Usability Analysis of Prototype Partial Task Tourniquet Trainers

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ABSTRACT

Recent studies have found that hemorrhage is the cause of 83% to 87% of potentially survivable combat deaths. To address this issue, increased use of tourniquets and hemostatic agents has been emphasized in training. In an effort to improve the technology used in the training of tourniquet application, a number of prototype partial task trainers have been developed by the Army Research Laboratory's Simulation and Training Technology Center. These trainers simulate the look and feel of a wounded human arm with simulated brachial and radial pulses. Each trainer can simulate arterial and venous bleeding. After proper tourniquet application, the device responds with appropriate feedback, including cessation of both bleeding and pulse. With the variety of capabilities available in these devices, it is important to objectively analyze the devices for usability in training scenarios. The study included approximately 10 participants attempting to apply a tourniquet to each training arm and ultimately stop simulated blood loss. This study analyzed a number of usability metrics gathered during the study including: task completion, time of task, efficiency, and self-reported metrics. Finally, the results of the analysis are reported, along with discussion of the findings in respect to future development of partial task trainers, including a thigh tourniquet trainer.

ABOUT THE AUTHORS

Matthew Hackett is a research engineer for the Medical Simulation Research Branch of the Army Research Laboratory, Simulation and Training Technology Center. Mr. Hackett was trained as an engineering intern at the Program Executive Office for Simulation, Training and Instrumentation and worked within PM Training Devices. Mr. Hackett received his Bachelor of Science in Computer Engineering from the University of Central Florida and his Masters of Science in Biomedical Engineering from the University of Florida. During his time at the University of Florida, he was a research assistant in the computational neuroscience laboratory. Currently, he is pursuing his Ph.D. in the Modeling and Simulation program at the University of Central Florida.

Jack Norfleet is the Chief Engineer for the Medical Simulation Research Branch of the Army Research Laboratory, Simulation and Training Technology Center (STTC). He is responsible for managing a multidisciplinary team of researchers as well as planning, and executing medical simulation research projects. Mr. Norfleet has 26 years of experience in modeling, simulation and training as an electronics engineer, test engineer, project engineer and science and technology manager. In addition to his work at the STTC, he has held positions of increasing responsibility within various U.S. Army and U.S. Navy training and simulation organizations including the Naval Training Equipment Center, the Naval Training Systems Center, and the U.S. Army Simulation, Training and Instrumentation Command. Mr. Norfleet started his career as a GS-1 co-op student directly out of high school. Mr. Norfleet received a Bachelor of Science in Electronics Engineering from the University of Central Florida and a Master of Business Administration Degree from Webster University. He is currently enrolled in the Modeling and Simulation Doctorate program at the University of Central Florida. Mr. Norfleet is a member of the Acquisition Corps and is Level III certified in Systems Planning Research Development and Engineering.

Ms. Beth Pettitt is the Branch Chief for Medical Simulation Research (MSR), Simulation and Training Technology Center, Army Research Laboratory, Research Develop and Engineering Command. The MSR Branch is leading the way in Medical Simulation Technologies. Prior to this position, Ms Pettitt was the Medical Simulation Technologies Team Lead for the Simulation, Training and Instrumentation Command (STRICOM) where she was instrumental in establishing STRICOM's Combat Trauma Patient Simulation and Advanced Trauma Patient Simulation Defense Technology Objective programs. She has been actively involved in medical modeling and simulation research for over fifteen years and is currently pursuing her Ph.D. in Modeling and Simulation.

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BACKGROUND

Tourniquet use has been prevalent in the U.S. military since early in the Civil War. Surgeons soon realized that tourniquets could be used outside of aiding amputation procedures, but could in fact be used to stem extremity hemorrhage (Marby, 2006). In subsequent years, the use of tourniquets has been debated, with safety and utility being the two contentious issues (Richey, 2007). Some experts believe tourniquets cause excessive nerve damage and tissue death due to cessation of blood flow, and believe that they are overused and many times ineffectually applied (Parker and Clasper, 2007). Others believe tourniquets to be a life-saving battlefield intervention (Parsons, 2004; Hodgetts and Mahoney, 2007). Current US military treatment protocols allow tourniquet applications as the only treatment during care under fire. Military protocols also call for tourniquets as the primary treatment for life threatening extremity hemorrhage in all field treatment modalities. During Operation Iraqi Freedom, a study was done showing that pre-hospital tourniquet use improved hemorrhage control, particularly in severe injury. Furthermore, the study found fifty-seven percent of preventable deaths may have been avoided with earlier tourniquet use (Beekley, 2008). A more recent study focusing on hemorrhage found that 83% to 87% of potentially survivable deaths could be attributed to hemorrhage, showing that hemorrhage control is still a major problem to be solved (Blackbourne et al., 2010). Based on these studies, it is apparent that improved training of tourniquet application and of other hemorrhage control techniques could improve the survivability of wounded Soldiers.

