Haptics-Based Combat Medical Training Effectiveness

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ABSTRACT

Lessons from the research and development of a Haptics-Based Combat Medical Training System, as well as summative evaluation findings, are discussed with an emphasis on best practices that can be benchmarked by training stakeholders. The multiyear research effort has yielded informative lessons learned that instructional designers would benefit from when developing similar training technologies. Given the mandate to aggressively minimize preventable deaths, and the difficulties inherent to providing care in foreign theaters, it is necessary to continuously scrutinize and evolve the best practices leveraged to train, certify and sustain medical personnel.

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OVERVIEW OF TRAINING REQUIREMENTS

The battle-space has been largely invariant since World War I in terms of the types of wounds Warfighters sustain. The leading cause of preventable death in the battle-space remains exsanguinations from extremities often as a result of explosions. The second and third leading causes of preventable death are tension pneumothorax and airway obstruction, respectively. Lessons learned from the first and second Gulf Wars highlight the importance of timely medical care and medical personnel expertise in minimizing preventable deaths but some deficiencies remain in the training systems employed to prepare U.S. forces.

An Army Small Business Innovative Research (SBIR) topic was submitted to design and develop a prototype for enhanced, realistic, casualty scenario-based training tool with haptic feedback for Army health care specialist (68Ws). This effort was tasked to enable trainees to perform scenario-based, hands-on training of key medic tasks. Further, the training system was required to provide accurate feedback to the trainee without the help of an on-site instructor.

Combat Medic and Combat Lifesaver Training

While combat medics are trained to be the primary medical care givers on the battlefield, individuals other than combat medics may be called upon to assist in providing medical care in a combat environment. Examples include the Army "Combat Lifesaver (CLS)," one who is not a medic, but who has received basic medical training in specified life-saving skills. CLS are essential, especially when there are multiple casualties to treat; when the hospital corpsmen or combat medic is among the injured; or when there is no corpsman or medic present at the scene to treat the casualty.

The leading cause of preventable death on the battlefield is exsanguination due to uncontrolled bleeding, therefore a wireless, instrumented mannequin arm to teach hands-on tourniquet skill was developed first. Correctly applying a Combat Application Tourniquet (CAT) is an extremely important skill for CLS and combat Medics. Applying a tourniquet on a live, uninjured human can be painful and should not be done. Currently, combat medics and CLS train on various improvised devices including a 4X4 piece of lumber wrapped in carpet or a Rescue Randy. The problem with this training technique is that there is no feedback to tell the trainees if they have applied the tourniquet properly (at the right spot and with the right pressure.)

As a complement to the tourniquet trainer arm, a wireless, instrumented mannequin tourniquet leg trainer was also developed to train the more difficult task of applying a tourniquet to this part of the body. A leg wound will often hemorrhage much faster than an arm. It also requires more pressure and may necessitate multiple tourniquets to stop the hemorrhage. Students don't initially realize how much pressure is required to occlude the femoral artery when applying a tourniquet on a leg for the first time. Additionally, a different technique is employed to apply the combat application tourniquet to the leg as compared to the arm.

The development of the Instrumented Tourniquet Training system took into account the varied methods of training across the services. It combines a Computer-Based Training (CBT) module (viz., didactic slide content, multimedia-based demonstrations, learning assessment, developmental feedback) with several Scenario-Based Training (SBT) practice trials (viz., an instrumented manikin leg providing real-time and after action review performance feedback).

While not all encompassing, the learning experiences fostered by the tourniquet training system are believed to be useful for developing and certifying the tourniquet task performance of Combat Medics and CLSs. The study was developed and executed to evaluate the tourniquet training system as a federation of systems (FoS) that can be employed to train Combat Medics and CLSs to perform tourniquet application tasks during Tactical Combat Casualty Care (TCCC).

