Enabling Point of Injury Care in Live Force-on-Force Exercises

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ABSTRACT

Large-scale military exercises involving force-on-force engagements provide a valuable opportunity to train collectively in realistic battlefield conditions. Unfortunately, battlefield medicine and casualty response have often been excluded due to the burden inherent in their implementation. To date, including medical activities in these training events has required medical manikins or patient actors, which both require extensive resources and manpower to prepare and utilize. With this manuscript, we describe a capability to enable medical care organic to the exercise, without the need for manikins or patient actors. To achieve this, medical equipment has been instrumented to create surrogate equipment, which collects data during treatment to provide feedback and update patient state. The surrogate equipment is paired with a computer vision system, which uses man-worn cameras to monitor participants and provide measures of task performance. During a training engagement, when a participant is injured by a simulated munition, the trainee uses surrogate equipment to treat the casualty, and is assessed using data from the surrogate equipment as well as the camera system. A user evaluation of the system was conducted during the Synthetic Training Environment Soldier Touch Point 6 for Live Training Systems, at the National Training Center. A total of 19 participants (16 infantry; 3 combat medics) tested the system, providing feedback on the usability, training utility, and current performance of the system. Results were positive for all individual system components and the overall system. Based on initial testing, the use of surrogate equipment combined with a computer-vision enabled camera system represents a feasible and highly useful capability to enable medical care in large-scale military training.

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Ed Stadler is a systems engineer and SIMETRI's Chief Engineer with 32 years of experience in the simulation and training industry. He has served as technical lead and chief engineer for complex simulation and training programs over the past 17 years and has extensive experience in the full life cycle development and production of simulation systems and products. Ed received his BS in Electrical Engineering from the University of Central Florida.

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INTRODUCTION

In order to be prepared for the challenges inherent in battlefield and austere medicine, military medical providers require a broad set of knowledge, skills, and abilities (KSA). On the battlefield, these providers are typically combat life savers (CLS) and combat medics, who serve as first responders. In these circumstances, the standard of care is known as tactical combat casualty care (TC3), which focuses on treatment of the common preventable causes of death (Butler et al., 1996). TC3 emphasizes hemorrhage control, airway management, and respiration / circulation treatments in order to stabilize patients (Tien et al., 2008). To impart the KSAs associated with TC3, the military employs a scaffolded educational process. Training begins with foundational didactic content, including anatomy, physiology, common pathologies and symptoms, and treatment procedures. Once the didactic portion is completed, trainees move to individual psychomotor skills training on part-task trainers or medical manikins. These skill stations focus on critical TC3 procedures such as tourniquet application, needle decompression of the chest, application of a pressure dressing, and insertion of a nasal-pharyngeal airway. With knowledge and individual skills mastered, trainees advance to polytrauma simulations, requiring full trauma assessments and multiple treatments. Finally, culminating events include squad-level training, wherein squads move through a tactical lane, encounter opposing forces, and render care to multiple simulated patients. Recently, TC3 training was standardized across the services using a tiered approach, ensuring all Service-members have casualty response training commensurate with their role (Hackett et al., 2020).

The current paradigm of TC3 training at the CLS and combat medic level results in a population of first responders that are prepared to treat battlefield casualties. However, casualty response is seldom integrated into large-scale, collective military exercises. These exercises often include multiple brigades, thousands of participants, and complex tactical and strategic planning. Training objectives within the events encompass nearly all warrior tasks underlying the core tenets of move, shoot, and communicate (STP 21-1-SMCT, 2009). These large-scale exercises include force on force engagements typically using live engagement systems, such as the multiple integrated laser engagement system (MILES). MILES systems use laser transmitters and detectors to simulate a variety of direct and indirect munitions and effects (Munera III, A, 1977; Rozman, 2020).

Despite the comprehensive simulation of the battlefield, medical care training is often excluded due to the logistical complexity of current medical simulations. Presently, exercises desiring medical training capabilities employ either medical manikins or patient actors, which both have significant downsides. Medical manikins are expensive to procure and maintain and require an instructor or technician to operate (Zendejas et al., 2013). Patient actors necessitate additional specialized personnel who need significant setup time to apply moulage and other special effects for appropriate injury presentation (Pettitt & Karwowski, 2020). Further, both manikins and patient actors require that the mechanism of injury and incident location are pre-determined. For example, a simulated IED in the exercise would require that the manikin or patient actor be pre-positioned nearby the IED and have the appropriate injury moulage before the event occurs. In short, inclusion of medical training capability is costly in terms of time, personnel, and funding, and requires scripting of medical incidents. For these reasons, individual medical care and broader casualty response are often excluded from large exercises, with medical personnel instructed to train separately. Collective training without medical care can result in reduced preparedness for the downstream effects of battlefield casualties at squad levels and above.

