An Examination of Surgical Skill Performance under Combat Conditions Using a Mannequin-Based Simulator in a Virtual Environment

Dr. Mark W. Scerbo[1], Dr. Leonard J. Weireter, Jr., M.D[2], Dr. James P. Bliss[1], Ms. Elizabeth A. Schmidt[1], and Ms. Hope Hanner[1]
[1]Old Dominion University, Norfolk, VA 23259 USA
[2]Eastern Virginia Medical School, Norfolk, VA 23501 USA

mscerbo@odu.edu

SUMMARY

The present study examined the performance of a surgical procedure under simulated combat conditions. Fifteen medical students were taught to perform a tube thoracostomy on a mannequin-based simulator in a traditional medical school setting under the direction of an ATLS® certified surgeon. The participants then performed the procedure in a fully immersive CAVE virtual environment running a combat simulation including gunfire, explosions, and a virtual sniper under both daylight and nighttime conditions. The results showed that completion times depended on the order of daylight and nighttime conditions with a slight disadvantage for the nighttime condition. However, the quality of the procedures performed by the students suffered in the simulation and particularly under the nighttime conditions. Further, there were nine instances in which the participants were killed by the virtual sniper before completing the procedure. Taken together, these results suggest that the surgical skills acquired by students in a traditional medical school setting may be compromised when they are called upon to perform them under hazardous conditions. Further, the findings from this study show that virtual environments can provide a safe environment for military medical personnel to train for dangerous duty.

1.0 INTRODUCTION

Simulators have been a standard component of military training for many years in a variety of contexts including aviation, ground operations, weapons training, and decision making in command and control operations. By contrast, the use of simulation technology for training medical procedures is relatively new. Although medical simulation devices have been around since the 1940s, most of them have been little more than physical models with limited functionality. However, the current breed of medical simulators is quite sophisticated and many have impressive levels of realism. In addition, the number and variety of systems commercially available has increased dramatically over the last decade (Dawson, 2002; Satava, 2001). Further, medical schools are beginning to incorporate simulation technology into training curricula as they face increasing pressure to train physicians and surgeons to higher levels of competency, in shorter periods of time, while simultaneously improving safety (Healy, 2002).

The advantages of training with simulators are well documented. They provide an environment to train specific skills in the absence of uncontrollable influences, an unlimited number of trials to acquire skills, immediate performance feedback, and an opportunity for trainees to diagnose and treat rare or infrequent conditions. Perhaps, the most important advantage is that they permit the opportunity to train under conditions that would be too dangerous in actual operational settings. Although this last area represents a standard use of

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simulation for training many different skills in military contexts, it has been largely overlooked in the medical arena.

The goal of the present study was to examine the performance of surgical skills in a virtual environment (VE) under simulated combat conditions. Military medical personnel who have been in war often acknowledge that the training they receive in traditional medical schools does not always transfer to combat situations (see for example Miller, 2003). Thus, the specific purpose of this study was to determine the extent to which surgical skills acquired in a traditional medical school might be compromised in a simulated combat scenario. Toward this end, a common emergency surgical procedure, tube thoracostomy (chest tube insertion) was selected for study.

Tube thoracostomy involves decompressing the chest cavity to release a pneumothorax or hemothorax. The procedure entails making a 1 – 2 cm transverse incision in the skin near the pectoralis major muscle lateral margin, spreading the chest wall musculature, puncturing the pleural space, and guiding a tube into the opened pleural space to permit drainage.

For this study, medical students performed a thoracostomy on a mannequin-based simulator in a CAVE virtual environment under simulated combat conditions. These conditions included visual and auditory depictions of munitions fire, gunfire, and a virtual sniper who would shoot at the participants if they did not take proper cover. Thus, the battle scenario was designed to provide a heightened sense of realism in which to examine performance of the thoracostomy procedure. The participants performed the procedure under two different lighting conditions: daytime and nighttime. The two lighting conditions were included to create different levels of workload and stress within the combat scenario. In particular, the nighttime condition was included because military medical personnel might not always have control over the visibility conditions in which they must perform. It was expected that if performance were compromised under the simulated combat scenario, it would suffer more under the nighttime visibility conditions.