INSTRUMENTED TOURNIQUET TRAINING TRAINER SYSTEM EVALUATION OVERVIEW

As part of the present evaluation effort, the differential effects of the HapMed system (Instrumented Tourniquet Training) relative to those attributable to an alternative tourniquet training FoS (viz., CLS Correspondence Course tourniquet module and Rescue Randy practice) (Alternative Training) on trainee learning outcomes were also estimated in an analysis of alternatives. The overall effort was guided by research questions about:

- whether Instrumented Tourniquet Training trainees learn to apply tourniquets as a result of their training experience;
- whether Instrumented Tourniquet Training trainees perceive their experience to be enjoyable, engaging and useful; and
- whether differential learning effects result from the use of alternative training systems.

An experiment-based evaluation study was planned and executed to answer a set of research questions and thereby help evidence the impact of the Instrumented Tourniquet training system on trainee learning outcomes. The study was informed by a training evaluation framework that includes trainee reactions, learning, behavior, and results as the critical outcomes that can be affected through the delivery of a well-designed training intervention with meaningful learning experiences (Kirkpatrick, 1959). The present study is concerned with reaction and learning criteria. Behavioral (e.g., tourniquet application performance during actual TCCC events) and results (e.g., improved unit response time during TCCC tactical evacuation events) criteria are critical as well but remain beyond the present scope.

The effort to document the effects of Instrumented Tourniquet Training on trainee learning was also guided by an expanded conceptualization of trainee learning outcomes (viz., affective, behavioral, cognitive or the ABCs of learning) (Kraiger, Ford, & Salas, 1993). Specifically, during the field experiment trainee cognitive (e.g., knowledge), affective (e.g., task specific efficacy, potency), and behavioral (e.g., task performance, task performance outcomes) learning outcomes were measured to more accurately triangulate trainee maturation over time. Moreover, in accordance with recent training evaluations which have invoked a temporal lens to better understand, frame, and model how trainee development unfolds over time (Stagl, Sheehan, Fowlkes, Shrader, Rosopa & Jentsch, 2010), the present study draws upon a time-based framework to frame the chain of learning experience-outcome effects as trainees gradually acquire tourniquet application expertise.

Figure 1. Fort Drum, NY Participant

Evaluation Conceptual Foundation

The time-based framework was advanced to quickly encapsulate the key components of the Instrumented Tourniquet Training system (viz., Multimedia CBT, Instrumented Practice and Developmental Feedback). The framework also depicts the ABCs of learning trainees should develop from the learning experience fostered by the relevant Instrumented Tourniquet Training instructional component. The framework does not imply that Instrumented Tourniquet Training trainees will not also acquire knowledge of tourniquets during the second phase of the tourniquet training process. Rather, the delivery of the Instrumented Tourniquet Training CBT module at the beginning of the training process is deliberately timed to help impart knowledge that is foundational to effectively applying tourniquets during the second phase of the Instrumented Tourniquet Training process. Therefore, it is important to ensure trainees have acquired the requisite knowledge prior to initiating practice trials in phase two. Embedded learning assessment tools serve this purpose and this example speaks to how the theory-based framework below helps inform both training system design decisions and evaluation concerns.

The framework examines the linkages between training manipulations and learning outcomes at a finer granularity than is typical of most evaluation studies. This stems from a belief that training is far too often conceived as a monolithic event; which helps explain why stakeholders often seek to answer the single question of whether training worked. Such a question assumes a single criterion of training effectiveness and

a dichotomous yes or no response. In contrast, the present approach assumes training is a multifaceted intervention and anticipating its likely multidimensional effects requires a sound theory of the: (a) nomological network of endogenous constructs, (b) myriad of manipulations to be delivered, (c) relationships between the key independent, intermediary, and dependent variables, and (d) conditions under which the asserted relationships will and will not hold. The additional insight generated from decoupling the bundle of activities collectively known as the Instrumented Tourniquet Training system, and evidencing the impact of specific components on specific learning outcomes, should yield actionable guidance for iteratively shaping Instrumented Tourniquet Training via targeted system enhancements.

