

Usability Assessment of an Augmented Reality Application for Procedural Guidance on Cricothyrotomy and Thoracostomy

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Abstract

Previous studies have shown that the use of clinical decision support systems can help clinicians perform tasks beyond their usual scope of practice. The Augmented Reality Surgical Assist Manager (ARSAM) was developed to assist combat medics with emergency surgical interventions, such as the Cricothyrotomy (Cric) and Chest Tube (CT) insertion. Using mixed reality technology combined with instructional text, pictures, videos, and holographic overlays, ARSAM enhances the ability of medical personnel to perform surgical procedures. This manuscript presents results of a study conducted to evaluate ARSAM's overall usability in a simulated environment for two lifesaving surgical interventions, Cric and CT insertion. ARSAM was designed and tested using the Microsoft® HoloLens 2™ platform. Clinical content was created using various military resources, which were reviewed by medical subject matter experts. Participants were recruited from the staff working within our medical center. No medical experience was required. Following training, participants were asked to perform simulated Cric and CT procedures using ARSAM. Notes and videos were taken throughout the procedures. Participants completed a System Usability Scale (SUS) survey and a custom Participant Usability Survey following each procedure. After both tasks were performed, a Post-Simulation Survey was completed, and responses were used to guide after-action discussion. ARSAM achieved mean overall SUS scores of 74.5/100 on Cric and 79/100 on CT insertion, indicating strong usability. Participants reported that ARSAM contained accurate medical information, however, 9 aspects of the software potentially needed improvement. Concerns centered around unfamiliarity with the system, potential crashes or system instability, and difficulty with voice recognition in noisy environments. Our study demonstrates the potential for ARSAM to improve performance in two emergency interventions. Although users found the clinical decision support software to be acceptable in its current state, feedback was obtained to increase usability and likelihood of adoption.

Keywords: Mixed reality; Decision support; Thoracostomy; Cricothyrotomy; Surgical guidance

Abbreviations: AR: Augmented Reality, ARSAM: Augmented Reality Surgical Assist Manager, CDSS: Clinical Decision Support Systems, CT: Chest Tube, Cric: Cricothyroidotomy, LSCO: Large Scale Combat Operations, SUS: System Usability Scale

Introduction

Successful management of the airway is vital for trauma patients, as failed treatment can result in severe hypoxia, hypotension, aspiration, or cardiac arrest [1]. This is evident in a study of battlefield deaths that reported, following haemorrhage, airway obstruction and tension pneumothorax were the next most common focuses of potentially survivable deaths [2]. Clinicians caring for patients with airway and chest injuries have several lifesaving interventions available for treating these types of conditions, including Cricothyroidotomy (Cric), needle decompression and Chest Tube (CT) insertion. While Crics are within the scope of practice for some prehospital professionals, it is a high acuity, low occurrence procedure

for which many are not comfortable performing [3]. In the civilian sector, surgical airway is seen as a last-ditch effort and is done only when other methods of securing a patient's airway are unsuccessful. Similarly, CT insertions are not typically performed by emergency medical technicians, medics, or paramedics. Current guidance for the battlefield treatment of tension pneumothorax includes up to two rounds of needle decompression [4]. If unsuccessful, medics are trained to proceed to management of circulation. The complication rate for trauma-related CT insertion averages 19%, which may be a reason for limiting the procedure to advanced providers [5]. Insertion is typically performed in the emergency room by physicians; however, other clinicians such as paramedics and nurses with advanced training can sometimes perform the procedure if warranted by patient condition and setting. This leaves to question how teams can safely care for patients with airway or chest trauma when advanced providers are unavailable for extended periods.