To address this issue, a medical training capability was developed to enable organic casualty care without the need for manikins or patient actors. Within this manuscript, the development and integration of instrumented medical equipment and a computer vision assessment system is detailed, resulting in a turn-key solution to allow basic point of injury (POI) care to be embedded within large scale military exercises. To assess the system for user acceptance, usability, and technical maturity, an evaluation was conducted at a Soldier Touch Point. This manuscript reports results of the evaluation, discussion of the capability for the broader community, and future research directions.

METHODS

System Components

In order to enable organic medical treatment within large scale events, the capability must remove the dependency for manikins or patient actors. To achieve this, researchers combined surrogate medical equipment with computer vision. Each component is detailed herein.

Surrogate Medical Equipment

MILES and other laser engagement systems utilize surrogate weapon systems which are based on real weapons platforms (AT4 Light Anti-Armor Weapon, M4 rifle, M17 handgun, etc.) instrumented with laser emitters. Using a similar concept, surrogate medical equipment was developed using real medical equipment that was modified and instrumented for use in training environments. The initial surrogate device is the combat application tourniquet (CAT). The CAT is a military standard hemorrhage control device provided with most individual first aid kits (IFAK) and medic aid bags. The CAT is applied by looping it around an extremity, securing the Velcro strap, twisting the windlass (tightening rod), and securing the windlass in the clip (Wall et al., 2019). This process causes the tourniquet to mechanically tighten around the limb, thereby cutting off circulation and stopping extremity hemorrhage. When applied correctly, the tourniquet applies extensive pressure to the limb which can cause additional injury and pain.

To avoid the potential for harming participants, the surrogate tourniquet was modified by removing the capability to mechanically tighten. The standard CAT uses the windlass to tighten fabric around the limb; the modified CAT attaches a variable force feedback system to the windlass (Figure 1; left). In this way, the trainee feels tension when tightening the windlass, but the tourniquet does not mechanically tighten; instead, the variable force feedback system isolates the force to the windlass only. This allows the tourniquet to be applied to other trainees without risk, while still providing the haptic sensation of real tourniquet application. Further, a pressure sensor is fitted below the windlass and connected to a small circuit board, which measures the force being applied. Once the force reaches a threshold amount, the surrogate tourniquet wirelessly signals that appropriate tension is achieved. This message serves as an objective measure of tightness and triggers an event indicating that application is complete. A tablet and mobile application collect the data from the tourniquet and provide a display for the user to view their performance (Figure 1, right).

Figure 1: Surrogate Tourniquet Modified with Force Feedback System (left) and Mobile App Screen (right)

Computer Vision System

Proper tourniquet application requires two conditions: proper placement and sufficient tightness. During the first phase of TC3, care under fire, the guidance suggests that the tourniquet be placed high and tight on the wounded extremity. The surrogate tourniquet provides a measure of tightness but cannot determine its location on the casualty. To provide information on tourniquet position, a camera system employing computer vision was integrated with the surrogate

tourniquet. The Camera Analytic System for Training, Learning, and Education (CASTLE) system uses ego-centric (man-worn) cameras to automatically detect medical activity, creating an automated debrief and objective measures of performance (Figure 2) (VanVoorst et al., 2022). CASTLE uses a variety of computer vision techniques to detect medical activities and equipment, including the scale invariant feature transform (SIFT) algorithm (Lowe, 1999) and a region-based convolutional neural network (RCNN) (Lian & Hu, 2015, Ren et al., 2015). Specifically, the SIFT implementation uses OpenCV (OpenCV, 2022) and the Faster RCNN implementation uses Detectron (Facebook, 2022). These CV techniques enable CASTLE to detect when the tourniquet is removed from the pouch, when application begins, and the location the tourniquet is applied. Combined with the measure of tightness from the surrogate tourniquet, the composite metric provides a complete assessment of a trainee's tourniquet application.