Evaluation Research Hypotheses

The testable hypotheses advanced below about the effects of Instrumented Tourniquet Training on learning outcomes are focused on cognitive, behavioral, and affective learning outcomes, performance outcomes, and reactions.

Cognitive Learning Outcomes

The first research question addresses the primary cognitive outcome (viz., TCCC tourniquet knowledge) that is likely to be affected by the Instrumented Tourniquet Training CBT module. Performance theory suggests declarative knowledge (i.e., knowledge of what to do), procedural knowledge (i.e., knowledge of how to perform a task), and strategic knowledge (i.e., knowledge of when and why to perform a task) are proximal antecedents to task-work performance effectiveness. During training, declarative, procedural, and strategic knowledge can chunk to form rich mental models later leveraged by medical personnel to execute to apply tourniquets during actual TCCC events downrange. Therefore, it is critical the Instrumented Tourniquet Training CBT component helps impart TCCC tourniquet knowledge.

Instructional systems design and learning theory suggest the time and trials Instrumented Tourniquet Training CBT trainees invest in lesson review, demonstrations, assessment, and gaming should ultimately serve to impart knowledge of tourniquets. In contrast, however, because the alternative condition in the present study involves trainees learning the basic facts, rules, concepts, and principles of TCCC tourniquet application by reading the paper-based CLS Correspondence Course, differences in trainee knowledge are expected due to the manipulation of the respective learning experiences. The authenticity and interactivity of the Instrumented Tourniquet Training learning experience is posited to impart more knowledge.

Hypothesis 1A: Instrumented Tourniquet Training trainees will have more knowledge at CBT exit than at CBT entrance

Hypothesis 1B: Instrumented Tourniquet Training trainees will have more knowledge at CBT exit than alternative trainees

Behavioral Learning Outcomes

Theories of human performance also suggest the knowledge acquired by trainees during Instrumented Tourniquet Training CBT should prepare them to effectively apply tourniquets during the second phase of Instrumented Tourniquet Training. The second phase of the Instrumented Tourniquet Training system is comprised of a series of practice trials. The practice trials provide an opportunity for Instrumented Tourniquet Training trainees to further improve their task performance through hands-on tourniquet applications conducted in a variety of TCCC scenarios. Thus, the second set of research questions addressed via the present experiment-based evaluation focused on whether trainees learn to perform the tasks required to successfully apply a CAT from their Instrumented Tourniquet Training experience.

In the present study, trainee performance was operationalized via evaluator observations of trainees' performance of each of the tasks that must be completed to stanch bleeding from an amputated leg. Evaluator observations of trainee performance of several additional tasks executed to prepare a casualty to smoothly transition to a TCCC Casualty Evacuation setting were also recorded as a secondary performance operationalization but due to manuscript space limitations this criterion is not discussed further herein. The performance outcome of seconds to stanch casualty blood flow was also recorded for all trainees.

Hypothesis 2A: Instrumented Tourniquet Training trainees will exhibit more effective tourniquet application task performance during the fourth training practice trial than during the first training practice trial

Hypothesis 2B: Instrumented Tourniquet Training trainees will require less total time to stanch blood flow during the fourth training practice trial than during the first training practice trial

Hypothesis 2C: Instrumented Tourniquet Training trainees will exhibit more effective tourniquet application task performance than trainees in the alternative condition during the first training practice trial

Hypothesis 2D: Instrumented Tourniquet Training trainees will require less total time to stanch blood flow than trainees in the alternative condition during the first training practice trial

Affective Learning Outcomes

The third set of questions driving the present evaluation effort dealt with whether trainees develop confidence in their capability to successfully execute the task-work processes collectively comprising tourniquet applications during TCCC. Trainee task-specific self-efficacy (viz., a trainee's belief that s/he can perform a specific taskwork process) was operationalized in the present study as efficacy to execute: (a) TCCC situation assessment, (b) casualty screening, (c) casualty diagnosis, (d) casualty treatment, and (e) casualty monitoring. Trainee potency, or a trainee's generalized belief about his or her capability to effectively perform all of the relevant tourniquet tasks, was also measured during the evaluation effort.