2.0 METHOD

2.1 Participants

Fifteen medical students from the Eastern Virginia Medical School in Norfolk, VA participated in the study. All students were in their second or third year of training and none had prior experience with the thoracostomy procedure or the simulators used in this study. The participants received $30 as compensation for their time.

2.2 The Training System

The method used to teach tube thoracostomy was based on the ATLS® course curriculum as described in the ATLS® Instructor Manual 1997 edition. The procedure was taught using the TraumaMan® system by Simulab, Inc. TraumaMan® is a mannequin-based simulator used throughout the world for surgery education and is the only simulator approved for the ATLS® Surgical Skills Practicum by the American College of Surgeons. The TraumaMan® system is the standard training device for ATLS® courses at Eastern Virginia Medical School. The simulator includes a realistic anatomical model of the neck, chest, and abdomen with replaceable tissue components and fluid reservoirs that permit instruction on six surgical procedures. Only the thoracostomy procedure was used in the present study.

2.3 Training

Students were trained in two separate sessions and worked in groups of three or four. All students received a didactic session reviewing the indications for the thoracostomy procedure, the technical aspects of the procedure, and the potential complications that could be encountered. Following this, the students were shown how to perform the procedure on the mannequin. Critical determinants of successful performance on the task included correct topographic anatomic landmark identification as well as whether the tube entered the pleural space. Students worked in teams of two and were allowed approximately 90 minutes of practice under the supervision of an attending surgeon qualified to teach ATLS®. Each student was required to perform a successful procedure (see below) for the instructor in less than two minutes in order to move on to the simulation session.

2.4 Virtual Environment Implementation

The VE used in the study was the CAVE (CAVE Automatic Virtual Environment). The system consisted of two main computers connected through a 100-mbps network switch. An SGI ONYX 2 computer was used to display the application in the CAVE, provide the sound playback, and read the information from the tracking device. This computer used VEGA, and IRIX 6.5. An SGI O2 computer served as the main console and was used to launch the application and issue command overrides controls during the simulation. This computer used IRIX 6.5, Motif, and Buttonfly. Images were presented on three 10x10 ft walls of the CAVE with a resolution of 1024x768.

A Radio Shack electronic beam was fixed to the top of the boxes (approximately 3 ft. above the ground). The electronic beam was used to engage the virtual sniper (see below).

2.5 Combat Simulation

The combat simulation depicted a small town under fire. One building was in flames, but most of the other combat cues were auditory in nature. Combat was simulated using the VEGA special effects module to trigger visual and auditory explosion events as well as background gunfire at specific times. The events were timed to repeat at specific intervals. The entire scenario was run in a continuous loop until the participant finished the procedure.

Day and nighttime conditions were created by adjusting the luminance intensity of the image with the time-of-day feature in the VEGA software. Under the daytime conditions, there was enough ambient illumination emanating from the walls of the CAVE to make the barricade, mannequin, and instruments easily visible. Under the nighttime conditions, however, there was very little illumination provided by the CAVE walls. Thus, the participants performed the procedure in near total darkness except for the occasional explosions that provided temporary increases in illumination.

The audio track was created using Sound Forge software. Sound samples from unrestricted sources on the internet were downloaded and filtered. Voice samples were saved in mono at a 22.1 kHz sampling rate. Background and other supplemental audio sounds included gunfire, explosions, machine gun fire, and some M1 tank fire. The files were converted to Audio Interchange File Format Version C (.AIFFC) for final presentation in the CAVE environment.

The audio files were presented over two channels. The left and right speakers were placed at approximately 225 and 315 degrees, respectively. The speakers were mounted on speaker stands at an elevation of approximately five feet. None of the audio sounds exceeded 90dB during the session.

