EVALUATION AND ASSESSMENT OF A VIRTUAL ENVIRONMENT ADVANCED TECHNOLOGY DEMONSTRATOR

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ABSTRACT

There are several systems currently under development which allow the individual combatant to participate in force-on-force distributed simulation. Although the simulations are interesting and show great promise, there have been few investigations into the transfer of training from these simulations to real-world tasks.

The Team Tactical Engagement Simulator (TTES) Advanced Technology Demonstrator (ATD) is a distributive interactive simulation-compliant ATD which provides the capability for US Marine Corps deployed, reinforced rifle squads to participate in force-on-force engagements against computer-controlled hostiles in a virtual environment. The system allows trainees to practice team tactics and decision-making skills by providing the ability to traverse the virtual environment together with other trainees, use a variety of weapons, and engage simulated hostiles and neutrals.

TTES underwent an Early Operational Assessment (EOA) in April 1997. The purpose of this EOA was to investigate the utility of the TTES system as a training device for military operations on urban terrain (MOUT), to gather information from the user community to provide future direction in TTES system development, and to gather program evaluation data and TTES system design information.

This paper will briefly define virtual environment (VE) training and the associated research. An explanation of the TTES components is provided. Included is a discussion of relevant findings and recommendations applicable to TTES and other individual combatant simulators, as well as ideas for future VE research.

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INTRODUCTION

The Team Tactical Engagement Simulator (TTES) is an Advanced Technology Demonstrator (ATD) begun in 1993 by the Naval Air Warfare Center Training Systems Division (NAWC-TSD). The objective of the TTES ATD is to demonstrate a core technology that allows individuals and small units to train in a virtual environment (i.e., synthetic battlefield) as a supplement and complement to standard field and range training. A goal of the system is to enhance the maintenance of critical and perishable combat skills, particularly in deployed and expeditionary settings. The initial focus for the TTES effort is Military Operations in Urban Terrain (MOUT) scenarios.

Recently, an early operational assessment (EOA) of the TTES ATD was performed at Camp Lejeune, North Carolina with the purpose of:

- evaluating the effectiveness of TTES as a training device
- gathering information from the user community to provide future direction in TTES system development
- gathering program evaluation data and TTES system design information

This paper will briefly define virtual environment (VE) training and the current research concerns associated with the design, application, and use of a VE trainer in a real-world setting. Included is a discussion of relevant findings, hindsight observations, and recommendations applicable to TTES and other individual combatant simulators, as well as ideas for future VE research.

Virtual Environment

Usually described as virtual reality (or synthetic environments, virtual worlds, or artificial reality), VE technology can provide both visual and auditory information of such fidelity that the observer can "suspend disbelief" and accept that he or she is actually somewhere else (Chung, et al., 1989). Further, the technology also permits perceptual and tactile interaction with the synthetic environment, enabling the user to transcend the role of passive observer and actively participate in shaping events (Minsky, et al., 1990). Instructional research has shown that students learn faster and remember what they have learned for longer periods of time if they are provided an opportunity to practice (Alessi, 1988). TTES demands active participation on the part of students and allows them to practice/review many fundamental tasks required in MOUT environments, such as strategizing, approaching a building from a covered location, traversing an open area, entering a building, clearing a room, communicating with team members, and engaging hostiles/neutrals.

Current Research Concerns

On the surface, VE appears to be a perfect fit for operational skills training within the applicable operational environment. However, the training risk of VE development is high. This high risk stems from a relatively immature technology base, the small number of quantitative training transfer effectiveness studies, a lack of public access to research data, performance features that induce physical discomfort (simulator sickness), and distracting artifacts in the presentation which create a negative transfer of training (Golas, et al., 1996).

Research related to the effectiveness of TTES as well as safety during its use are important factors for the future development of TTES and other related systems. To date, very few studies (Whitmer, et al., 1994; Tate, et al., 1995) have examined the effectiveness of training transfer as compared to the number of studies that focus on design research related to improving VE technology and system components.