In terms of proximal effects, a trainee's efficacy and potency beliefs can fuel performance practice persistence thus cultivating additional learning that can further bolster a trainee's confidence in applying a tourniquet. Instrumented Tourniquet Training leverages a rich set of increasingly difficult training practice trials to provide trainees several opportunities to make errors while practicing complex tasks without the risk of injury to others. Instrumented Tourniquet Training trainees should become increasingly more confident in their tourniquet task performance during training and this confidence is expected to enhance performance during actual TCCC events. Given this line of thinking, it is expected that trainees participating in the Instrumented Tourniquet Training system will be more confident, in both a task localized and more procedure generalized manner, after Instrumented Tourniquet Training.

Hypothesis 3A: Instrumented Tourniquet Training trainees will have more TCCC situation assessment efficacy

Hypothesis 3B: Instrumented Tourniquet Training trainees will have more casualty screening efficacy

Hypothesis 3C: Instrumented Tourniquet Training trainees will have more casualty diagnosis efficacy

Hypothesis 3D: Instrumented Tourniquet Training trainees will have more casualty treatment efficacy

Hypothesis 3E: Instrumented Tourniquet Training trainees will have more casualty monitoring efficacy

Hypothesis 3F: Instrumented Tourniquet Training trainees will have more potency at training exit than they had at entrance

Trainee Reactions

A final set of questions underpinning the present evaluation addressed trainee's evaluative perceptions of Instrumented Tourniquet Training. Evaluative reactions about whether Instrumented Tourniquet Training was engaging, enjoyable and effective provide insight about whether medical personnel trainees deemed the Instrumented Tourniquet Training experience to be valuable while also being indicative of whether trainees intend to apply the lessons learned from training downrange during TCCC. In fact, Instrumented Tourniquet Training trainee reactions are also likely to serve as antecedents to declarative and procedural knowledge, motivation to transfer, and self-efficacy. The measurement of trainee reactions can thus help evidence the impact of Instrumented Tourniquet Training as well as inform targeted system enhancements.

Trainee content and technology affective, difficulty, and utility reactions were operationalized in the present evaluation study. Given the rigor of the CBT module and guided practice trials of Instrumented Tourniquet Training, the research team expected the Instrumented Tourniquet Training system would foster favorable trainee affective and utility reactions to its content and technology. It was also anticipated that system attribute capability differences between the alternative training systems would manifest in more favorable reactions by Instrumented Tourniquet Training trainees than trainee exposed to the alternative tourniquet training FoS evaluated.

Formative Evaluation Method

Trainees in both tourniquet training conditions used in the present study completed: (a) identical pre-training forms, tests, and measures, (b) a 30-minute training block of tourniquet training, (c) identical during-training tests, (d) a 20-minute training block consisting of three tourniquet application practice trials and one performance certification trial, and (e) identical post-training measures. Derivations of a within-and-between-subjects research design were used to statistically evidence the trainee learning outcome effects and differential effects hypothesized in the Evaluation Conceptual Foundation section.

Upon arrival at the training site, trainees: read, had read to them, and signed an informed consent form; completed a demographics questionnaire; completed pre-training tests and measures; and were randomly

assigned to learn from either the Instrumented Tourniquet Training or alternative tourniquet training system. Trainees also completed a measure of knowledge after completing the Instrumented Tourniquet Training CBT module or CLS Course as well as efficacy, potency, and reaction measures at the end of the tourniquet training process. When the training process was terminated, each trainee was thoroughly debriefed on the purpose of the present evaluation study and to help verify that they were comfortable with their respective training experience.

Formative Evaluation Results

This section includes a discussion of the results of statistical analyses conducted during the evaluation. The results reported herein must be considered in light of the small sample sizes achieved thus far during the ongoing evaluation of Instrumented Tourniquet Training.