Research and development projects have also been conducted to determine if the current training curriculum could be augmented through the use of advanced training technologies. The current training standard is to place a tourniquet on a classmate until the distal pulse is no longer felt in the limb. These projects have resulted in a series of partial task tourniquet trainers that can provide objective metrics and a standardized platform for trainees to use to hone their skills. Three of these prototype trainers were studied to compare the usability differences of their unique technological solutions. Presented herein are the procedures and results of the study.

METHOD

The objective of the study was to document the strengths and weaknesses inherent in the various technologies being used. The three trainers being tested were the Simulaids training arm {BLUE} (Figure 1), Metter's training arm {GREEN} (Figure 2), and the Hapmed training arm {RED} (Figure 3). The BLUE tourniquet arm attaches to a partial body, providing structure to hold the arm in a realistic manner. The GREEN tourniquet arm is fixed to a metal stand, which prevents users from moving it in an unnatural manner. The Red tourniquet arm is free of attachments.

Tourniquet Training Devices

Both the BLUE and GREEN systems flow fluids through the arm and these fluids can be warmed to increase realism. To stop bleeding in these systems, the user must compress the simulated blood vessels. Water was used instead of simulated blood to prevent permanent damage to the testing area and to the participants' clothing.

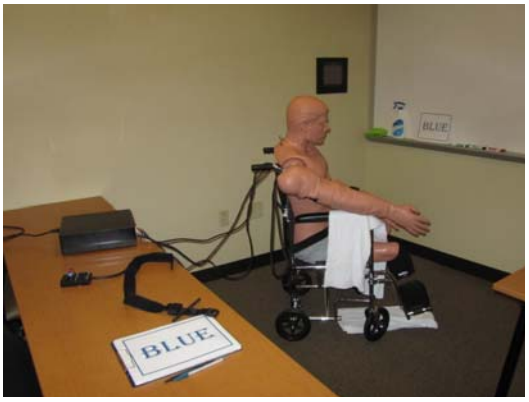

Figure 1: Simulaids {BLUE} Arm Tourniquet Trainers

Figure 2: Metter's {GREEN} Arm Tourniquet Trainers

The RED system is a partial arm that can be secured with a large suction cup to a wall or can be left unsecured. For this test, it was unsecured. The RED system has pressure sensors embedded in the treatment areas of the arm. To stop simulated blood flow, which is indicated by red lights, the tourniquet must be applied on or near the sensors, and a predetermined amount of pressure must be applied (Fowlkes et al., 2011).

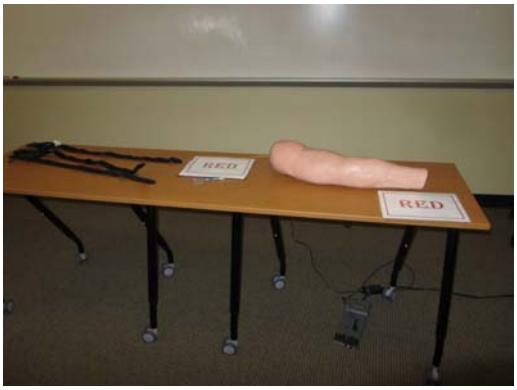

Figure 3: Hapmed {RED} Arm Tourniquet Trainer

Testing Methodology

The partial task trainers were set up in the University of Central Florida (UCF) College of Medicine (COM) Simulation Center on April 13th, 2011. The study population consisted of 12 first year medical students. These students participated in the study during down time between laboratory training exercises. Independent Review Board approval was obtained from Army Research Lab as well as from UCF.

Prior to the formal test, seven engineers from the STTC completed a series of pilot tests in order to validate and refine the test procedures. The pilot tests revealed a number of issues. During the first attempt, it was discovered that laying the BLUE system on a flat surface caused significant leakage. Also, attempts to use the blood heating capability of the BLUE system caused a hole to be melted through one of blood reservoirs. Testing was halted and rescheduled while the BLUE system was repaired.

During the second internal pilot test, the heating elements were not used on either the BLUE or GREEN system to avoid potential hazards. As the second pre-test proceeded, needs for additional materials like clip boards were identified. Needs for a standard pre-brief as well as a standard tourniquet demonstration were also identified. Demographics questions were added to document the gender of the participant, as differences in hand strength seemed to impact the ability to tighten the tourniquet.