A virtual sniper was included in the combat scenario as well. If the participant disrupted the electronic beam, an audio file would be played that provided either a warning or informed the participant that they had been killed.

2.6 General Procedure

Participants reported to the CAVE facility within two hours of training. All participants were scheduled in 20-min increments and were run individually. Participants were told they were going to play the role of an Army medic with a team of soldiers under fire. A member of the team had been injured and required a thoracostomy. Their goal was to get to the patient and perform the procedure to save his life.

They were handed a kit that contained a knife, chest tube, and clamps and were escorted into the CAVE. They were told that they would perform the procedure twice: once under daylight and once under nighttime conditions. Each attempt began with the participant standing at a starting point marked with tape on the floor. They were instructed to listen for a call for a medic. As soon as they heard the call, they were to get to the patient and perform the procedure as quickly as possible. They were not required to assess the need for the procedure. Further, they were not required to anesthetize the patient or suture/tape the tube to the patient after placing it in the pleural space. When they finished, they were told to return to the starting mark on the floor. Figure 1 shows the configuration of the CAVE facility and a participant performing the procedure.

Figure 1: Participant performing the procedure under daylight combat conditions.

The participants were also told that there was a sniper in one of the nearby buildings and that they had to take cover behind the barricade. Thus, the participants needed to perform the procedure while kneeling or lying on their stomachs. Further, if the sniper got them in his sights he would shoot to kill and they would hear a loud rifle shot. If the sniper missed, they would hear someone say "Get down." If they were hit, they would hear the phrase, "Hasta la vista, baby." At that point, they were considered dead; however, they were instructed to continue and finish the procedure. They were not fired upon again.

In actuality, all participants received one warning shot if they disrupted the electronic beam. If they disrupted the beam a second time, they would be killed.

The participants each performed two sessions and the order of day and nighttime conditions was counterbalanced across participants. After the first attempt, the simulation was stopped, the mannequin was rotated 180 degrees, and the participant performed the subsequent procedure on the opposite side of the mannequin. After their second attempt, the participants were escorted out of the CAVE and asked to complete a brief survey. They were then debriefed and allowed to offer comments or ask questions about the study. During this interval, the surgeon who had conducted the initial training session examined the mannequin and rated the participant's performance based on the criteria listed below.

2.7 Dependent Measures

There were two dependent measures: completion time and performance ratings. The total time to complete the procedure was recorded from the initial call for the medic until the participant returned to the starting mark. The performance ratings were based on three criteria: topographical location for the skin incision, tube placement in the pleural space, and posterior angulation to ensure the tube was in a dependent portion of the thorax. Ratings for each were divided into three categories: good, adequate, and poor. The following was used to assess performance:

GOOD: tube inserted at the nipple line, 4th intercostal space, between anterior and posterior axillary line, with 45 degree posterior angulation. Tube entered in the pleural space.

ADEQUATE: tube placement was within 1 cm of the criteria specified above without angulation. Tube entered the pleural space.

POOR: tube outside above 1 cm radius without angulation and/or did not enter the pleural space

3.0 RESULTS

3.1 Performance

The mean completion times for each attempt and the day and nighttime conditions are shown in Table 1. The completion times were analyzed with a mixed ANOVA for the factorial combination of attempt (first and second, the within-subjects variable) and order (groups 1 and 2, the between-subjects variable). The results revealed a significant main effect for attempt, $F(1,13) = 4.99$, $p<.05$, indicating a decrease in mean completion time from the first attempt (M=92.60, SD=24.73) to the second attempt (M=75.13, SD=20.46). However, neither the main effect of order nor the interaction between attempt and order was significant. A second mixed ANOVA was performed on day and night conditions (the within-subjects variable) and order (groups 1 and 2, the between-subjects variable). None of the main effects was significant; however, the interaction between day and night conditions and order was significant $F(1,13) = 2.54$, $p<.05$.