Participant Demographics

The trainee participants sampled (N = 17) were a mixture of 68W Combat Medics, certified CLSs, and representatives of other U.S. Army military occupational specialties (viz., 11A, 11B, 11C). Trainees were sampled on a convenience basis from Fort Drum, NY. The participants self-identified their MOS as follows: 5 Combat Medics, one 11A, 8 11B's, and 3 11C's. It should be noted that one of the 11B participants was a former Combat Medic. All of the participants sampled were male ranging in age from to 18-years to 37-years. The participant trainees had military experience (M = 2.7-years) and had participated in tourniquet training prior to the present evaluation (M = 33-hours).

Reliability Estimates

The estimated internal consistency reliability of the 10-item pre-CBT tourniquet knowledge test was .61. The estimated reliability of the identical 10-item test administered post-CBT tourniquet training was .39. The test reliability estimates are low relative to conventional standards for informing decision-making. The test-retest reliability of the knowledge test was .81; somewhat high given the context of the study. Item analyses suggest the psychometric properties of the tourniquet knowledge test can be improved. Steps will be taken to enhance the properties of this assessment tool prior to further data collection. All of the internal consistency reliability estimates were deemed acceptable in the present study. All other study hypotheses were tested via data generated from the employment of single-item scales.

Correlation Analyses

The temporal theory of trainee learning outcomes underpinning the present evaluation effort provides some insight about the expected nomological networks of the various learning outcomes included in this study. Trainee tourniquet knowledge and tourniquet application performance during training were expected to be correlated. Similarly, trainee tourniquet performance and tourniquet application efficacy were also expected to be correlated. Pearson's correlation coefficients were calculated between the relevant trainee learning outcomes.

There was a moderate, negative correlation (r = -.492, p < .05) between trainee tourniquet knowledge and total seconds to stanch casualty blood flow during the initial tourniquet training practice trial. There was also a moderate, negative correlation (r = -.500, p = .05) between trainee tourniquet knowledge and total seconds to stanch casualty blood flow during the second tourniquet training practice trial. Given the use of a one-tailed significance test, there was a moderate, negative correlation (r = -.394, p = .05) between tourniquet knowledge and total seconds to stanch blood flow during the third trial. A moderate, negative correlation (r = -.520, p < .05) was also found between seconds to stanch blood flow and trainee casualty monitoring self-efficacy during the final performance certification training trial.

Paired-Samples *t*-test Analyses

This subsection provides a discussion of the results generated from analyses conducted to statistically evidence improvements in trainee cognitive, behavioral, and affective learning outcomes due to participation in the Instrumented Tourniquet Training system.

TCCC Tourniquet Knowledge

Hypothesis 1A stated Instrumented Tourniquet Training trainees will have more knowledge at CBT exit than at CBT entrance. In regards to Hypothesis 1A, the result of a paired-samples t-test suggests trainee tourniquet knowledge was greater at CBT exit than upon entrance (t(8) = -2.53, p < .05); supporting Hypothesis 1A.

Tourniquet Application Performance

Hypothesis 2A stated Instrumented Tourniquet Training trainees will exhibit more effective tourniquet application performance during the fourth training practice trial than during the first training practice trial. In regards to Hypothesis 2A, the result of a paired-samples t-test suggests trainee tourniquet application performance was more effective during the fourth trial than the first trial (t(8) = -2.80, p < .05); supporting

Hypothesis 2A. Similarly, Hypothesis 2B stated Instrumented Tourniquet Training trainees will require less total time to stanch blood flow during the fourth training practice trial than during the first training practice trial. Despite observing a reduction in the total seconds required to stanch blood flow (M = 41) during the fourth training trial from the first trial (M = 48), the result of a paired-samples t-test failed to support Hypothesis 2B.