TTES SYSTEM DESCRIPTION

The TTES system configuration for the EOA consisted of three types of simulation applications which communicate via Distributed Interactive Simulation (DIS) protocol data units (PDU):

- 2 Trainee Stations
- 2 Computer-controlled Hostile/Neutral nodes
- 1 Operator Station/Simulation Manager

The TTES Trainee Station (shown in Figure 1) provides the trainee with a means of interacting with a simulated environment in order to train individual and team tactical skills. With the MOUT database loaded, it provides the capability to traverse a combat town environment, interact with other squad members, and use the M16A2 to engage hostile and neutral entities. Each Trainee Station has a large rear-projection display screen (70 X 50 degree field of view at 6 feet) illuminated by a high resolution (1280 x 1024) projector with a frame rate of 10-15 Hz. The overall dimensions of each station are approximately 10 feet (width) by 20 feet (length).

Trainee movement within the virtual environment is controlled by a combination of force-sensitive foot pad and head tracking system. Movement direction is controlled by direction of gaze. Looking to the left or right edges of the screen causes the world to rotate to the right or left and effectively changes the trainee's view and direction. Trainees can talk to each other via microphones and headphones. They can also see computer-generated representations (avatars) of each other on their respective visual displays. The graphic depiction of team members includes position, stance (standing, kneeling, and prone), and an indication of weapon firing.

The Computer-controlled Hostile/Neutral node generates entities which behave in response to trainee actions.

The Operator Station/Simulation Manager is intended to be the user's single point of entry into the TTES system for an individual controlling a TTES training exercise (i.e., a fire team leader, squad leader, training instructor, etc).

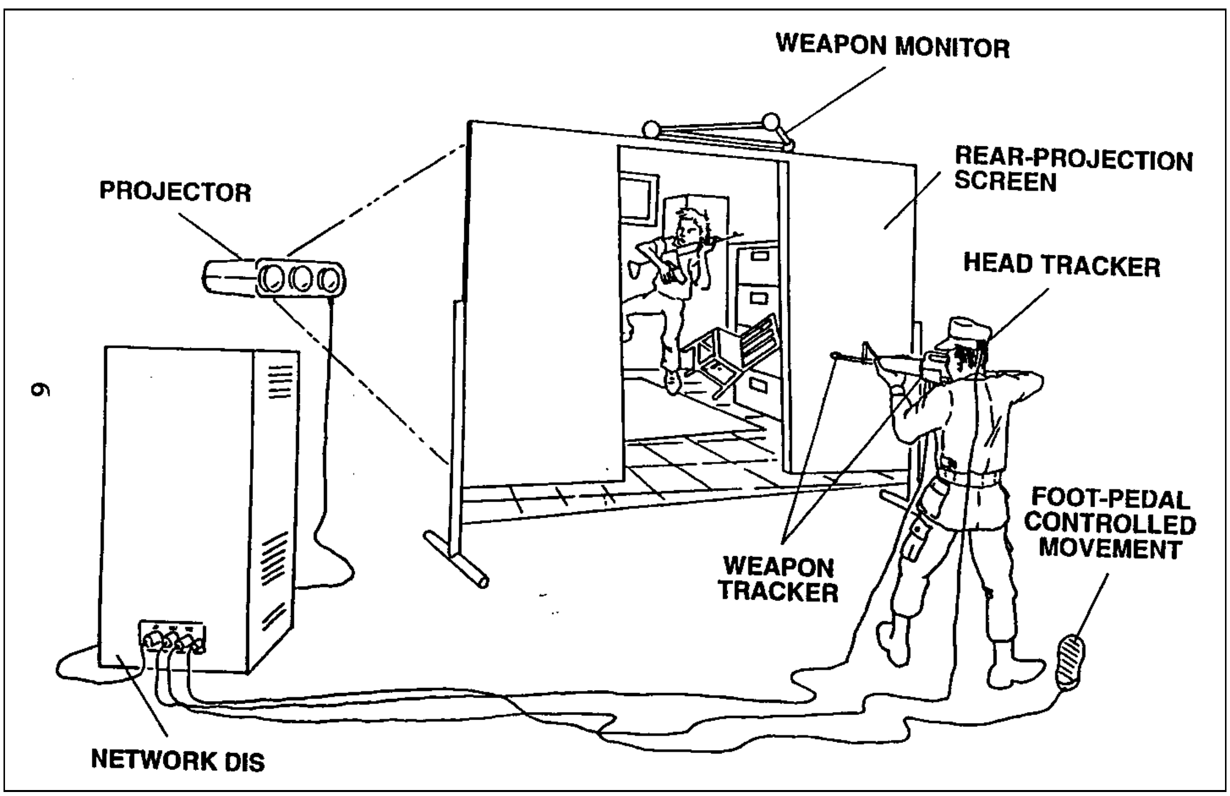

Figure 1 - TTES Trainee Station

METHOD OF ASSESSMENT

In order to evaluate the training capability of the TTES system, the assessment was organized into two main areas based on the system components: Trainee Station and OS/SM station. This paper addresses only the results of the Trainee Station assessment. Three different aspects of performance are included: training transfer effectiveness, simulator side effects, and user interface.

