Implementation of a Proof-of-Concept Virtual Reality Medical Simulation Training Capability for USAF Pararescuemen

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ABSTRACT

High-fidelity medical simulation training is one of the few evidence-based interventions demonstrated to reduce medical errors and improve trainee readiness for medical techniques, tactics, and procedures. Additionally, simulation training provides a realistic setting to assess student skills. Debrief sessions immediately after a simulation exercise also allow timely feedback to teach gaps in knowledge and reinforce correct behaviors. In this research, we report our preliminary investigation into the adaptation of a commercially available civilian virtual reality (VR) medical simulation training platform for use in a novel curriculum for United States Air Force (USAF) Pararescuemen (PJs).

An interprofessional clinical educator working group was formed, consisting of the Principal Investigator, emergency physicians, emergency medical technicians, emergency physician assistants, registered nurses, USAF Pararescuemen, and a USAF Pararescue Medical Director, which collaborated on the specification phase of the project. In the specification phase, the learner population was identified, a scenario and environmental overview were created, and specific learning goals were identified, with cross-references to appropriate tactics, techniques, and protocols (TTPs). The scenarios were then implemented and evaluated during training exercises by the PJs and Combat Controllers at Hurlburt Field AFB.

The developed curriculum included the following scenarios: chest pain, airway burn, anaphylaxis, asthma exacerbation, blast injury, blunt trauma, heat stroke, helicopter transport, high altitude pulmonary edema, pediatric abdominal pain, and penetrating trauma. Various virtual environments were also developed, such as the interior of HH-60 and the urban battlefield. These scenarios underwent initial testing and evaluation during PJ training exercises and were well received by students and faculty as a useful addition to provide realistic field simulation and assessment. Based on this result, an expanded capability is currently being developed and evaluated.

ABOUT THE AUTHORS

Jennifer Polson PhD serves as a program manager for the research and development team at SimX. She is responsible for assisting in the operations of SimX's research & development efforts. She has supported numerous DOD-supported research projects at SimX and has authored or co-authored several academic works.

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Talia L. Weiss directs SimX's scenario and training production program, overseeing the company's production pipeline with more than 150 scenarios. She has managed multiple platform enhancement and new curriculum projects, including nursing, TCCC, and aeromedical transport. Talia has experience in medical visualization, digital media, and healthcare management consulting, and served as the manager of the Stanford Virtual Human Interaction Lab.

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Ryan J. Ribeira MD MPH is the founder and Chief Executive Officer of SimX, Inc. Under his leadership, SimX has attained the market-leading position in professional-grade virtual reality medical simulation training and become the standard for VR simulation at a variety of prestigious institutions in the United States and around the world. He is a sought-after speaker on medical simulation, and has spoken at TechCrunch Disrupt, the International Meeting on Simulation in Healthcare, the Tech+ Forum, and many more.

Karthik V. Sarma PhD, is co-founder and Chief Technology Officer of SimX and Principal Investigator of the Virtual Advancement of Learning for Operational Readiness program. Karthik has led the development of the SimX platform since co-founding the company in 2014 and is a leading expert in virtual reality training and simulation. In addition to receiving multiple awards and authoring peer-reviewed works, he has been the recipient of grants to support his research efforts, including ten Phase II Small Business Innovation Research (SBIR) grants.

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INTRODUCTION

As training methodologies, peer pressures, and multi-domain combat operations change and evolve, so must the technologies, tools, and curriculum by which trainees are taught, tested, and evaluated. In the face of such a change, efforts to achieve standards such as the “Golden Hour” (the doctrinal requirement to provide definitive care within 60 minutes of sustaining traumatic injuries) become overwhelming and nearly impossible to achieve (Keenan & Riesberg, 2017; Riesberg et al., 2017).

Training needs for medical personnel require readiness in myriad operational and medical situations. At the fundamental level, US warfighters with medical training learn the Clinical Guidelines for Tactical Combat Casualty Care (TCCC) (Butler, 2010). These publicly available guidelines, developed by the Joint Trauma System of the United States Defense Health Agency, detail evidence-based practices for several phases of combat trauma: fire care (CUF), tactical field care (TFC), and tactical evacuation care (TACEVAC). TCCC serves as the base for the United States and several Partner Nation operational medical training regimens. Beyond TCCC, military providers are expected to retain knowledge, skills, and abilities (KSA) for these phases of care and additional operational variations, such as prolonged casualty care (PCC), small unit care (SUC) for deployed servicemembers, veterinary care for military working dogs and other service animals, and medical response to chemical, biological, radiological, nuclear and high explosives emergencies (Nemeth et al., 2021).