When a physician is not available in-person, telemedicine has been utilized to assist clinicians in caring for complex, critical patients. Telemedicine or telehealth, refers to the use of technology to deliver health services from a distance [6]. While this capability has emerged as a valuable resource, it is not always available in remote locations where network connectivity may be limited. Localized Clinical Decision Support Systems (CDSS) have been proposed to guide medical personnel by reducing the complexity of injury management and providing critical information in real time, without the need for an outside connection [7]. A literature review by Panicker and George evaluated adoption of CDSS in numerous use cases, including reducing prescription errors by general practitioners [8,9], improving management of antibiotics and genome-guided prescriptions [10,11], prompting physicians of the need for immunizations [12], and management of patients with diabetes [13]. Most CDSS have been developed to integrate with familiar interfaces, such as a patient health dashboard or web/mobile application [14,15]. However, these interfaces require physical inputs from the user via touchscreen or keyboard to interact with the system. In contrast, Augmented Reality (AR) systems overlay virtual content onto a user's real-world view through glasses or other heads-up displays, allowing users to receive hands-free information [16]. Overlay can include text or images, which may float in the air or overlay onto patients and equipment. AR applications are currently being used for medical training, surgical assistance, and patient monitoring and can be delivered via head-mounted displays or other mobile devices for untethered, remote use [17-19]. Research shows AR increases performance accuracy and reduces cognitive burden when used for medical training and surgical assistance [20,21].

Use of CDSS in the military will need to support Large Scale Combat Operations (LSCO) that will be resource-limited and access to communications networks will be denied due to electronic warfare, such as signal jamming [22-24]. Additionally, it is anticipated that the number of military surgeons will be inadequate to care for the number of anticipated casualties [25]. Consequently, clinicians will be forced to provide care and critical interventions

beyond their normal scope of practice or expertise. While network disruptions preclude the use of telehealth, self-contained CDSS could mitigate this issue by providing users with embedded guidance materials, including written and visual instruction. Voice- and gesture-controlled AR CDSS could provide robustness in these environments, along with a host of other benefits such as sterile field maintenance, step-by-step guidance in text and video formats, and holographic visualizations directly onto casualties.

We hypothesize that AR-based CDSS can help novice clinicians perform tasks beyond their usual scope of practice, helping them to meet the challenges of an austere environment. The Augmented Reality Surgical Assist Manager (ARSAM) was developed to assist combat medics with emergency surgical interventions, such as Cric and CT insertion, which are commonly performed due to airway and chest trauma. ARSAM utilizes instructional text, pictures, videos, and holographic overlays to aid medical personnel in performing surgical procedures. Instructions are simplified from what would normally be provided in medical literature and clinical practice guidelines, and users are allowed to move backwards or forwards through the steps of each intervention using hand gestures or voice commands. While ARSAM was developed with combat medics in mind, the application could also be used by civilian personnel in rural or remote environments or in mass casualty environments where there are more patients than skilled providers. If ARSAM is to be adopted and fielded for high-stakes critical care scenarios, it must meet a high standard for usability and performance. The purpose of this paper is to present the results of a study conducted to evaluate ARSAM's overall usability in the simulation of two lifesaving surgical interventions: Cric and CT insertion.

Materials and Methods

Regulatory approval and standards

This research study was conducted under a protocol (M-11021), approved by the headquarters' Institutional Review Board.

Inclusion/exclusion criteria

The study sought to evaluate the design and functionality of our clinical decision support software, which was intended for clinicians with limited experience. For this reason, participants were recruited from the staff working at our medical center, however, no medical experience was required to participate. It was anticipated that a mixed volunteer population would optimize feedback by collecting both clinical content and interface design feedback. Participants had to be at least 18 years of age and willing to dedicate up to four continuous hours to training, simulation, and providing feedback.

Materials

ARSAM was developed and tested on the Microsoft® HoloLens 2™ (Redmond, CA) mixed reality system. The system consists of an untethered, hands-free, head-mounted display that is controlled through voice or hand gestures. Clinical content was created using military training resources, skill checklists, and clinical practice guidelines, and was reviewed by medical subject matter experts

within the organization. Instructions and graphics were developed using Unity® with the Mixed Reality Tool-Kit (MRTK). Unity® projects were deployed to the HoloLens 2™ through Visual Studio. The Laerdal SimMan® 3G (Wappingers Falls, NY) and SynDaver® Adult Cric Trainer (Tampa, FL) were used for performing surgical simulations. Slight modification were made to the manikin and trainer to allow for all steps in the procedures to be completed.