Figure 2: Participant wearing CASTLE helmet (left) and Helmet-Mounted Camera (Right)

Trigger Detection Module

To trigger the need for medical care, the live engagement system must generate a casualty. For example, to initiate a simulated gunshot hit, a MILES or other live engagement system must ascertain that a weapon was fired, oriented towards the opposing force, and the projectile impacted the target. To initiate a casualty for this effort, a geo-pairing or e-Bullet solution known as the Trigger Detection Module (TDM) was used. The TDM can be installed in the pistol grip or on a Picatinny rail, enabling simple conversion of real or surrogate weapons for use in a training environment (Figure 3). An additional transmitter / receiver is attached to trainees, and a mobile unit, known as the rover, is deployed in the surrounding area. The TDM, receiver, and rover use a wireless personal area network and GPS to pair the weapon and orientation with trainee location to determine a hit or miss.

Figure 3: Pistol Grip and Picatinny Rail Versions of TDM

Integrated System

The organic POI training capability was developed by integrating the three components detailed above. In our configuration, the TDM is installed in the pistol grip of an M4. Participants wear receivers on a helmet, to facilitate geo-pairing with the TDM; in this case, the participant becomes the casualty. The medical provider wears a helmet-mounted camera, and a surrogate tourniquet is placed in the pant pocket of the casualty. The incident begins when the TDM detects a shot and successful hit. The TDM systems sends that information via Bluetooth Low Energy (BLE) to an android tablet controlling the surrogate tourniquet. Once received, the tablet begins a physiology simulation that models blood loss. To provide a visual indication of wounding, the tablet hit also signals an active gunshot wound moulage device to start bleeding. The provider renders care to the casualty, applying the surrogate tourniquet. The

camera communicates wirelessly with a processing computer, to detect medical activity and determine correct tourniquet placement. Once the tourniquet is tightened and applied in the correct location, both systems provide that data to the tablet and back to the TDM, ending the scenario. The trainee can then view an AAR, including video from the helmet mounted camera. The components and communication protocols of the integrated system are shown in Figure 4.