Maintaining operational readiness is becoming increasingly crucial across NATO forces, requiring fast, effective training, and sustainment of operational medical KSAs (Scalese et al., 2022). However, simultaneously, the ongoing drawdown in major combat operations reduces the contribution of practical deployed experience to maintaining readiness in these KSAs, and alternative civilian assignments often do not expose medical warfighters to the full scope of practice that they must fulfill when deployed. Current medical simulation training (MST) regimens are reliant on high-fidelity manikins and field exercises, the cost and logistical complexity of which preclude frequent and repeated training opportunities. There is an operational medical need to provide accessible, immersive training and skill sustainment for warfighters (Remick et al., 2021; Zahiri et al., 2018).

Virtual reality MST (VR-MST) is not new in the current technological climate, but recent advances in virtual reality technologies have the potential to expand the combat capabilities of NATO nations, reduce casualty counts, and improve training for combat forces (Feron & Hofmann, 2012; Planchon et al., 2018). Since its inception in 2020, the Virtual Advancement of Learning for Operational Readiness (VALOR) program R&D program has used these recent technological advances to improve military MST. This work specifically sought to answer the following questions: (1) What are the current capability gaps of military MST, and (2) Can mission-ready multi-role TCCC medical simulation training be achieved using VR with virtual telepresence for distributed teams? First, we describe the methodological approach used for adaptation identification, development, and refinement. Then we describe the identified capability gaps and proposed adaptations.

Virtual Advancement of Learning for Operational Readiness (VALOR) Program

The VALOR program, funded and led by the United States Air Force, has the mission of increasing combat readiness across multi-domain operations. The main objectives of the VALOR program are to improve realism, increase flexibility, and reduce the cost of operational medical training for elite military personnel (Bruppacher et al., 2010; Cohen et al., 2010; Kizakevich et al., 2006). The VALOR effort provides VR-MST capabilities that cover techniques, tactics, and protocols (TTPs) in the care phases of TCCC and beyond.

The VALOR program represents a partnership between SimX, Inc. and USAF stakeholders. The team utilized a user-centric, agile framework that requires a balance of two principles: prioritizing user needs along every facet of development and working just in time to meet needs flexibly and expeditiously (Brhel et al., 2015). A common approach among software development teams, this process integrates ideation/discovery and implementation into a centralized process (Dhandapani, 2016). Based on current military MSD paradigms, we chose to emphasize heavy collaborator input during the needs analysis, capability ideation, design, and implementation phases of the VALOR platform creation.

VALOR's core research and development team comprises subject matter experts, VR engineers, technical artists, and research scientists. The VALOR leadership team includes practicing clinicians with backgrounds in medical simulation, military medicine, and emergency medicine, and medical professionals are embedded in every core function of VALOR development. In addition to serving as subject matter experts on the medical oversight board, doctors, medics, nurses, and other allied health professionals play key roles in the design, production, testing, and deployment processes. This clinical presence enables rapid iterative feedback from those with practical experience in medical simulation for specific military use.

METHODS

Following the user-centric approach, the team maintained continuous engagement of the end users and stakeholders from inception. Engagement involved launch meetings including live demonstrations of the VALOR prototype platform and simulation scenarios. During these demonstrations, stakeholders participated in the simulations as both trainees and moderators, allowing them to experience the VALOR platform and evaluate recently implemented adaptations. The meetings then proceeded with discussions of initial strategic directions and operational milestones. Engagement was maintained through regular in-person site visits and virtual teleconferences, during which the R&D team sought feedback about new functionality and capabilities of the VALOR platform.

Needs and Gap Analysis for Current Military MST

In the first stage of the analysis, we sought to identify current military MST needs and gaps through partnerships with current military service members. Military trainees and simulation educators were asked to participate in survey interviews and focus groups, depending on their availability. The survey questions were based on the literature detailing the military MST modalities for team-based training and iterated throughout the interview process (Sattler et al., 2020; Stathakarou et al., 2021). During the survey interviews, participants were asked to reflect on their experiences in simulation training as a trainee and, if applicable, as a moderator, educator, or assessor. Trainee participants were asked about the medical training they had received and the role of MST in their training and support activities. Regarding MST specifically, they were asked about which modalities they used for simulation and how frequently they used MST during both initial training and sustainment. For each MST modality, participants were asked about the usability, accessibility, and immersion of the training approach. Finally, participants were asked about the challenges faced during training and support for military MST. Military medical simulation subject matter experts (SMEs) involved in creating and administering medical MST curricula were also interviewed regarding current training routines and challenges. In particular, SMEs were asked about the learning objectives of current training courses and curricula and how they were currently addressed with MST modalities. Participants were asked to reflect on challenges with current MST modalities in their courses, with particular focus on the ability to perform team-based MST across multiple roles of care. Finally, SMEs were asked to reflect on the ability of current MST modalities to meet their learners' training goals and any particular benefits and challenges of each as a standalone instrument.