Table 1: Mean Completion Times for Attempts and Day/Night Conditions (standard deviations in parentheses).

	All Participants	Participants Who Were Not Killed
Attempt 1	92.60 (24.73)	99 (14.76)
Attempt 2	75.13 (20.46)	79.57 (17.27)
Day	77.87 (20.26)	86.29 (17.21)
Night	89.87 (26.57)	92.29 (20.48)

The nature of the interaction is shown in Figure 2 as a function of attempt. As can be seen in the figure, completion times were longer on the first attempt, but were clearly tied to the order of day and nighttime conditions. As would be expected, those who operated under nighttime conditions on the first attempt performed slowly. However, when this group performed their second attempt under daytime conditions they were much quicker. On the other hand, the participants who began with the daytime condition performed more quickly on their first attempt than the other group who began with the nighttime condition. However, when this second group moved onto their next attempt under nighttime conditions, their completion times improved, but not nearly as much as those of the other group.

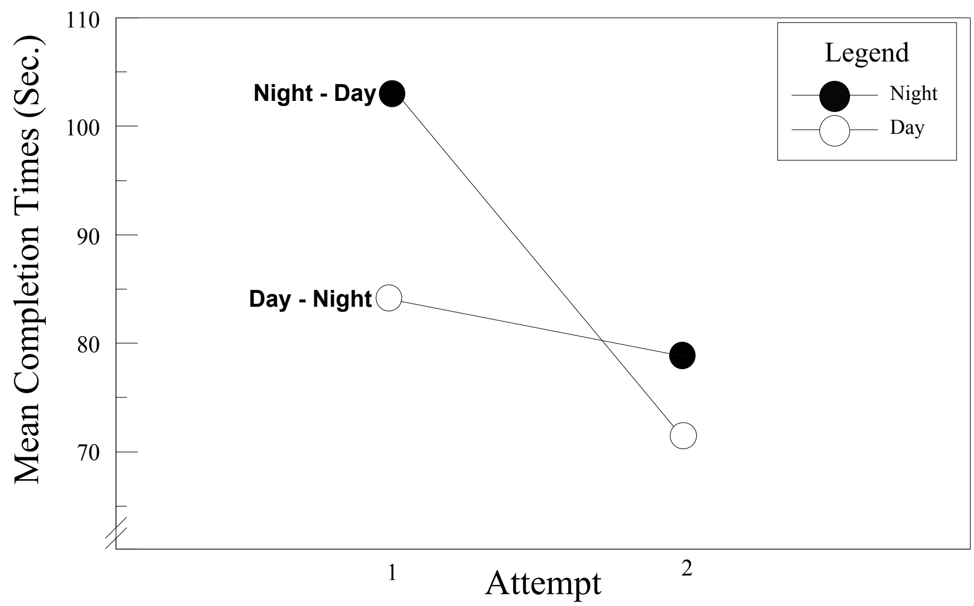

Figure 2. Mean completion times for order of day and night conditions plotted for each attempt.

The analysis of completion times included data from all participants because the sample size in this study was fairly small. However, there were several instances in which participants were "killed" by the virtual sniper. These data are shown in Table 2. As can be seen in the table, most of the participants who were killed were shot during their first attempt. Although participants in this study who were killed were allowed to continue and complete the procedure, one could argue that these data should not be included in the overall means. Thus, the mean completion times were recalculated excluding data from participants who were killed. These recalculated means are also presented in Table 1 and show that completion times increased when the scores for those who were killed are removed from the data.

Table 2: Participants "Killed" by Sniper

Condition	Attempt 1	Attempt 2
Day	4	1
Night	3	1

The performance ratings are shown in Table 3. The number of participants who received good, adequate, and poor ratings is shown for all three criteria. The ratings show that performance suffered in the simulation and particularly so for tube placement. There are no other consistent patterns among the frequencies except for a slight disadvantage for the night condition.