Application design

The software was designed as a stand-alone, executable application for the Microsoft® HoloLens 2™ using the Unity™ platform. The main menu consisted of virtual buttons that allowed users to select the surgical procedure for which they needed assistance. After selection, a holographic phantom appeared in

the users' visual field, either a head (for Cric) or a chest cavity (for CT), depending on the procedure selected. Users had to manually overlay the phantom onto the applicable manikin (Figure 1). This step was critical to ensuring that instructional holograms appeared in the correct locations during procedures. For usability evaluation, a member of the research team placed the phantoms prior to handing the headsets off to participants. Within each sub-application, there were two main screens: one with contextual instructions and a second (when applicable) with either a video or image. Interactive buttons with "next" and "back" were displayed below the instructional screen to assist users in advancing to the next steps or going back to previous steps. These buttons could be selected or spoken. Some steps included additional holographic overlays on the surface of the patient manikin.



Figure 1: Manual placement of the phantom figures (left: head for cricothyrotomy procedure, middle: chest for chest tube insertion) over the manikin so that instructional holograms appear in the correct place (right: thoracostomy cut line).

Study design

Participants were oriented to the AR device using an embedded training application, which was designed to look and operate the same as the surgical application being tested. Using the headset, they were provided written instructions and pictures or short video clips which demonstrated how to operate the device and software. Instructions were followed by a series of practice exercises. Participants were also given a brief questionnaire to complete which captured demographics and experience. After training, participants were asked to perform two manikin-simulated procedures: Cric and CT insertion. Both procedures were performed using the ARSAM software, however, some participants also completed the procedures using non-AR tools, if they wanted and if time allowed. To assist participants with non-AR tasks, the Deployed Medicine [26] application library was available via tablet. This military medical reference tool contained both clinical practice guidelines and videos. Since the study aimed to evaluate usability of the software, we did not need comparison data between modalities. However, having a few participants complete the procedures using both AR and non-AR allowed us to prepare for performance testing that would take place after usability testing and software updates were complete. Notes and videos were taken by the research team throughout all AR and non-AR procedures to record observations,

participant reactions, and problems that were encountered. For safety, participants could skip steps they did not feel comfortable performing, such as those involving the use of sharps.

Following each AR-assisted procedure, participants completed a System Usability Scale (SUS) survey and a custom Participant Usability Survey. The SUS is a validated, ten-item Likert questionnaire with positively and negatively worded questions to quickly assess usability of a system [27]. A SUS score above 68 (range 1-100) implies acceptable software usability. The Participant Usability Survey consisted of 57 questions for each AR procedure. Questions were developed around 9 usability heuristics adapted from Jakob Nielsen's usability design principles [28]: Help/documentation, feedback, satisfaction, integrating physical and virtual worlds, user interactions, consistency, recognition, cognitive overload, and comfort. After both simulation tasks were performed, participants completed a Post-Simulation Survey. This survey was developed by the research team and gathered data on each participant's previous experience with the procedures, overall study experience, and opinions regarding how the technology might be used. Survey responses were used to guide an after-action discussion on more granular aspects of the surgical tasks, AR software, hardware, and overall study experience. Figure 2 shows the complete study design, including procedures and survey instruments.