Participants

Two Marine MOUT instructors from the Camp Lejeune School of Infantry (SOI) helped determine performance measures, design the Evaluator Surveys, and develop scenarios and related support materials. They also evaluated the Marine participants on the TTES Trainee Station and at the Camp Lejeune Combat Town (training facility with permanent structures), as well as provided feedback as to the usability and possible application of TTES in US Marine Corps training.

Three squads of US Marines stationed at Camp Lejeune participated in the evaluation. There were two squads (23 participants) in the experimental group which interacted with the TTES Trainee station, and one squad in the control group. The Marine participants varied with experience from two to four years. Before interacting with TTES, the participants completed a background survey which collected general data related to age, health condition, and previous MOUT training/ experience.

Training Transfer Effectiveness

The objective of the training transfer effectiveness study was to evaluate the degree to which learning takes place on the TTES system and to determine the extent to which tasks performed by participant Marines in the synthetic TTES environment were transferable to real-world tasks.

The experimental group used TTES to complete two defined scenarios. The control used traditional methods of review (lecture and discussion). The experimental group was divided into two-man teams within their familiar fire team (four persons). Each two-man team was briefed on TTES and allowed to practice with the technology. The participants were then briefed on scenarios with regard to rules of engagement, objectives, and geographic (map) position. The team was then allowed time to strategize. Performance was noted by two SME evaluators using Evaluator Surveys previously briefed to the participants. The Evaluator Survey consisted of 23 items rated on a scale of 1 (unsatisfactory) to 5 (outstanding). The items were divided categorically into strategizing and preparation, negotiating terrain, room clearing and communication techniques, weaponeering, and situational awareness. Each team performed two scenarios with a performance debrief by the SME evaluators following each scenario.

Each of the three squads then performed two scenarios of similar scope at Combat Town. To ensure consistency, the same evaluation criteria, data collection instruments, and SME evaluators were used for both the TTES and Combat Town scenarios.

Simulator Side Effects

The objective of this assessment was to gather data on potential simulator side effects which may occur through use of the TTES system. The participants (all in experimental group) completed the Simulator Sickness Questionnaire (SSQ) (Kennedy, et al., 1992) before entering and immediately after performance in the TTES environment. The study evaluated SSQ total severity, subscale (nausea, occulomotor, disorientation), and item scores.

Based on prior experience with obtaining reliable subjective responses to questions of physical side effects from military subjects (even when guaranteeing anonymity of data), postural stability (Kennedy, et al., 1993) and heart rate (Miller, et al., 1993), measurements were incorporated in an effort to validate the participants' self-reported SSQ scores. The Standing-on-Nonpreferred-Leg (SONL) postural stability test was given before and after the TTES experience to help determine/validate the presence of simulator side effects.

Heart rate data was gathered from the participants at various points as they interacted with Trainee Station.

Trainee Station User Interface

The objective of this assessment was to gather subjective ratings related to the TTES Trainee Station user interfaces. After performing the scenarios, the participants evaluated the components of the Trainee Station: foot pedal, head tracker, visual system, sound, and weapon handling. The surveys consisted of specific questions that the participant answered on a predetermined scale (1-5) as well as open-ended questions collected by personal interviews.

RESULTS

Training Transfer Effectiveness

The mean score of the 23 items for each participant's scenarios was calculated for Squad 1 (see Table 1) and Squad 2 (see Table 2).