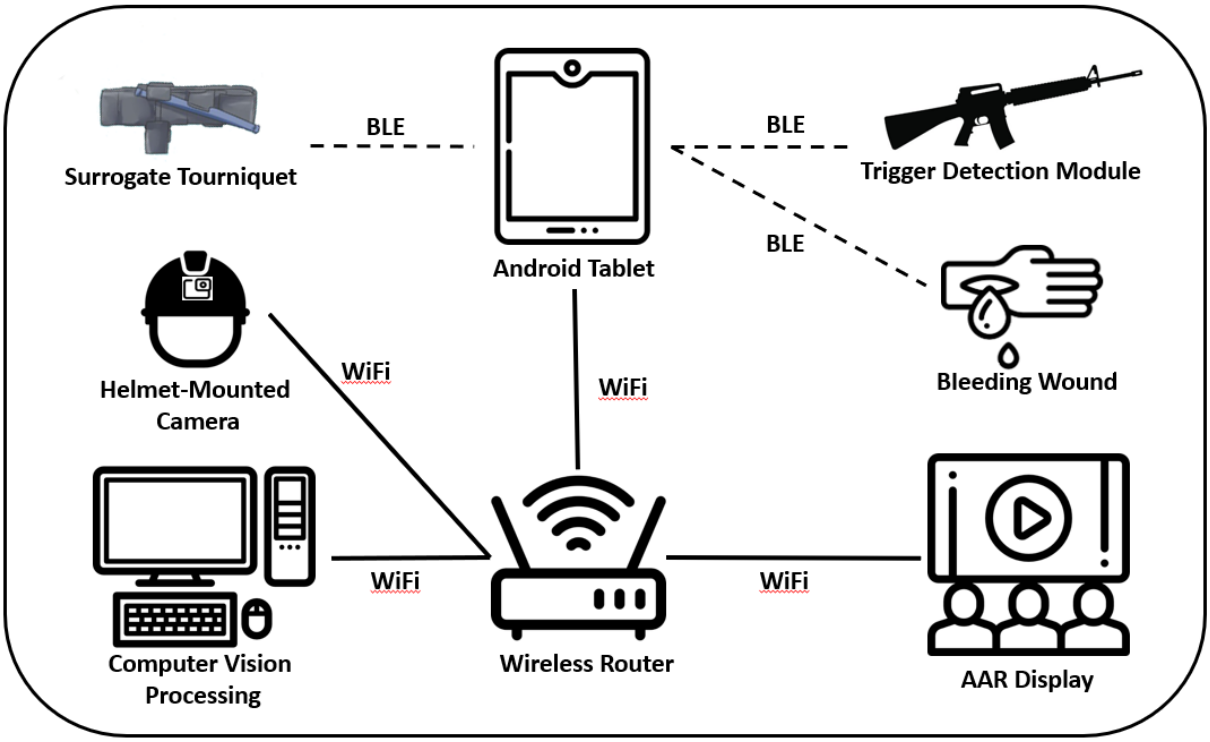

Figure 4: Integrated System Diagram

System Evaluation

Metrics

The system was evaluated for usability and user acceptance using a 5-point Likert scale survey. The survey was broken into 4 areas: surrogate tourniquet, realism and bleeding system, AAR and computer vision, and integrated system. Questions in each area focused on user perceptions of training utility, ease of use, haptic sensation, and fidelity.

The system reliability and accuracy were tested for the tourniquet and computer vision components. The tourniquet was tested for durability and force measurement accuracy. Force measurement accuracy was assessed using an expert observer (experienced combat medic) to determine ground truth associated with sufficient tightness, as compared to the pressure sensor reading. The computer vision capability was tested for accuracy using the F1 score as the core metric (see eq. 1). The F1 metric utilizes precision and recall determining the accuracy of the model. Precision is the positive predictive value, given by the fraction of true positive examples (tp) divided by the number of false positive examples (fp). Recall is the specificity of the model, given by the number of true positives (tp) divided by false negatives (fn). The F1 score is the harmonic mean of the precision and recall, which gives a balanced measure of accuracy (Tan et al., 2013).

$$F_1 = \frac{2}{\frac{1}{\text{recall}} \times \frac{1}{\text{precision}}} = 2 \times \frac{\text{precision} \times \text{recall}}{\text{precision} + \text{recall}} = \frac{\text{tp}}{\text{tp} + \frac{1}{2}(\text{fp} + \text{fn})} \quad (1)$$

Experimental Design

The system was evaluated as part of the Synthetic Training Environment Soldier Touch Point 6, focused on Live Training Systems. The evaluation occurred at the National Training Center in Fort Irvin, CA, at the Tiefort City military operations in urban terrain (MOUT) site. Participants included combat medics (68W) and infantry soldiers (11B). The event began with a short briefing on the purpose of the experiment. Each participant began inside a building within the MOUT site, wearing a helmet-mounted camera. To begin the event, a member of the research team fired the TDM-outfitted weapon, which registered a hit on the casualty. Once registered, the casualty started bleeding, and the participant went outside to render care. Following tourniquet application, the participant was shown their after-action review and video debrief. The survey was administered after viewing the AAR.

RESULTS

A total of 19 participants are included in the evaluation; 3 participants were combat medics and 16 were infantry soldiers. The demographics of the participants are provided in Table 1, including age, prior TCCC and tourniquet experience, and years of service. All participants in this event were male.

Table 1: Participant Demographics

Variable	Value
Average Age	23.3 ± 3.1 Years
Average Years of Service	2.3 ± 1.5 Years
Percentage with Prior TCCC Training	74% (14 of 19)
Tourniquet Applications (training)	19.4 ± 14.0
Tourniquets Applications (in situ)	0.9 ± 2.5

The results from the evaluation were highly positive across all subjective measures. The Likert scale values ranged from 1 (strongly disagree; negative sentiment) to 5 (strongly agree; positive sentiment). The questions are grouped and averaged within the thematic system metrics, rather than individual questions (Table 2). Medical personnel reacted very favorably to the surrogate tourniquet, system realism including bleeding, AAR and computer vision system, and overall system. Similarly, the response from the infantry participants was highly favorably towards all system components. The lowest rated individual question was related to the mobile application and feedback metrics, rated at 4.2 ± 0.5; this question is nested into the AAR system metrics.