VR-MST Capability Mapping and Feasibility Assessment

The second stage of this study involved determining the capabilities of the VR-MST in question and analyzing the feasibility of addressing the needs currently unmet by the military MST. Research efforts began with the current capabilities of the commercially available Virtual Reality Medical Simulation System (VRMSS, SimX, Inc.). An interdisciplinary team of internal and military SMEs collaborated to map the needs identified from the gap analysis to these capabilities, when possible. Finally, the R&D team worked with end-user SMEs to develop a set of feasible and prioritized adaptations for VR-MST to meet these needs. Discussions centered on the following questions: (1) Which specific training requirements would most benefit from a VR medical simulation solution?; (2) What mission-appropriate platforms should be supported to meet training goals?; (3) Which sets, kits and outfits have the most training value and usage?; and (4) What techniques, tactics, and protocols for medical emergencies should be included in a comprehensive simulation training capability?

Design and Implementation

To build and implement the curriculum and functionalities of the VALOR platform, the team followed an iterative build, measure, and learn approach. The core research team solicited feedback from military stakeholders before, during, and after the implementation process to gain a full understanding of the needs of those who would most benefit from the proposed capability. The creation of each new feature or scenario involved four phases: design, development, internal testing, and external refinement. The process for simulation scenario creation was as follows: During the design phase, the military stakeholder generated a high-level case concept that broadly defines the case and the educational learning goals. From this concept of the case, a medical SME worked with the end-user stakeholder to develop the case specification, which outlined the flow of the case, characters, tools, and environments. The end-user stakeholders gave their input on the learning objectives and concepts covered, as well as the critical actions required by the trainee. Once the case specification was approved, the research team generated asset reference documentation for any new visual, auditory, and procedural developments required for the scenario. The scenario then entered the development phase, during which assets were created and case engineering documentation was finalized. The case engineering documentation provided the basis from which the VRMSS platform generates the scenario. Once the initial scenario was completed, the case entered the internal testing phase, which involved testing by VR production specialists for visual quality assurance, medical SME testing for medical accuracy, and final integration testing. When a scenario completed all three rounds of testing, it was subjected to external testing and refinement, during which feedback was collected regarding the fidelity of the scenarios to the guidelines of clinical practice and the realities of operational deployment. The VALOR design process with end-user engagement is summarized in Figure 1.

Figure 1: VALOR Scenario Creation Process. Red boxes indicate input received from end-user stakeholders.

FINDINGS

Military MST Needs and Gaps

Thematic synthesis of initial military stakeholder interviews indicated that there were three primary capability gaps for military MST: immersion, flexibility, and cost. Accordingly, qualitative analysis revealed several axes of functionality currently missing from military MST paradigms: portability, assessment/readiness tracking, multi-team training, simulation customization, and operational realism. These functional axes were validated from civilian surveys and from the literature. The feasibility analysis of VR-MST identified key adaptations within each axis that were then designed and implemented for deployment on the VALOR platform, which are detailed below.

Operational Realism

The VALOR program's virtual scenarios are intended to allow learners to "train how they fight," not only with the actions and movements of scenarios but also with the psychoenvironmental realism of military environments essential to warfighter training. In order to accomplish this goal, end users require a wide array of scenarios in order to enable MST-VR training that is as broad as high-fidelity manikin simulation training. Consequently, the full curriculum of the program covers TCCC clinical practice guidelines, TCCC-directed training for pararescue, PCC, SUC, mandatory certifications (CERT) and other essential operational medical curricula. Table 1 provides a summary of the cases included in the current and future VALOR deployment. The VALOR program includes a broad range of diverse simulated environments, patients, sets, kits, outfits, and tools necessary to increase immersion and enrich the VR learning experience. To enable this broad set of use cases, a modular platform design was adopted, which enables the use of these virtual assets for the creation of additional simulation content. Additionally, end-user SMEs led to the development of an integrated Battlefield-assisted trauma distributed observation kit (BATDOK) simulator. This simulator allows learners to perform vital sign monitoring, documentation, and hand-off with the same workflow as the live BATDOK capability. This allows trainees to train with more realism and to reinforce key competencies related to documentation with the newly introduced requirement.