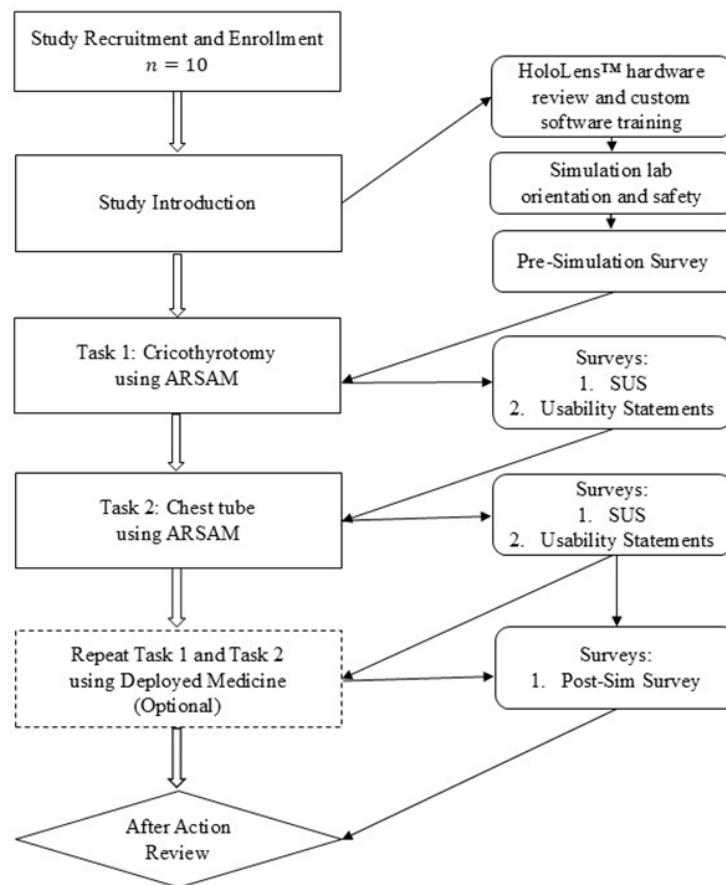


Figure 2: Study design flow.

Usability analysis

Data gathered in this study were used to provide a quantitative analysis of the ARSAM software for the two surgical tasks. Survey data using continuous variables are expressed as mean \pm standard deviation. Analysis was completed using JMP®, Version 16 (SAS Institute Inc., Cary, NC). Usability heuristic data from the Participant Usability Survey were analyzed to identify areas of consensus and improvement needs. “Strong” consensus, where the percentage of agreement was 60-100% for positively worded statements, required no additional evaluation for software improvement. Statements with very low consensus (0%-40% agreement) were prioritized areas for improvement. For negatively worded statements, “strong” consensus identified areas that did require improvement. For mixed consensus (40-60% agreement), we recorded those statements for further evaluation by the research team.

Results and Discussion

Ten participants were recruited and enrolled in the study, consisting of 6 females and 4 males with an average age of 40.8 years. The majority (n=8) were familiar with or had knowledge of augmented reality devices. While most (n=7) had never used the Microsoft® HoloLens 2™, half of the participants had used some

other head-mounted display device (such as another augmented, mixed, or virtual reality device) (Table 1).

Table 1: Participant demographics.

Demographics Table		
Average Age:	40.8 (27-58)	
Gender:	Male: 40%	Female: 60%
Race:	White: 80%	Multi: 20%
Ethnicity:	Hispanic: 60%	Non-Hispanic: 40%
Familiar with AR:	Yes: 80%	No: 20%
Previous HL Use:	Yes: 30%	No: 70%
Previous HMD Use:	Yes: 50%	No: 50%

From the SUS survey, the lowest-rated positive statement concerned participant confidence using the ARSAM software (Cric=3.7 \pm 1.2, CT=4.1 \pm 0.7) (Table 2). The highest-rated negative statement indicated that participants needed assistance when using the app (Cric=3.5 \pm 1.1, CT=2.9 \pm 1.4). Overall, SUS scores demonstrated ARSAM was a usable application for guiding inexperienced clinicians in performing a Cric or CT insertion procedure (Cric=74.5 \pm 15.1, CT=79.0 \pm 15.7).

Table 2: System usability survey results.

SUS Questions	Cricothyrotomy (mean±std)	Chest Tube (mean±std)
I think that I would like to use this application frequently	4.3±0.8	4.4±0.7
I found this application unnecessarily complex	1.5±0.5	1.6±1.0
I thought this application was easy to use	3.9±0.9	4.1±1.1
I think that I would need assistance to be able to use this application	3.5±1.1	2.9±1.4
I found the various functions in this application were well integrated	4.4±0.5	4.3±0.7
I thought there was too much inconsistency in this application	1.2±0.4	1.5±0.5
I would imagine that most people would learn to use this application very quickly	4.2±0.9	4.7±0.5
I found this application very cumbersome/awkward to use	1.9±0.9	1.8±0.6
I felt very confident using this application	3.7±1.2	4.1±0.7
I needed to learn a lot of things before I could get going with this application	2.6±1.6	2.0±1.3
Total SUS Score	74.5±15.1	79.0±15.7

SUS=System Usability Scale

SUS scores were compared to the standard passable score [68].