Table 2: Participant Perceptions of System Components

System Metrics	Medical Personnel	Infantry	Overall
Surrogate Tourniquet	4.8 ± 0.3	4.5 ± 0.4	4.5 ± 0.4
System Realism	5 ± 0	4.4 ± 0.4	4.5 ± 0.4
AAR and Computer Vision System	4.9 ± .1	4.5 ± 0.4	4.6 ± 0.3
Integrated System Effectiveness	5 ± 0	4.5 ± 0.4	4.7 ± 0.4
Overall Average	**4.9 ± 0.2**	**4.5 ± 0.4**	**4.5 ± 0.4**

The reliability and accuracy of the technical components was also assessed. The tourniquet accurately measured the force of application in all instances. One surrogate tourniquet suffered a mechanical failure during the test and was repaired on site. The computer vision capability functioned well in the MOUT environment (Figure 5). The tourniquet was detected in nearly all runs, with no false positives, resulting in an F1 of 0.93; as a reference, an F1 scope of 1 represents perfect recall and precision. The location of tourniquet application was not successfully detected during the exercise; this finding and underlying causes are explained in the discussion.

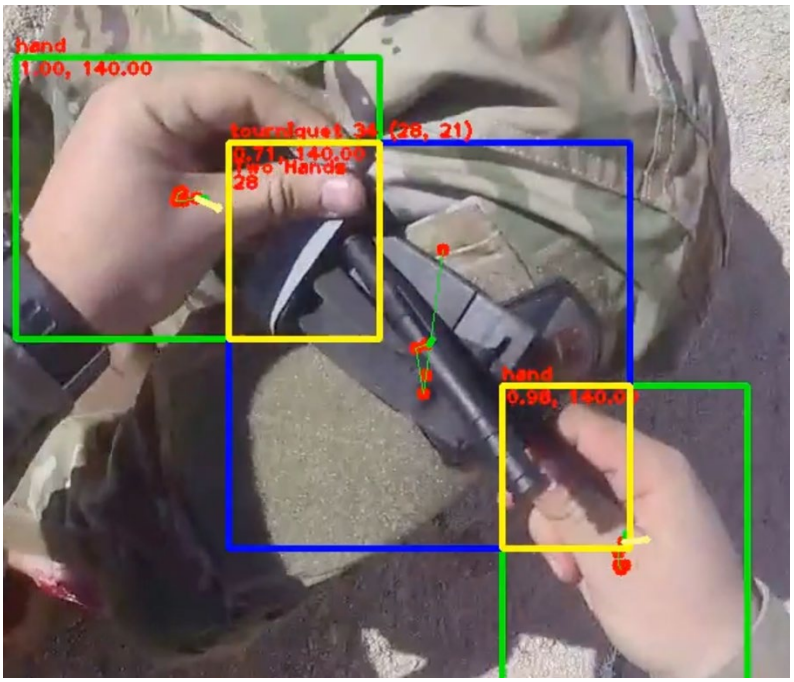

Figure 5: Computer vision overlay on participant video. Hands (green boxes), tourniquet (blue box), and tourniquet / hand interaction (yellow boxes) are identified by bounding boxes.

DISCUSSION

The inclusion of medical care within collective training events is critical to ensuring comprehensive readiness. This is particularly important if theater operations shift from counter insurgency to large-scale combat operations (LSCO), wherein the quantity and frequency of casualties will be much higher (Tien & Beckett, 2022). Further, future combat against peer or near-peer adversaries has a high likelihood of delayed casualty evacuation due area denial and contested airspace, thereby expanding the 'golden-hour' of treatment to prolonged casualty care (Travers et al, 2019; Vertu et al., 2021). These factors increase the importance of first responders, who must be prepared to stabilize patients to minimize preventable battlefield deaths. Within this effort, researchers developed a capability that enables point of injury care within large-scale collective training, without the need for manikins or specialized patient actors. This represents a significant achievement, as the resource and logistical burden of current medical simulation capabilities inhibit the inclusion of medical training in many of these events. The capability was tested at a soldier touch point, to assess the functionality and reliability of the technologies as well as user perceptions of the capability.

The key technologies included surrogate medical equipment and computer vision to assess medical activity. The surrogate tourniquet performed well during the testing event. The pressure sensor accurately provided force data associated with tourniquet tightness, without significant measurement drift or the need for recalibration. One tourniquet failed during the testing event, where an internal wire was broken; this was able to be fixed on site. Despite the extreme forces on the tourniquet, the current design provides extensive reuse of the device; however, additional hardening of both the electronics and the fabric will be required.