Table 1 - Squad 1 Average Evaluation Scores

Participant No.	Scenario 1	Scenario 2
111	2.83	3.35
112	2.83	3.61
113	2.65	3.52
114	2.74	3.70
121	3.26	4.35
122	3.35	3.22
123	2.35	3.61
124	2.70	3.48
131	3.17	2.78
132	3.26	2.83
133	2.83	4.52
134	2.78	4.52
Squad Avg	2.90	3.62

Table 2 - Squad 2 Average Evaluation Scores

Participant No.	Scenario 1	Scenario 2
211	4.00	4.70
212	3.74	4.78
213	2.74	4.30
214	2.74	4.48
221	3.26	4.35
222	3.39	4.39
223	3.22	3.74
231	4.43	4.43
232	4.43	4.96
233	2.26	4.35
234	2.00	4.52
Squad Avg	3.29	4.45

The SME evaluators observed statistically significant performance differences ($p<0.05$) between Scenarios 1 and 2 for 83% of the experimental group (i.e., 19 out of 23 participants had a significant increase in performance after Scenario 1). Of the four participants who did not show improvements between scenarios, one was observed to have continual problems manipulating the user interface. This situation likely prevented him from moving past the familiarization stage where he could apply basic infantry skills. Another participant (#231) received a high score on Scenario 1, but did not show a significant improvement on Scenario 2. He was observed to be adept at manipulating the interface, and was teamed with an individual with a relatively high degree of MOUT experience (#232).

The squad averages for the Combat Town scenarios (see Table 3) are the average values from the 23 evaluated performance aspects established for the TTES scenarios.

Table 3 - Combat Town Scenario Results

	Scenario 1	Scenario 2
Squad 1 Avg	4.04	4.22
Squad 2 Avg	4.69	4.52
Squad 3 Avg	3.39	4.48
F	5.907	.518
P-value	.0044	.598
F crit	3.136	3.136

An analysis of variance between all three squads at Combat Town indicates there was a statistically significant difference in Scenario 1 performance between the experimental group (Squads 1 and 2) and the control group (Squad 3). The squads which had performed scenarios on TTES prior to Combat Town performed better at the squad level than the control group which had not experienced TTES.

There was no statistically significant difference in Scenario 2 performance between the three squads. This result seems to indicate that the Combat Town experience and debrief that the control group received after the first Combat Town scenario provided a training experience sufficient to raise their performance to a level closely matching that of the squads in the experimental group.

Simulator Side Effects

There was a statistically significant difference between the Pre SSQ (Mean=3.41, StDev=6.76) and Post SSQ (Mean=12.03, StDev=8.58) Total Severity Scores ($p=0.0002$). Further investigation showed that the SSQ Total and subscale score Nausea appeared to be greatly affected by a single item, sweating. Due to the closed room evaluation environment and lack of adequate air conditioning, the room temperature was 85 degrees or warmer. The item 'sweating' was rated to be at least slight (13 participants) and often moderate (8 participants).

Sweating was then zeroed out in all the post-test scores for further evaluation of the Total SSQ scores. With this factored in, there was no significant difference ($p=0.128$) between the Pre (Mean=3.41, StDev=6.76) and Post (Mean=6.34, StDev=7.60) SSQ scores. Because of the broad assumption included in zeroing out the 'sweating' item and the resulting low p-value, further analysis was performed on the data. Individual SSQ survey items were evaluated as to the percent of participants that experienced an increase in a factor.

There was a recorded symptom change (see Figure 2) in more than 10 percent of the participants in general discomfort (1), fatigue (2), eye strain (4), sweating (7), and difficulty concentrating (9). There was also a recorded positive change in less than 10 percent of the participants in headache (3), increased salivation (6), blurred vision (11), dizziness with eyes closed (13), and stomach awareness (15). None of the participants experienced a change in the remaining six items.

Interestingly, there was no statistically significant change in postural stability ($p<0.664$) before and after interaction with the TTES Trainee Station. There was also no correlation between the change in heart rate and either SSQ scores or length of time spent on the Trainee Station.

Trainee Station User Interface

The results are divided into the major interfaces: foot pedal, head tracker, visual system, sound system, and weapon.

The foot pedal received an overall average score below 3 (5-point scale), which is considered only marginally effective. More than a third of the participants rated the foot pedal as a 1 or 2 in terms of providing basic forward and backward movement. The foot pedal was also found by the participants to be largely ineffective as an interface for movement control in kneeling or prone positions.