(note: SUS questions used Likert scale, 1 thru 5)

Of the 57 statements analyzed from the Participant Usability Survey, mixed agreement was found amongst participants on 9 statements, indicating areas of the software that could be improved (Table 3). These statements fell under the heuristic principles of feedback, integration of physical and virtual worlds, user interactions, consistency, recognition rather than recall, and cognitive overload. Feedback, user interactions, and consistency had the most statements that needed to be addressed (n=2). We compiled both heuristics survey data and after-action review notes to determine specific areas of software changes for each heuristic principle (Supplemental Data Table 1). After-action

discussion topics centered around encountered problems with the software, concerns and frustrations, areas for improvement, clinical value, enjoyment, and side effects (Supplemental Data Table 2). Problems that were encountered included application closure during a procedure, difficulty with voice recognition and gesturing or manipulation of screens. While most participants responded that instructions were understandable, some requested improved resolution of the videos. Several also stated they would prefer instructions be broken into smaller steps, reducing the volume of words and information being displayed at once.

Table 3: Participant usability survey results.

Principles (n, statements per principle)	Cricothyrotomy		Chest Tube	
	n, Statements that need to be addressed based on mixed disagreement	n, Statements that need to be addressed based on strong disagreement	n, Statements that need to be addressed based on mixed disagreement	n, Statements that need to be addressed based on strong disagreement
Help/Documentation (3)	0	0	0	0
Feedback (2)	1	0	1	0
Satisfaction (8)	0	0	0	0
Integration of Physical and Virtual Worlds (6)	1	0	0	0
User Interactions (8)	2	0	0	0
Consistency and Standards (6)	1	0	1	0
Recognition rather than recall (5)	1	0	0	0
Cognitive Overload (11)	1	0	0	0
Comfort (8)	0	0	0	0
TOTAL (n = 57)	7	0	2	0

Compilation	
Cricothyrotomy Principle and Statements that need to be addressed	Chest Tube Principle and Statements that need to be addressed
Feedback: Was the system status visible? (battery life)	Feedback: Was the system status visible? (battery life)
Integration: Were the holographic/3D objects overlaid appropriately on the simulator?	Consistency and Standards: Did you find yourself making mistakes when using the application?
User Interactions: For steps that had virtual holographic overlays, did you notice them?	
User Interactions: Did you utilize the virtual holographic overlays to assist you in that step?	
Consistency and Standards: **Did you find yourself making mistakes when using the application?	
Recognition rather than recall: Does the application avoid large amounts of memorization in order to complete the tasks?	
Cognitive Overload: Does the application avoid clutter? (e.g. avoid large amounts of text, too many pictures or videos)	

Mixed response=Statements where 60%-40% of the respondents did not agree with the statement

Strong disagreement=Statements where more than 60% of the respondents did not agree with the statement

**Questions that were worded in the opposite/negative tone were analyzed in reverse.

Supplemental Data Table 1: Software change list based on users' heuristic feedback.

CRIC	
Feedback:	Change application status updates by adding step numbers Add step numbers (X of XX) Add purpose title
Integration	Improve holographic overlay precision (over task trainer) Add fiduciary markers for overlay placement Change simulator setup to ensure stability (low table) Disable voice read-aloud
User Interactions	Improve holographic overlay for noticeability Improve visibility of holographic cut lines Adjust opacity of cut lines Enlarge button icons Enlarge check boxes
Consistency and Standards	Enlarge button icons Enlarge check boxes Add icons to notify user if additional instructions are available in visual field (video, picture, or hologram)

<p>Recognition rather than recall</p>	<p>Break down the steps: Step 1: Change “BVM” to “Ambu bag” Change “fixation device” to “Ties or fixation device” Remove “Don gloves” from step 1, create new step 2 Step 2: Remake video on darker background to improve visibility Step 5: Change video to improve anatomical view of larynx Add a hologram Step 6: Change picture, format of step 1. “Prep area with alcohol wipes” 2. “Stabilize larynx by applying slight downward pressure. Avoid pressing lateral structures such as jugular veins” Step 7: Remove existing hologram, only have box with cut lines “Make a 1-inch vertical incision into the skin over the cricothyroid membrane area. Leave your scalpel in place to maintain incision opening.” Step 8: Reword. “Separate skin to expose the membrane. Make a horizontal cut across the cricothyroid membrane. Insert trach hook towards the patient’s shoulder then rotate hook towards the legs. Remove scalpel.” The video should be cut in half with holograms to correspond with each step. Add additional step: “Insert bougie into the trachea. You may feel the tracheal rings as you advance into the airway. Absence of tactile feedback does not mean incorrect placement.” “Remove tracheal hook and slide the cannula tube down the bougie, into the airway.” Step 10: Reformat Step 12: Add larger boxes Step 13: Needs major formatting</p>
<p>Cognitive Overload</p>	<p>Add additional slide and improve media</p>
<p>Chest Tube</p>	
<p>Feedback</p>	<p>Add step numbers (X of XX)</p>
<p>Consistency and Standards</p>	<p>Duplicate CRIC format changes</p>