The formal test began by providing participants with the standard pre-brief and tourniquet demonstration (Figure 4). The participants were then shown the various features of the Combat Application Tourniquet (CAT) (Figure 5). Further instruction was given on the current Army protocol for application, which directs tourniquets be placed as proximal on the extremity as possible. After the briefing, all participants were given time to ask questions.

Figure 4: Tourniquet Demonstration

Figure 5: Combat Application Tourniquet

Testing began at one of the randomly selected training arms. By randomizing the order in which the systems were evaluated, bias was mitigated in the overall result by counterbalancing potential learning across the simulations. At each station, simulated bleeding was initiated and the participants were then given a CAT tourniquet and instructed to stop the bleeding. The participants were timed and observed throughout their trial (Figure 6). The trial ended when the bleeding was successfully stopped and the tourniquet secured, or when the participant indicated they could not tighten the tourniquet further. At this point, task success was recorded. Additional observations were recorded including errors and any damage to the equipment. Participants completed a survey following each trial, which focused on questions regarding realism and perceived training efficacy. This protocol was repeated until the participant had tested each arm. At the conclusion of the exercise, a final comprehensive survey was completed by participants, where they provided comments and ranked the various devices in terms of realism and training efficacy. Through recorded observations and the use of surveys, data was gathered on task success, time on task, errors, user frustration, user perceived level of realism, and additional user comments. Summarized data from all participants is presented in Appendix C.

Figure 6: Participants Evaluating Systems

RESULTS AND ANALYSIS

Although not a primary focus of the study, the three evaluators had the opportunity to document usability issues from the perspective of the system operator. System BLUE had some obvious issues. The fluid canisters inside the chest cavity were nearly impossible to remove to refill so the opening in the back of the BLUE device was enlarged. Even with this modification, the system still required at least two people to refill the canisters: one person pried open the back and the other poured fluids into the canister. The design also made it very difficult to prevent the heating element from touching the sides of the reservoir. The reservoir system needs to be totally redesigned as the current design presents a significant shock and fire hazard to the operators. The RED and GREEN systems were fairly easy to set up and no major design issues were identified.

During the test, a number of metrics were gathered, both self reported and performance based. The performance based metrics included task success, time of task, and errors. Task success was measured by whether the simulated bleeding was stopped by the participant. The participants achieved 100% success using the BLUE arm, 90% success with the GREEN, and 70% success with the RED (Figure 7). The time on task was also representative of the difficulty in successfully stopping the bleeding on each system. The results indicated that the BLUE arm was the easiest to apply, with an average time on task of 51 seconds; RED and GREEN were both significantly slower ($p=0.0477$; $p=0.0427$) with participants taking an average of 71 and 72 seconds, respectively (Figure 8).

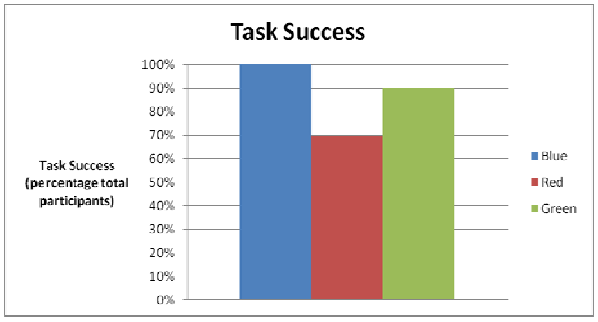

Figure 7: Task Success

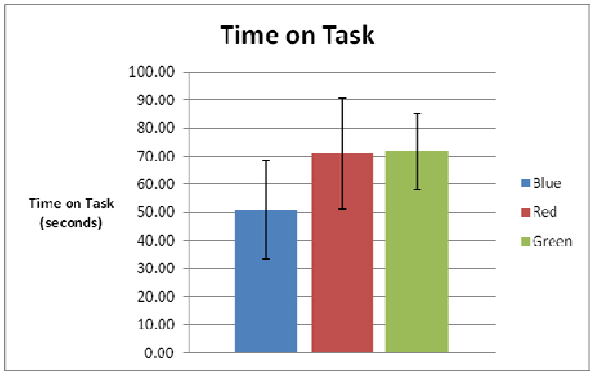

Figure 8: Time on Task ($\alpha=0.05$)

Following each trial, the participants completed surveys in order to gather the self-reported metrics. The individual surveys gathered data regarding realism, perceived success of training, and whether the participants thought the system was too complex. Because the wording of question seven was such that the scale was reversed, (6 was negative and 1 was positive), responses were flipped to make the analysis

meaningful. Analysis of the responses indicated that the participants felt most favorably towards GREEN with an average of 5.26 and BLUE with an average of 5.15. RED scored significantly lower than both, with an average of 4.41 (Figure 9).