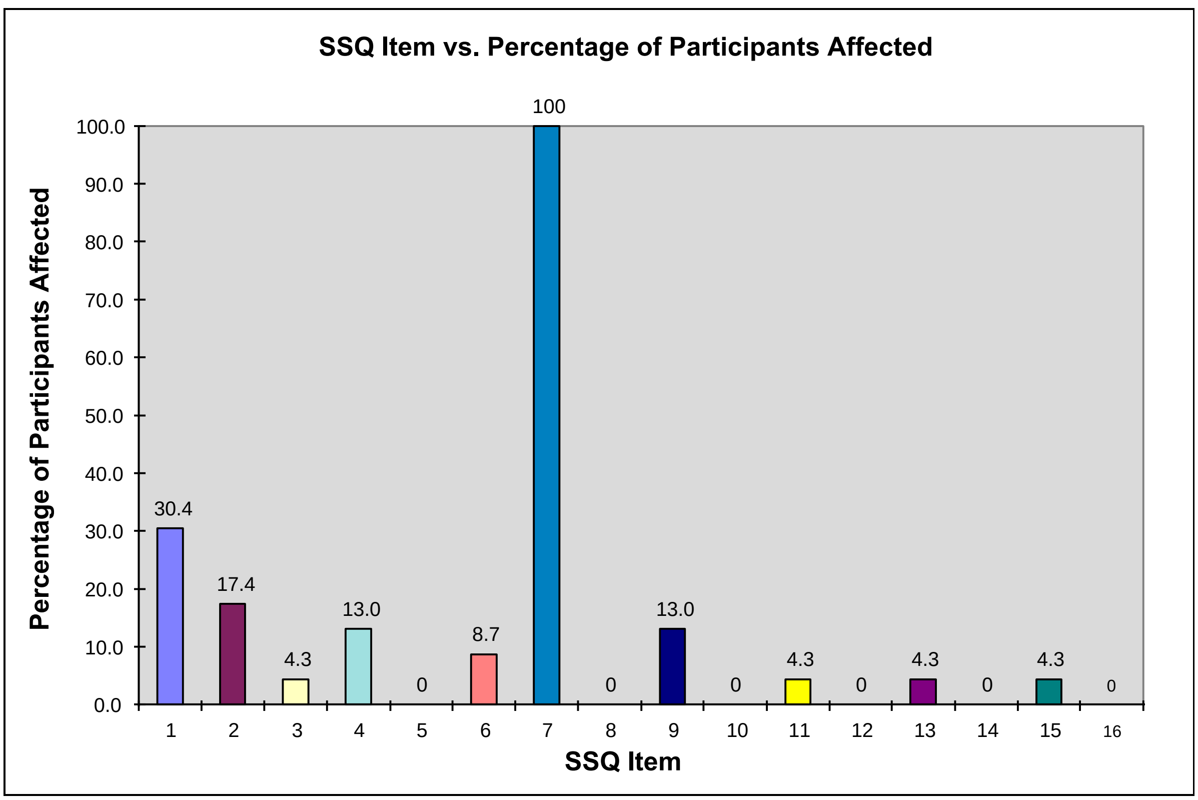

Figure 2 - Percentage of participants reporting a positive change in SSQ

The head tracker received average scores from 2.9 to 3.7, which could be considered marginally effective. 30% of the participants rated the head tracker interface a 1 or 2 in terms of controlling direction of gaze outside and around building corners. More than a third of the participants rated the head tracker interface as a 1 or 2 in terms of providing direction of gaze control inside buildings and within stairways.

Overall, the visual system received high ratings. The main weakness indicated was related to an inability of the systems to provide orientation feedback to the participants with regard to their own orientation as well as the location of their teammate. More than a third of the participants rated the visual system effectiveness as a 1 or 2 with regard to providing an awareness of location and orientation inside buildings for both themselves and their teammate. Other low ratings were given for inside visuals and visuals while moving up and down stairways.

The sound system received high ratings. The main weakness was ineffectiveness in providing location feedback. 48% of the participants rated the effectiveness of sound location as a 1 or 2. The ratings of sound system needs indicate that the participants felt the system needed to provide a richer sound environment of movement and combat sounds.

The weapon simulation also received high ratings. The primary weakness was related to weapon accuracy. 43% of the participants rated the weapon accuracy effectiveness as a 1 or 2.

There were two miscellaneous items to which participants were asked to respond regarding self-orientation awareness and communication ability. 30% of the participants rated self-orientation awareness (the effectiveness of the system in providing a sense of how the trainee was oriented relative to his surroundings) as a 1 or 2. The communications ability was rated well overall, with an average rating of 4.