<p>Recognition rather than recall</p>	<p>Break down the steps:</p> <p>Step 2: Review sources/CPGs for language about arm positioning.</p> <p>Step 4: Format text</p> <p>Add "Look down at the patient for the holographic locator"</p> <p>Step 5: "Prep the anterior and lateral chest of the affected side with chlorhexidine or iodine swab"</p> <p>Step 6: Format change – reference the Deployed Medicine app</p> <p>"Load 10mL of 2% lidocaine into a syringe"</p> <p>Add a next step- "Numb the area by injecting the tip of the needle into subcutaneous tissue. Inject a small amount multiple times without pulling out the needle. Push deeper into the surrounding areas. Aspirate to avoiding intravascular injection"</p> <p>Step 7: Add cue to look down at the holographic incision site</p> <p>Step 8: Add video</p> <p>Step 9: Reformat video</p> <p>Step 11: Reformat the text to reduce reading</p> <p>Step 14: Replace graphic of how to tape sutures to the tube</p> <p>Video is not complete–need to have video or pictures of the suture procedure</p> <p>Step 15: Need a new video of cutting the chest seal and wrapping it around the tube</p> <p>Step 16: Need new pictures with close-up and distance showing how to secure tube</p> <p>Step 17: Edit the video for necessary steps</p>
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All participants were pleased with taking part in the study and felt they learned something, whether it be about the procedures or the technology. However, participants were split about the ideal use for ARSAM. Some felt it was optimal for real-time decision support, while others saw it being used for training. Concerns regarding real-time use centered around unfamiliarity with the system, potential crashes or system instability, and difficulty with voice recognition in noisy environments. No cyber sickness or other side effects were reported among the 10 ARSAM users who participated in this study (Supplemental Data Table 2). This study evaluated the usability of ARSAM, a prototype AR CDSS for guiding novice users through two high-acuity, low-frequency trauma procedures. Despite the complexity of the tasks and the mixed levels of user

experience, SUS scores indicated that ARSAM was generally well-received, with average scores of 74.5 for Cric and 79.0 for CT- both exceeding the accepted threshold of 68 for usability. These results support the feasibility of using AR-based support tools to guide critical interventions in resource-limited or austere environments. While usability metrics were favorable, heuristic feedback and after-action reviews highlighted important areas for refinement. Specifically, reported issues related to interface interactions such as challenges with gesture and voice command recognition and application crashes, which can be critical barriers in high-stakes clinical environments. Although distrust in CDSS is generally attributed to errors in content, rigidity in systems, or alert fatigue [29], our application's challenges arose primarily

from the hardware/software interface rather than the content itself. However, improvements in content presentation were noted for software development planning to improve cognitive overload in users. Streamlined content for rapid assimilation is essential, especially under stressful conditions. Therefore, a revision of the

content delivery was essential for the next version of ARSAM. Additionally, technical instabilities, though expected in prototype systems, underscore the need for improved system robustness prior to deployment for simulated clinical performance testing.

Supplemental Data Table 2: User after action compilation.