Tourniquet Task-work Confidence

Hypotheses 3A – 3F collectively stated Instrumented Tourniquet Training trainees would develop greater confidence in their capabilities to execute tourniquet application task-work processes, as well as more generalized potency, from the Instrumented Tourniquet Training learning experience. The results of paired-samples t-tests suggest trainees had more: TCCC situation assessment efficacy ($t(8) = -4.27$, $p < .01$), casualty screening efficacy ($t(8) = -3.09$, $p < .01$), casualty diagnosis efficacy ($t(8) = -2.60$, $p < .05$), casualty treatment efficacy ($t(8) = -4.09$, $p < .01$), casualty monitoring efficacy ($t(8) = -2.68$, $p < .05$), and potency ($t(8) = -2.85$, $p < .05$), at Instrumented Tourniquet Training system exit than entrance. These results collectively support Hypotheses 3A – 3F.

Independent-Samples t-test Analyses

This subsection provides a discussion of the results generated from analyses conducted to statistically compare the impact of the Instrumented Tourniquet Training system, relative to that of the alternative tourniquet training system, on trainee cognitive and behavioral learning outcomes.

TCCC Tourniquet Knowledge

Hypothesis 1B stated Instrumented Tourniquet Training trainees will have more TCCC tourniquet knowledge at CBT exit than trainees participating in the alternative tourniquet training condition. Despite observing expected differences in the post-CBT tourniquet knowledge means of Instrumented Tourniquet Training trainees (M = 7.78) and alternative condition trainees (M = 6.63), the results of an independent-samples t-test failed to support Hypothesis 1B. Trainee tourniquet knowledge is addressed in more detail in the discussion section.

Tourniquet Application Performance

Hypothesis 2C stated Instrumented Tourniquet Training trainees will exhibit more effective tourniquet application task performance than trainees in the alternative condition during the first practice trial. A negligible difference was observed in the tourniquet application performance of Instrumented Tourniquet Training trainees (M = 5.22) and alternative condition trainees (M = 5.25) during the first trial; failing to support Hypothesis 2C.

Hypothesis 2D stated Instrumented Tourniquet Training trainees will require less total time to stanch blood flow than trainees in the alternative training condition during the first training practice trial. The result of an independent-samples t-test suggests Instrumented Tourniquet Training trainees required less time to stanch casualty blood flow than trainees participating in the alternative tourniquet training condition ($t(15) = -2.72$, $p < .05$) during the first practice trial; supporting Hypothesis 2D. Additional evidence for Hypothesis 2D is presented next.

While not hypothesized, the results of exploratory analyses conducted to examine between condition performance differences during the second, third, and fourth Instrumented Tourniquet Training SBT tourniquet practice trials employed in the present study are also reported in this subsection. The result of an exploratory independent-samples t-test suggests Instrumented Tourniquet Training trainees required less time to stanch blood flow than trainees participating in the alternative tourniquet training condition ($t(15) = -2.34$, $p < .05$) during the third practice trial. Moreover, given the use of a one-tailed test, the result of an independent-samples t-test suggests Instrumented Tourniquet Training trainees required less time to stanch blood flow than trainees participating in the alternative training condition ($t(15) = -1.96$, $p < .05$) during the second practice trial.

Post-Training Reaction Means

Trainee affective and utility reactions to Instrumented Tourniquet Training content were measured in the present study. The mean of trainee affective reactions to Instrumented Tourniquet Training content was 17.33 out of a possible 18. The mean of utility reactions to Instrumented Tourniquet Training content was 17.22 out of a possible 18. Trainee affective and utility reactions to Instrumented Tourniquet Training technology were also measured in the present study. The mean of trainee affective reactions to Instrumented Tourniquet Training technology was 11.11 out of a possible 12. The mean of utility reactions to Instrumented Tourniquet Training technology was 11.44 out of a possible 12. Trainee Instrumented Tourniquet Training content and technology difficulty reactions were also operationalized during the present study. The mean of trainee difficulty reactions to Instrumented Tourniquet Training content was 5.44 out of a possible 12. The mean of trainee difficulty reactions to Instrumented Tourniquet Training technology was 2.56 out of a possible 12. These preliminary results suggest Instrumented Tourniquet

Training trainees reported the tourniquet training experience was enjoyable, engaging, and useful.