Table 3: Frequencies of Performance Ratings for Topographical Location, Angulation, and Tube Placement

	Location			Angulation			Tube Placement		
	Good	Adequate	Poor	Good	Adequate	Poor	Good	Adequate	Poor
Day	13	1	1	11	1	3	4	8	3
Night	11	1	3	12	0	3	3	10	2

3.2 Participant Responses

Participants completed a nine-item opinion questionnaire following the experimental session. The first item required participants to rate the realism of the thoracostomy procedure under simulated combat conditions. Although 9 participants (60%) reported that the simulation was either "somewhat" or "moderately" realistic, 40% reported that it was "extremely" or "quite" realistic. Participants were also asked to report whether the noise in the simulated combat environment distracted them. Despite the loud gunshots and explosions, 12 participants (80%) reported that the noise was not distracting or "slightly" distracting. Only 3 participants found the noise to be "moderately" or "extremely" distracting. The participants also indicated whether the lighting conditions and their physical position complicated the procedure. Twelve participants (80%) reported that the procedure was either "slightly" or "moderately" complicated under nighttime conditions, but the remaining 3 indicated that the nighttime conditions "significantly" complicated the procedure. Likewise, most of the participants reported that their physical position did not complicate the procedure. In fact, none of the participants believed that it had a "significant" or "extreme" impact on their performance.

The participants were also asked to describe any strategies they adopted for performing the procedure in the day and nighttime conditions. In the daylight condition, 57% of the respondents indicated that their main strategy was to remain low to the ground while performing the procedure. Several participants also reported that they attempted to "block out" the loud noises and focus only on the task at hand. Under nighttime conditions, approximately half of the participants (46.7%) followed the same strategy as in the daylight conditions, but the remaining participants reported that they relied more on anatomical landmarks and tactile feedback. Finally, the participants were asked to report the easiest and most difficult aspects of the experiment. Most participants agreed that the actual thoracostomy was the easiest part of the experience. On the other hand, they identified several portions of the experiment that were extremely difficult including: (1) knowing how low to remain to the ground, (2) trying to remain calm under pressure, (3) inserting the chest tube while lying down, and (4) feeling around for the equipment in the dark. In particular, participants commented that it was very difficult to remove the equipment from the bag and to place the cover back on the scalpel.

4.0 DISCUSSION

The primary goal of the present study was to examine the extent to which training in a typical medical school environment would generalize to simulated combat conditions. Students were taught how to perform a thoracostomy on the standard simulator used in ATLS® courses. In fact, they were given nearly twice as much time to practice the procedure as they would in a typical ATLS® course. By the end of the training session, each student performed the procedure to the satisfaction of the instructor, in under two minutes. They were then asked to perform the procedure in a fully immersive VE under simulated combat in daylight and nighttime conditions.

The findings were mixed. On the one hand, the results for completion times suggest that the participants were fairly efficient at performing the procedure. Overall, the mean time to complete the procedure was 84 sec (sd = 22) and the completion times dropped significantly from a mean of 93 sec (sd = 25) in the first attempt to 75 sec (sd = 20) in the second attempt. As expected, the completion times were affected by lighting conditions, but the results were tied to order. Specifically, the participants took 24 sec longer on average to perform the procedure under nighttime conditions if it was their first attempt, but if the nighttime conditions occurred on their second attempt, it increased completion times by only 13 sec over the daytime conditions. Thus, the participants required less time to perform the procedure on their second attempt and the effects of low visibility were less severe on their second attempt. Further, the overall completion times were not dramatically different from what they achieved at the end of their training session. Although the findings for completion times were encouraging, the results for the quality of performance were less so.