At completion of the survey, participants were given the opportunity to make additional comments. They were not directly queried with regard to the effectiveness of TTES as a training device. Despite the current limitations of the system, 57% of the participants chose to comment that TTES was a positive training experience.

DISCUSSION OF RESULTS

Training Transfer Effectiveness

The significant difference in Combat Town Scenario 1 scores of the experimental and control groups points to the fact that the TTES experience better prepared the participants for a “real-world” MOUT scenario than the more traditional methods of review (lecture, drill, and practice). Though the same information is presented to the students, the TTES system provides the ability to interact with the environment rather than imagine it.

The second scenario at Combat Town showed there was no statistical difference in the performance of the three squads. This shows the value of training at a MOUT facility. Although VE training is *not* a complete replacement for “time in the dirt” at a MOUT facility (such as Combat Town) or real-world MOUT experience, it can be a valuable resource for instructors, squad leaders, and students to review fundamental MOUT skills. This review of skills will help to make the time spent at a MOUT facility more productive by enabling instructors and squad leaders to teach more complex MOUT skills, strategy, and techniques.

TTES also affords the SME (instructor or squad leader) the ability to work with students on a squad, fire team, and individual basis. This allows for more meaningful feedback from an SME directly to a student specific to that person’s strengths and weaknesses. The ability to play back a trainee station session allows the SME to review an individual’s or team’s performance in terms of decisive moments during the scenario. Since the scenario can be replayed from the participant’s point of view, the student can explain why he did or did not perform correctly, while the SME can explain mistakes made such as where they should have been moving, elements in the environment they did not notice, or mistakes in communication. Currently when a MOUT facility performance is complete, the SMEs have only notes and their memories with which to debrief. The debrief usually occurs at the squad level or above, which does not talk to specific mistakes made by individuals that can in fact affect the performance of the entire team.

Due to the limited availability of training facilities and the expense in maintaining/operating a MOUT facility, most Marines are not given the opportunity to attend MOUT classes nor participate in MOUT exercises outside of their basic training experience. The TTES system could be used to refresh infantry MOUT skills on an individual, fire team, or squad basis without involving the entire platoon or tying up MOUT required resources and support.

The TTES system currently uses the Quantico Combat Village database as the MOUT environment model. However, any compatible database may be loaded. With a goal of being deployable, TTES can be shipped with Marines as they are heading to a mission destination. This would allow mission preview and rehearsal enroute. Familiarization with buildings, environment, street signs, population flow, etc., will help decrease the level of acculturation shock. This familiarization will aid in the development of appropriate mental models of the layout, environment, and support locations prior to mission deployment.

Simulator Side Effects

Due to the large environmental effect on the SSQ scores during the assessment, the conclusions are based on item scoring. If the effect responses of sweating and large portions of general discomfort and fatigue may be explained by the warm room temperatures (85 degrees and above), the remaining side effects experienced by the participants are closely related to occulomotor responses. Eye strain (17.4%), difficulty in concentrating (13.0%), headache (4.3%), and blurred vision (4.3%) effects point to the occulomotor system as being affected. Slight nausea and disorientation effects are also present as seen in the other items scored: increased salivation (8.7%), stomach awareness (4.3%), and dizziness with eyes closed (4.3%). Though the side effects were experienced by a low number of participants and only at a slight level, possible causes should be investigated in order to improve the system. The side effects may be caused by a variety of TTES Trainee Station design factors with regard to scene contrast, field of view, refresh rate, resolution, time lag, or complexity of scene content (affects update rate), or may be task-related (Kolasinski, 1995).

An inherently large amount of quick head and body movements is required in MOUT performance, which only adds to the opportunity to develop eye-strain and disorientation effects. During the assessment, participants were required to traverse terrain to approach a building, respond to snipers atop roofs, and interact with hostiles and neutrals within buildings. Much head movement was required to perform these tasks. In order for the participant to change (or rotate) his field of view, they must look off the edge of the screen. This would then move his field of view in that direction within the virtual world. Similarly, if a participant wanted to change their direction of locomotion, they must look off the edge of the screen and then push the foot pedal. Exaggerated head movements (as compared to those required in the real world) were required to “see” within the virtual world as well as to “move” within it. The resulting inconsistent information about body orientation and motion received by the different senses can induce the minimal simulator side effects experienced by the participants.