Evaluation Findings Discussion

The preliminary findings discussed herein are also based on small overall and per condition sample sizes. The inclusion of participants with substantial experience applying tourniquets during training was an artifact of the convenience sampling process employed out of necessity in the present initiative. The sampled participants are likely more similar in experience to the population of medical personnel that would use Instrumented Tourniquet Training to conduct continuation training to comply with force certification directives. Given the experience of the trainees sampled, the magnitude of the effects discussed in this section may be perceived as somewhat conservative estimates of the impact of Instrumented Tourniquet Training and the alternative system. The planned continued evaluation of Instrumented Tourniquet Training relative to the alternative training system may involve a sampling of less experienced trainees and could result in a different overall picture of the impact of each system.

Tourniquet Knowledge Findings Discussion

The Instrumented Tourniquet Training CBT module was designed to help trainees acquire knowledge of tourniquet parts, purpose, and use during TCCC. The foundational knowledge acquired by trainees helps prepare them to properly apply a tourniquet during a TCCC event. The present study provides preliminary evidence of the effect of Instrumented Tourniquet Training on trainee tourniquet knowledge.

Instrumented Tourniquet Training CBT trainee knowledge increased 13%. Trainees also gained 13% more knowledge by learning about tourniquet applications via the alternative condition (viz., CLS correspondence course). Although there was not a statistically significant difference in the post-CBT knowledge of Instrumented Tourniquet Training trainees (M = 7.78), and trainees in the alternative condition (M = 6.63), these preliminary findings are intriguing and underscore the need to collect additional data to gauge the relative impact of the Instrumented Tourniquet Training CBT module.

Tourniquet Performance Findings Discussion

The findings distilled from the formative training evaluation study present a mixed picture of Instrumented Tourniquet Training's trainee behavioral learning outcome effects. For example, the findings suggest Instrumented Tourniquet Training trainees improved their effectiveness at performing the core tasks that are executed to apply a tourniquet during a TCCC event from when they entered Instrumented Tourniquet Training until their exit. In contrast, however, the observed decrease of seconds to stanch bleeding from the first trial to the fourth trial by trainees was ultimately not statistically significant. As additional participants are sampled this finding may change.

The preliminary findings from the present study partially evidenced a difference in the performance of Instrumented Tourniquet Training and alternative condition trainees during the first tourniquet practice trial. Trainees in both training conditions were observed to be equally adept at executing the core tasks required to apply a tourniquet during the first SBT practice trial. However, although there was not a significant difference between the performance of trainees in the Instrumented Tourniquet Training and alternative conditions, an inspection of the data for the seconds to stanch a casualty's blood flow lends some support to the supposition that Instrumented Tourniquet Training trainees were relatively more effective at applying tourniquets than the trainees that learned from the CLS correspondence course and a standard manikin. Instrumented Tourniquet Training trainees were 60%, or more than 1-minute, quicker to stanch casualty blood flow than alternative condition trainees during the first tourniquet practice trial. This is especially intriguing because all trainees received performance process and outcome feedback during and after each trial; which were collectively designed to be progressively more challenging over time. In fact, the stanch time of trainees in the competing conditions did not converge until the fourth and final trial.

Additional Findings Discussion

This section includes a discussion of some of the additional findings generated from the present Instrumented Tourniquet Training evaluation study, emphasizing affective learning outcomes, trainee reactions, and themes distilled from trainee responses for comments and suggestions to improve the Instrumented Tourniquet Training system.

Task Efficacy and Potency

In order to determine whether Instrumented Tourniquet Training trainees became more confident in themselves during the training experience, six hypotheses were advanced and answered during the present evaluation study. The findings from the first five hypotheses tested suggest trainees that participate in the Instrumented Tourniquet Training system will become more confident at recognizing the nuances of TCCC situations and rendering timely medical assistance in the form of a CAT. Instrumented Tourniquet Training

trainees experienced substantial gains in confidence in each of the task-specific affective learning outcomes, including: (a) TCCC situation assessment efficacy (27%), casualty screening efficacy (35%), casualty diagnosis efficacy (32%), casualty treatment efficacy (36%), and casualty monitoring efficacy (20%); as well as generalized potency (21%).