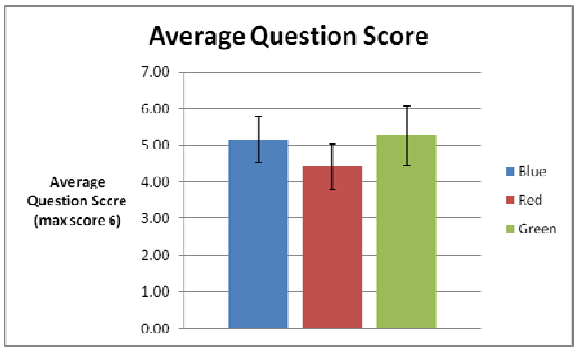

Figure 9: Average Question Score (α=0.05)

The perceived realism of the trainers was also important. Using radar graphs, the realism results can be visualized. The radar graph has 4 axes, which correspond to the measures of realism: overall realism, pulse feel, pulse location, and skin realism. The results showed the GREEN as having the most realistic pulse, pulse location, skin, and perceived realism (Figure 10). The BLUE was close in terms of most realism categories, but was significantly lower in pulse location (Figure 11). The RED was perceived as less realistic in all four areas (Figure 12)

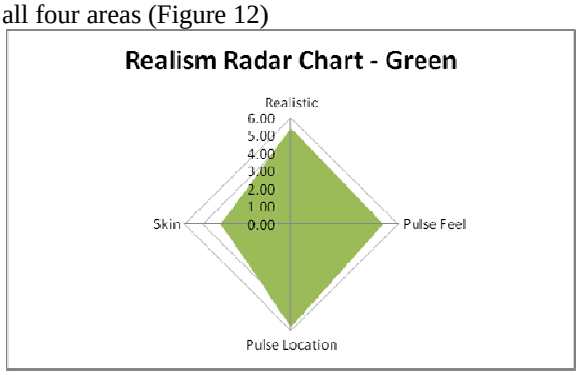

Figure 10: GREEN Arm Realism Radar Chart

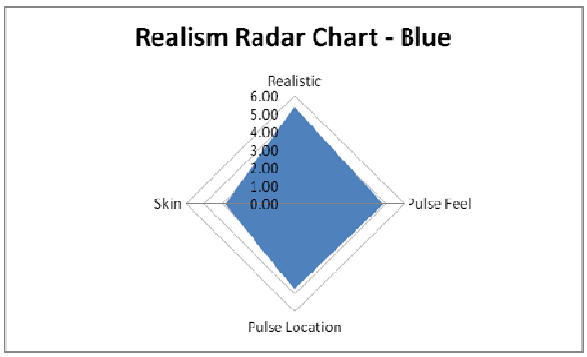

Figure 11: BLUE Arm Realism Radar Chart

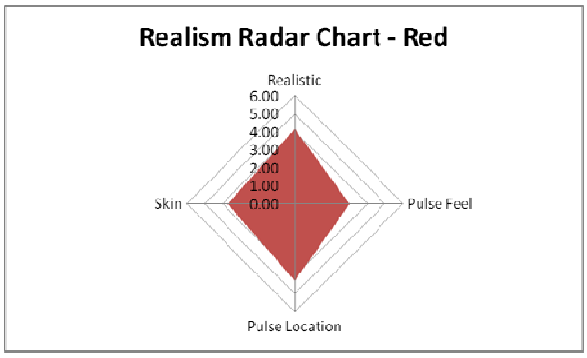

Figure 12: RED arm realism radar chart

Following all of the individual device assessments, the participants completed a comprehensive survey where they ranked the devices against each other. Participants ranked the BLUE trainer highest for overall realism, with GREEN as second and RED as third. The GREEN ranked highest for training experience, with BLUE second and RED as third.

Finally, an analysis was done factoring in the gender of the participants. The results indicated that females and males performed similarly on the GREEN and BLUE devices. The RED device required a statistically greater time to completion for female participants (Figure 13) (p=0.02). Task success rates were similar for both males and females (Table 1).