The computer vision performed very well on tourniquet detection and time to apply. The system was able to detect the tourniquet in all but one instance, with no false positive, resulting in an F1 of 0.93. The one instance of failure resulted from the trainee tackling and laying on the casualty, removing any visibility of the tourniquet in the camera's

field of view. The strong F1 score suggests that for basic metrics and task detection, the computer vision is a promising technology. However, the computer vision struggled when assessing the tourniquet location, failing in all instances. There were two root causes to this poor performance. First, in training the computer vision algorithms, an assumption was made that the wound would be visible to the camera, serving as the lower boundary for tourniquet placement, with the uniform shoulder patch serving as the upper boundary. In the testing environment, the wound was often covered by the uniform throughout the tourniquet application. Without the wound as a marker, the computer vision could not ascertain proper tourniquet placement. Additionally, in many instances, the field of view on the camera captured only a small segment of the body (ex: the shoulder, upper torso, and upper arm); most pose estimation tools in the CV domain are trained on full bodies (Wang et al., 2021), making detection significantly harder. In the future, the software will utilize a body segmentation technique to determine the location of application. The body will be segmented into upper / lower limbs, torso, neck, head, etc.; further, it will be trained on humans lying down with varying fields of view and occlusions. Using this technique, it is anticipated that system accuracy will significantly improve regardless of casualty position and visual occlusion.

Participant perceptions were positive across the study population for all components. Both medical and non-medical personnel felt the system was valuable, suggesting that the POI training capability is tailored to the appropriate fidelity and focused on critical tasks suitable for all warfighters. This is consistent with prior research, which found tourniquet training to be well received and retained by medical and non-medical personnel (Scalese et al., 2022). The realism of tourniquet was of significant interest, with all participants feeling the haptic sensation is consistent with real tourniquet application, and useful for training. The positive results from this research suggest the inclusion of medical scenarios in large-scale events has significant potential and reinforces the feasibility of the current technical approach. This finding is consistent with prior research from the Squad Overmatch program, which successfully integrated TCCC training, situational awareness, and team dynamics into a single curriculum, including a culminating squad-based activity using a variety of simulations (Milham et al., 2017). The current technical approach also enables extensive scaling, suitable for using from squad- to battalion-level training.

One downside to the current implementation is the necessity for a physical wound. In this case, moulage of a gunshot wound was applied to the participant prior to the event, with bleeding triggered by the TDM. In order to have a capability organic to the exercise, pre-determined casualties with pre-applied wounds are not feasible. Future work will address this through the additional of an electronic casualty card. Most live engagement systems (LES) include a display that provides the current status of the trainee (alive, injured, dead). An electronic casualty card will utilize existing LES displays to provide the wound information, visually or via text, thereby cueing a trainee on the appropriate treatment. The electronic casualty card will be updated based on the applied treatments, providing feedback to both the trainee and the larger exercise. Another alternative is the use of augmented reality to provide a virtual wound overlaid onto the wounded exercise participant (Leuze et al., 2021; Stanney et al., 2022). An electronic casualty card represents a near-term technical solution, while augmented reality provides enhanced realism with the tradeoff of increased cost and less technical maturity.

The evaluation has several limitations which should be discussed. The study took place in a controlled setting within the construct of a soldier touch point. As such, the performance of the system in an unstructured training event may differ. However, since the MOUT environment and medical procedures will be the same, researchers expect similar performance overall. Additionally, the event utilized a single procedure of tourniquet application. The system will require testing with multiple, interleaved procedures. This will entail expansion of the computer vision capabilities, as well as the development of additional surrogate equipment, such as needles or pressure dressings. Both research initiatives are presently underway.

CONCLUSION

In summary, this research developed and demonstrated a feasible approach for POI care within large-scale collective training events, filling a significant capability gap. Both the surrogate tourniquet and computer vision capability performed well based on reliability and accuracy. Participant feedback was positive, suggesting the user population would accept and implement this capability for training at squad and above levels of training. Future research will focus on developing additional surrogate equipment, integration of an electronic casualty card, and improving the computer vision system to enable improved measures of performance. Finally, larger evaluations are needed in unstructured training environments to ensure all components work as intended when fully deployed. The POI training capability has significant potential to improve casualty response, unit readiness, and ultimately patient outcomes.

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