Currently, the requirement of head movement as a guidance of direction for locomotion affords a large opportunity for simulator sickness to occur. Participants are required to perform actions that they would not normally do in order to steer their movement while other intuitive real-world movements are detrimental to their TTES performance. For example, when crossing a street, a person would normally look down the street to check for vehicles, hostiles, or other threats. As they looked down the street, they would continue moving in a direction perpendicular to the street, thus, crossing the street. However, within TTES, the person must look in the direction they are moving. As the participant crosses the street, their focus (or field of view) must remain perpendicular to the street preventing them from checking for threats as they move.

The lack of difference in pre- and post-postural stability scores is correlated with the fact that a low number of participants experienced even slight changes in the SSQ items. Recent research has reported that longer exposures increased the intensity and duration of postural disruption (Crosby, et al., 1982) but not when exposures are short (Hamilton et al., 1989). In the EOA, the exposure times ranged from 20 to 45 minutes in length. Though each participant was on the TTES Trainee Station three times (familiarization, Scenario 1, and Scenario 2), periods of scenario briefs, strategizing, and performance debriefs separated the exposure times, apparently lessening the additive effect of the exposure times. This also helps to explain the lack of correlation in heart rate data changes and time spent on the system.

Trainee Station User Interface

The results obtained from the Trainee Station User Interface survey have highlighted areas of the system that need improvement. The items rated the lowest on the survey and most often commented on by the participants were those related to the head tracker and foot pedal. The required use of these two components in order to move around in the virtual world is not intuitive and was often mentioned to be confusing. As in the example given in the previous section, the interface creates confusion and frustration during the training session. Because the participants must focus on how to move, they are paying less attention to the training domain (fundamental MOUT skills).

Overall the visual and sound components received high ratings, yet were rated low for orientation feedback. The participants noticed the absence of environmental support in the forms of visual and auditory information. In the real world, this environmental support aids a person in self-orientation, team orientation, enemy orientation and movements, knowledge of building structure, and combat readiness. For example, the shuffling of a teammate's boots makes you aware of his presence and location. On the Trainee Station, the participant would have to verbally ask the teammate where he was located, or turn to visually locate him in relation to himself. A richer sound environment of movement and combat sounds is needed to add to the realism of the interface.

CONCLUSIONS

TTES Assessment

The EOA was instrumental in showing the training transfer effectiveness of TTES. Coupled with the remarks that Marine participants had a positive training experience, VE systems, such as TTES, have a great potential for training in several domains.

The EOA also helped to define specific areas where improvements are needed to enhance the effectiveness of TTES: (1) the head tracking and locomotion devices must be closely reviewed for possible enhancements to or replacement of the components in order to increase the usability of the system; (2) environmental support in the form of combat and movement sounds, as well as visuals (sunlight, weapon effects, etc.) should be researched to evaluate their use in providing realism for training and orientation cues; and (3) the array of weapons available to the participants should be expanded as well as designed to have a greater shooting accuracy relative to real-world experience.

Future TTES R & D Consideration

Based on the EOA and other internal research efforts, TTES developers are evaluating similar components and systems that are applicable to the area of individual and team combatant training. These include tracking devices/systems, various means of locomotion, marksmanship trainers, and other devices targeted for virtual environment training.

TTES recently participated in experiments conducted under the Advanced Distributed Simulation Technology II (ADST II) Dismounted Warrior Network (DWN) efforts. One TTES trainee station was involved in both engineering and user experiments conducted in early June 1997. The results of those experiments will be reviewed and compared to the results of the TTES EOA described in this paper. It is anticipated that future TTES development will follow along technology lines that fared well in the DWN experiments.

Future Virtual Environment Research

The current technologies incorporated into the TTES ATD are ever-changing and improving. The incorporation of new or improved technologies should always be measured against an improvement in training transfer effectiveness.

Future research is needed in the areas of orientation cues. How a person "knows" where he is located in relation to his surroundings and others must be determined and incorporated into the VE system research. Future design of man-machine interfaces for tactile (and other sensory) feedback must account for intuitive and realistic interactions in order to preserve realism as well as avoid a negative transfer of training.

Additional training transfer effectiveness studies is needed. The shared findings from these studies will help to make individual combatant systems more effective in their goal to prepare the participant for performance in a real world task. Follow-up comments and case studies from the field are also needed to measure the true effectiveness of any training system in relation to real world tasks.

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