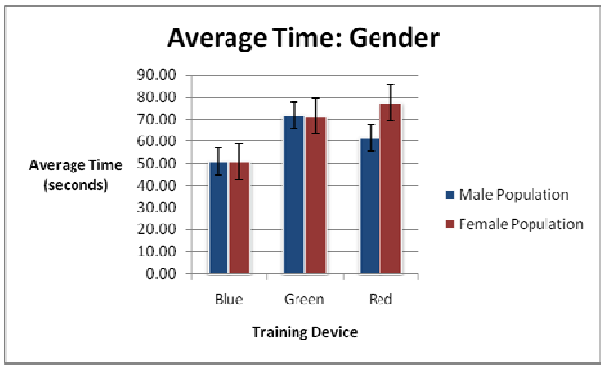

Figure 13: Time on Task separated by Gender

	Blue	Green	Red
Male	80%	100%	80%
Female	100%	100%	71%

Table 1: Task Success separated by Gender

OBSERVATIONS AND CONCLUSION

Seven female and five male first year medical students participated in this study. Based on observations in the pre-test there was concern that with the importance of hand strength in completing this task, i.e. gender might

influence the ability to successfully apply the tourniquet. The gender analysis revealed that there was no statistical difference between the performance of males and females on the BLUE and GREEN devices. On the RED device, the time on task was significantly greater for females, attributed to differences in hand strength.

The results of this study did reveal differences in perception between Army science and technology managers who conducted this study and COM participants. The Army has expended many resources, and much time trying to simulate the look and feel of the skin on medical simulators. The quest for ultra-realistic skin has been mildly successful yet the participants in this study rated the BLUE simulator, which had some of the least realistic skin, as most realistic overall. This indicates that skin realism is less important than was initially estimated. Regardless, none of the skins are perfect as they all bunched and slipped, interfering with the proper application of the tourniquet.

Another area where perception differed between developers and users was in the existence of a body. The common perception that an arm is all that is needed to train the task differs from the rating of the full body BLUE system as the most realistic in the comparative survey. The GREEN system did not have a full body but it was attached to a frame at the shoulder which introduced manipulation restrictions that mimic a body. The Green system ranked second in comparative realism. The least realistic and least effective simulator was the RED system and it was noted that the lack of a body like connection introduced negative training. For example, one participant rolled the RED system like a log to apply the tourniquet.

Most of the participants felt that the partial task training tourniquet arms were useful in training this life saving skill. The results also show that there is still much to be done to develop a tourniquet trainer that is educationally and practically effective.

Based on observations and analysis from this usability test, an ideal tourniquet task trainer would include:

- A body connection to serve as an anchor for the arm and to prevent unnatural manipulation of the arm. The whole body also appears to enhance the perception of treating a real human.
- Secure skin attachment on arm that addresses the pinching and bunching that occurs with plastic and silicon skins
- Realistic pulse and blood flow
- Real fluids, not lights

Additionally, an alternative design for keeping the cost down on tourniquet trainers might be to have a simple external fluid tank. Manufacture, refilling, and maintenance are potentially much simpler with an external tank vice housing the fluid in the body cavity.

This exercise showed that part task tourniquet trainers have promise but that additional development and experimentation is required. Tradeoff studies between full body simulators and stand alone limbs must be conducted.

Future trainers must also make sense from a financial standpoint in order to deploy enough units to teach the large number of Soldiers that require this training. Currently, trainees apply a tourniquet on the nearest Soldier and tighten it until the pulse disappears. Since the current training method is essentially free, significant savings in time, improvements effectiveness, or improvements in safety must be realized to justify the cost. The STTC intends to continue the usability evaluations of these systems using Soldiers to determine if the priorities and their perceptions differ from the first year medical students.

ACKNOWLEDGEMENTS

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Appendix A
Survey: Comprehensive Partial Task Trainers

Tourniquet Task Trainer Analysis					
Blue		**Green**		**Red**	
Overall Question Average	5.15	Overall Question Average	5.26	Overall Question Average	4.41
Overall Standar Dev.	1.102	Overall Standar Dev.	1.097	Overall Standar Dev.	1.429
Median	5.5	Median	6	Median	5
Average Time Complete	1:21	Average Time Complete	1:23	Average Time Complete	1:40
Average Rank Trng Exp	1.75	Average Rank Trng Exp	1.50	Average Rank Trng Exp	2.75
Average Rank Realism	1.58	Average Rank Realism	1.75	Average Rank Realism	2.67
Realism Question Average	4.71	Realism Question Average	5.10	Realism Question Average	3.78
Percentage Completed	100%	Percentage Completed	90%	Percentage Completed	70%
Averages:		Averages:		Averages:	
Q1	5.42	Q1	5.42	Q1	4.17
Q2	4.86	Q2	5.18	Q2	3.00
Q3	4.71	Q3	5.82	Q3	4.27
Q4	3.83	Q4	4.00	Q4	3.67
Q5	5.92	Q5	5.67	Q5	5.00
Q6	5.67	Q6	5.50	Q6	5.00
Q7	5.25	Q7	5.50	Q7	5.50