Table 1. Description of the VALOR Curricula. Each case covered in the initial and forthcoming VALOR deployments, including the phase of care covered and the number of patients

Status	Phase	Case Name	Number of Patients
Deployed	CBRN	Environment Safety	1
	CBRN	Organophosphate Toxicity	1
	PCC	Airway Burn	1
	PCC	Tanker Rescue	2
	PCC	Transport Pneumothorax	1
	PCC	Ventilator Management	1
	SUC	Anaphylaxis	1
	SUC	Asthma	1
	SUC	Back Pain	1
	SUC	Cellulitis vs. Abscess	1
	SUC	Chest Pain	1
	SUC	Concussion	1
	SUC	Dive Medicine - Arterial Gas Embolism (AGE)	1
	SUC	HAPE/HACE	1
	SUC	Headache	1
	SUC	Heat Stroke	1
	SUC	Pediatric Abdominal Pain	1
	SUC	Seizure	1
	TCCC	Blast Injury	1
	TCCC	Blunt Trauma	1
	TCCC	Dual Patient	2
	TCCC	Entrapment	2
	TCCC	Mass Casualty	6
	TCCC	Parachuting Mishap	1
	TCCC	Penetrating Trauma	1
	TCCC	Penetrating Trauma Under Fire	1
	TCCC	Severe Head Injury	1
In Progress	PCC	Transport Trauma Transload	1
	SUC	Corneal Abrasion	1

	SUC	Lateral Canthotomy	1
	SUC	Envenomation	1
	SUC	Otitis Media	1
	TCCC	Crush Injury	1
	TCCC	Hypothermia	1
	TCCC	Multi-Role Combat Casualty Care	1
	TCCC	Multi-System Trauma Evisceration	1
	TCCC	Virtual Manikin†	3
	CERT	Adult Megacode	1
	CERT	Pediatric Megacode	1

DISCUSSION

Our work seeks to identify the capability gaps in current routines for military MST, to determine the appropriateness of VR as a modality to address these needs, and to develop adaptations to existing VR-MST capabilities to bridge the gaps. Engagement with end users and other stakeholders revealed crucial gaps in military MST that were proved addressable using VR-MST. The VALOR team synthesized these findings into strategic developmental adaptations that would meet these needs alongside improvements to the VALOR platform as a VR-MST modality.

The VALOR program has been built off the commercial VRMSS (SimX, Inc.) and has adapted additional functionality to address current operational training gaps within the Air Force and Department of Defense. Adaptations completed include functions to support tracking & evaluation, multi-team training, integration with military documentation systems, and customizability, as well as assets and curriculum spanning TCCC CPGs, SUC, chemical, biological, radiological, nuclear, and high explosives (CBRNE) medical emergencies, and more. These developments were designed to enhance the platform and expand the training capabilities of the VALOR platform.

Limitations of Current VR-MST Capabilities

In addition to the capability gaps identified above, several instances were identified in which VR-MST may not be a suitable training modality given current technological capabilities. For example, procedural training of fine motor skills, such as suture techniques, may not be readily learned or assessed in VR with current commercially available setups, as their technical capabilities do not support fine motor control or tracking. Currently, most commercial setups require holding controllers so that the headset can track the movement of your hands. These are often hand-held, precluding the use of fine motor skills in VR and limiting the ability to perform certain physical maneuvers (such as chest compressions or Leopold maneuvers). Current research in VR technology that may enable these kinds of functions in the future. One such research area is controller-free hand tracking, which utilizes computer vision software to track the relative position and pose of the hands without the use of controllers (Masurovsky et al., 2020; Scheggi et al., 2015). This capability remains nascent and would require substantial validation before use in medical simulation modalities. Moreover, a controller-free VR experience would not be able to provide haptic feedback without the use of additional props or physical tools. Another such area is portable haptic technology, such as smart gloves with the ability to provide fine motor tracking and localized haptic feedback to both hands and fingers (Zhu et al., 2020). Some preliminary studies have demonstrated the potential utility of fine motor haptic feedback for procedural training (Proctor & Campbell-Wynn, 2014), although these required wired gloves that hinder training flexibility and immersion. Several recent untethered products have been developed and are in prototype testing for medical simulation applications; these are still in the early stages and have not been evaluated on a broad scale for usability or efficacy (Hanzaki & Boulanger, 2020; Li et al., 2022; Varun et al., 2019).

CONCLUSION

This ongoing work has illustrated that VR-MST can address military simulation training gaps in realism, accessibility, and cost. The VALOR platform represents the first substantial operational reduction in the practice of military VR-MST in several care roles, with several dozen installations currently operational. Additional prospective evaluations of the efficacy and acceptability of VALOR capabilities are currently underway, including the development of a randomized controlled trial of efficacy. Future adaptations include the development of curricula supporting aeromedical evacuation, advanced resuscitative care, prehospital transport/ Emergency Medical Technicians - Paramedic (EMT-P) certification, and CBRNE simulation training. These curricula will expand the scope of TCCC training capabilities and additional KSAs required for medical readiness.

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