with seven of these directed at the use of the foot pedal. Two suggestions (3%) were made for improving side-ways movement.

Twenty-one suggestions (30%) for improving weapon features were made. Eight of these dealt with correcting weapon inaccuracies, nine with adding weapons (pistol, grenade, etc.), and several with adding recoil and other weapon handling characteristics.

Several responses to additional training applications were provided by the participants. Four of these specifically supported MOUT training, although this was not the intent of the question. Three responses recommended using the system for general/jungle combat; one for decision making; one for ammunition awareness; one for situation awareness; and, one for marksmanship training. Five of the 13 participants also indicated that the system was either outstanding or very realistic in response to a final open-ended question related to any additional comments from participants.

Performance Ratings

A rating of participant movement through the virtual village was made on speed of movement, coordination of foot pedal and head tracker, and appropriate use of cover. Ratings of situation awareness regarding participant location and location of hostiles were also made. The following three-point rating scale was used:

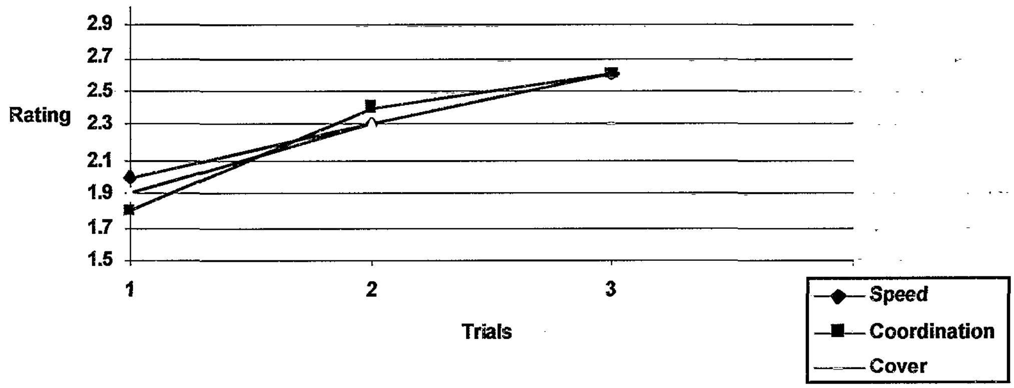
1 Poor
2 Average
3 Good

As mentioned previously, ratings of team coordination and communication were not included. Performance ratings were collected in an attempt to document possible training effects that may take place as a participant "learns" the skills required to properly clear the virtual environment. Average ratings for each of the three trials were computed for each of the five items identified above.

Movement

Measures of participant movement consisted of ratings of speed, coordination of control devices (headtracker, foot pedal) and appropriate use of cover. Figure 1 displays the average ratings for each of three trials given to all participants. There appears to be some slight trend toward improving performance related to each of these three items. Caution should be exercised in interpreting these data, however, as the subjective nature of the data collection and the lack of multiple raters allows for experimenter bias.

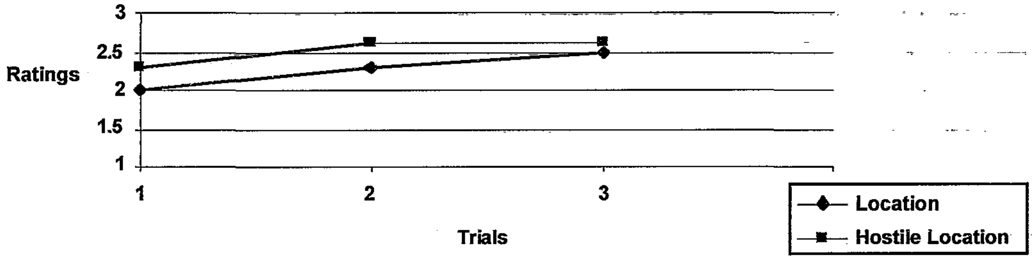
Figure 1.
Average Performance Ratings for Participant Movement



Situation Awareness

Ratings of how aware the participants were of their location in the virtual environment were made along with ratings of how aware participants were of hostile location within that environment. Average ratings across the three trials are displayed in Figure 2. Again, there appears to be a trend toward improvement across trials for each of these skills. The impacts of small sample size, experimenter bias and the reliability of the measurement instruments should all be considered when interpreting these results.

Figure 2.
Average Performance Ratings for Situation Awareness



CONCLUSIONS

The more quantifiable results of this evaluation are those dealing with simulator sickness and range estimation. The results of the Simulator Sickness Questionnaire indicate no symptom of sickness occurred at any level of significance. The extremely small sample should be considered and additional simulator sickness data should be collected whenever there is opportunity. Simulator sickness is a realistic concern for virtual environments and systematic analysis of these environments is essential before implementing training or other applications. The SSQ is a reliable and easily applied method for determining simulator sickness in virtual environments.

The range estimation results support previous contentions related to overestimation of distances in virtual environments compared to actual. This issue has not been resolved but does require additional development based on a near 50% overestimation of distances in the virtual world. This phenomenon has far reaching consequences, particularly in military applications where weapon delivery is often based on range estimation. Additional research on the relative effect for observer to object versus object to object estimations may have significance for military and other operator applications. All researchers in virtual environment applications should estimate errors associated with perceptual incongruities and consider the real world consequences of these errors. Experiments which focus on visual system resolution and figure-ground content should help in understanding this phenomenon.

Highly effective ratings of the visual system, sound system and weapon handling provide support for the representation of the perceptual environment. Lower, but still effective scores, were given to the mechanisms for controlling movement and vision within this environment. This is consistent with current development in virtual environments and indicates a lag between the perceptual medium and how we realistically interact with that medium. Systems that strive to make control mechanisms more natural, or transparent to the operator will most likely be perceived as more effective. However, it should always be recognized that changing the nature of the control mechanism from the actual mechanism (using a foot pedal vs. walking/running) introduces a source of conflict for transfer of training. This is one of the greatest obstacles in the application of virtual environments for operator training.

Overall, the effectiveness ratings lend considerable support for the use of the system in training MOUT skills. In general, most of the suggestions for system improvements can be easily incorporated into current development efforts. They are relatively low cost and should improve system effectiveness for meeting tactical objectives. Suggestions for expanding TTES application to other tactical training will also be explored.

Due to the loss of one of the trainee stations, full training capability tests could not be carried out in the present evaluation. Additional tests of multiple stations operating simultaneously will be conducted in order to assess the team related training aspects of the TTES.

REFERENCES

Hamilton, D., Johnson, D., Coker, G. & Wightman, D. Virtual Environment in Army Aviation Training. Minutes and Briefings of 8th Meeting of the Department of Defense Training Technology Technical Group (T2TG). May 1994.

Lane, N. and Kennedy, R. A New Method for Quantifying Simulator Sickness: Development and Application of the Simulator Sickness Questionnaire (SSQ). Naval Training Systems Center Technical Report EOTR 88-7, 1988.