Content and Technology Affective, Utility & Difficulty Reactions

As reported in the evaluation results section, trainees reacted positively to the content comprising Instrumented Tourniquet Training and perceived the overall learning experience as meaningful in terms of ultimately being effective when applying tourniquets during actual TCCC events downrange. Clearly, trainees also reacted positively to the technology comprising Instrumented Tourniquet Training and perceived the technology comprising the FoS to be meaningful in terms of ultimately being effective when applying tourniquets during TCCC events.

Qualitative Reaction Themes

An initial thematic analysis of the qualitative data collected from trainees during the evaluation study suggests the critical feedback provided can be distilled to two common themes: (a) further contextualize the system (e.g., battlefield stressors, audible cues, synthetic blood) and (b) continue to refine the CBT.

LESSONS LEARNED

The training effectiveness evaluation for the Instrumented Tourniquet Training trainer is the culmination of a year of foundational work where many lessons were learned.

The initial training, research and development requirements gathering and validation process affords the lesson for the need to find a joint services point of contact to validate the requirements gathered. This is particularly important for a year-long effort and the funding it entails. The HapMed program benefitted from interest and feedback by the Army, Air Force, Navy and Marines as well as the Department of Homeland Security Federal Law Enforcement Training Center. However, the requirements gathered from one service branch do not always completely overlap with requirements gathered from another branch.

A lesson learned in the gathering of requirements is that support is built from the grass roots of the organization and its end-users rather than from top down. While it may take time for these end users to report their impressions, their participation is vital.

Finalizing hardware requirements early is important. In order to support requirements discussions, it was necessary to create one-off demonstration models with much of the functionality of the final requirements yet to be implemented into the standardized fabrication process. This trade-off enabled us to gather requirements earlier than if we waited for the factory prototypes. The lesson learned is to develop initial demonstration prototypes as soon as possible and generate final requirements as early as possible.

Within the device development, lessons presented themselves throughout the process (from prototype research through production and system evaluation). In the research and development phase, multiple subject matter experts provided input. Sometimes this input would conflict or one item might be very costly to implement. This resulted in "give and take" in requests for features and the ability (or even cost) to implement such a request. Communication between sub-teams is important and this aspect worked quite well.

During the research phase, it is important to consider multiple possible solutions to a given sub-component. Obviously, this can provide a better potential solution to a given sub-problem. However, this was also useful in the final production phase due to obsolescence issues from earlier prototypes. This ranged from some sensors used down to even the simplest electronic components. These components had to be replaced with currently available versions. In some cases, this was simple; in others, an alternative approach was necessary.

Another issue in the final production phase dealt with coordination of sub-contractors. The Instrumented Tourniquet Training devices are built using three sub-contractors: one for molding, one for sensors, and one for printed circuit boards. Each has its own internals goals and schedules, which can result in the difficult task of getting all parties to deliver in a similar timeframe. Each component was being created for the first time in order to support ultimate mass production. Some components had more difficulties than others in meeting all the requirements, which caused some delay in completing the final demonstration versions.

Within the software side of the device development, we leveraged a number of past lessons learned. A flexible protocol, coupled with version identifiers, was produced. Each training device can identify itself by name as well as protocol and firmware versions. This allows the connecting tool (for example, a mobile device) to query data about the device and communicate accordingly. This will allow backwards

compatibility in the future as updates are released. Each device is built with the capability for an end-user to update the firmware (much like a computer's BIOS or wireless access point firmware is updated). Research of software platforms led our development team to the conclusion that the Android™ platform is the most suitable to our mobile application development needs. Early on in the project we determined that it would be worthwhile to leverage advances in commercial off the shelf technology and to develop the mobile remote control on the Android phone.

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