An analysis of the performance ratings showed that the ability of most medical students to perform the procedure was compromised in the simulation. Only 23% of the tube placements were judged as good and only one placement was judged good under nighttime conditions. Seventeen percent of the tubes were poorly placed. In addition, the topographical placement was judged to be poor on 13% of the attempts and the angle of placement was poor on 20% of the attempts. Thus, even though participants were able to achieve completion times in the simulation comparable to those from training, they did so by sacrificing the quality of their performance.

It is important to understand that these results present an optimistic picture of performance. There are several reasons for this. First, the results must be viewed within the context of the combat scenario. There were 9 instances where the participants failed to heed the warning shot and were "killed" before they could complete the procedure. A finding such as this is indeed troubling because it suggests a potential loss of critical medical personnel in addition to jeopardizing the safety of the patient. Further, the results in Table 1 clearly show that if the data from participants who were killed are excluded from the means, the completion times for the remaining participants are noticeably poorer.

Second, the participants performed the procedure within two hours of their initial training session. Under traditional medical school training paradigms, months or years could elapse before a student or resident would have the opportunity to perform the procedure on a genuine patient. Thus, the levels of performance obtained in this study likely represent a "best case" scenario. One might expect the performance levels seen here to become progressively worse as the interval between training and initial attempt increases.

Last, the results show that the ability to perform a newly acquired emergency surgical procedure is significantly degraded even under *simulated* combat conditions. It is quite likely that the performance problems observed in this study would be exacerbated under genuine combat conditions.

Subjective reports indicated that most participants felt the experience was fairly realistic. Several students commented that they had to make a conscious effort to remain calm and focus their attention on the task. Although not every participant found the nighttime visibility conditions to be problematic, those who did attempted to perform the procedure by relying on tactile information. Further, some students commented that they found it challenging to perform the procedure while lying down. Collectively, these comments suggest that the students took the experience seriously and recognized the value of training outside of traditional environments.

One criticism of the present study may lie with the choice of thoracostomy as the procedure of interest. One could argue that it is unlikely this procedure would be performed in the field. That is, the injured patient normally would be moved to a safer location before performing the procedure. However, it is important to remember that the primary goal of this study was examine how skills acquired in a traditional medical school setting would hold up under stressful conditions simulated in a VE. Toward that end, we chose thoracostomy as a representative emergency procedure. Moreover, even though standard practice might dictate moving the patient to a safer environment before performing the procedure, it does not preclude the possibility that transporting the patient would be unfeasible in some situations. Thus, emergency medical personnel might be called upon to perform such a procedure to prolong a patient's life until he or she could be moved at later time.

5.0 CONCLUSION

The present study was designed to examine how the ability to perform a surgical procedure would be affected in an immersive VE. The results showed that performance was significantly degraded under the simulated combat conditions. Moreover, the levels of performance seen here are probably better than what would be expected under more realistic conditions.

To our knowledge, the present study represents the first time that performance with a standard mannequin-based medical simulator has been studied within a fully immersive VE. From this perspective, our results show that VEs can be a valuable tool for medical training because they provide a rich context in which to examine performance. The benefits of this approach are numerous. First, VEs provide a safe environment for training medical personnel on a wide range of scenarios under a variety of stressful conditions. It is no longer necessary to rely on the reports of medics or corpsmen who have been to war as the sole source of data concerning the adequacy of their training and level of preparedness for practicing medicine in combat zones. It is now possible to address specific medical training needs before personnel are deployed.

Second, VEs extend the range of applications for current medical simulators. For example, the TraumaMan® system used in this study was designed primarily as an emergency medicine training device. However, we have shown that the simulator can also be used as research tool to study performance. Obviously, other mannequin-based or even VR simulators can be used in a similar fashion.

Last, VEs provide a safe environment for studying performance under simulated hazardous conditions. Virtual environments open up the possibility of examining a wider variety of medical procedures performed under an unlimited number of conditions. More important, however, they offer a laboratory in which to study new training techniques and countermeasures for medical personnel who must perform in dangerous situations.

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