Questions/Statements	AAR Responses
Were issues or problems encountered during the study?	<ul style="list-style-type: none"> · The instructions disappeared in the middle of the procedure. · Voice recognition · On my first use of the AR doing Cric, I didn't see any of the holograms. It wasn't until doing the chest tube when I looked further down that it popped up. Also, my hands accidentally interfered with the screen while performing the task, but we fixed that with the chest tube and a stool. · I had some trouble understanding the initial step for cric., understanding the relevant anatomy. · Figuring out what tools to use and how to use them, orient them, etc. · During instructional tutorial, the screen (video) froze due to the angle/location I moved it to. Tutorial had to be restarted. · Having control on video play. Turn off wrist menu during sim. (User wants control of video for stop, start, fast forward.) · Lack of clinical experience and experience with AR/VR was a bit intimidating. The staff put me at ease and the software further calmed me.
Simulation Instructions: Did they reflect how the procedures would be performed? Recommended changes?	<ul style="list-style-type: none"> · Yes, however the video instructions could be a little clearer. · They were very detailed. Concern is speed. In an emergency, the slower pace of step-by-step instruction might not be ideal. · The instructions were very clear. · The sim instructions were well done. The practice and explanation of the equipment & functions was helpful. Yes, they reflected the procedures performed. · I thought the instructions were clear, straight forward, and reflected the way the procedures would be performed. Except, there was one part on the chest tube when it was saying to inject lidocaine under the skin and aspirate - I had to verify it meant subcutaneously, which was a bit confusing. · I thought the chest tube instructions were clear, the CRIC instructions were unclear. · I believe they were accurate and helpful to the end user. · AR was accurate but [there were] way too many words/videos. Way too long for real-time utility. · There is confusion with voice feature (instructions read to users) and how fast individual reads. Voice makes it feel like more steps. · Great instructions, but text that takes up more than four lines of instruction could be less intimidating if broken up.
Changes to software?	<ul style="list-style-type: none"> · I would add video at the beginning of the entire procedure, non-stop, so the user can mentally prepare for what's ahead and have an understanding of what the goal is at the end. And THEN, start with the step-by-step process. · Decrease information per slide. Some instructions in the task were wordy. Also, some videos missed detail to ensure learners understood correct placement (i.e.: suturing technique for chest tube, ensuring trach membrane displayed in video) Cut down number of steps per slide. · If the user can't see an overlay on the simulator/mannequin, maybe a way to identify if the users see it is by asking if it's visible or including follow the overlay and/or a way they can bring it up if not. · Maybe move the "next" buttons. The window menu could also be moved up. Maybe provide a recommendation during training on how to setup menus with respect to a person's area of interest during training. · If fewer screens could be used (i.e. Video on instructional screen), I would only have to look at one screen <ul style="list-style-type: none"> · Bullets + Bold key words for instructions. · Difficult to see hologram overlays on Cric. · Have a virtual desk or box to put unnecessary screens (Virtual version of minimize function)

<p>Do you have concerns about use in remote locations?</p>	<ul style="list-style-type: none"> · Only the stability. If instructions disappear in a real situation, it could cause serious anxiety instead of comfort for a medic. · Software must ensure there's no space for ambiguity because there might be no one else to ask for clarification. However, a tool that can prioritize that knowledge is better than none at all, IMO. <ul style="list-style-type: none"> · Difficulty with voice recognition in loud environments. · Timing. Although AR program provided ease to perform these two tasks effectively, it still required time while the patient was decompensating. Perhaps ensuring end-users have enough time to practice procedures with AR before front line use. · The only concern I would have is if something went wrong and no additional information [was available] on what to look for or what to do should the person using the software not be clinically trained or trained to a level to handle it. <ul style="list-style-type: none"> · AR equipment failure (i.e. freezing screen) · Can be useful, but [this software] should not be used for the first time performing [live] procedures. <ul style="list-style-type: none"> · Connectivity. Recommend the list of supplies have pictures (Just pictures of the items)
<p>What did you enjoy most?</p>	<ul style="list-style-type: none"> · I think this is a great idea. It would give better hands-on training. It makes procedures easier to do in a real scenario. I'm excited to see our military use this. <ul style="list-style-type: none"> · The opportunity to play doctor. · Great visual interface with a simple non-distracting interface · I love sim! I was able to use sim in a different way than I had done before & [I] feel more confident. I enjoyed meeting the staff that is working on amazing projects/studies. I was able to see another side of AR vs. just video games. · I loved the entire thing. Performing skilled tasks, utilizing a visual/audible tool while getting to follow along in my opinion [is] the best learning tool possible. <ul style="list-style-type: none"> · I enjoyed learning and executing the physical process! It was challenging as well. Working with prompts, anatomy, tools to follow the appropriate sequence. · I did enjoy using the AR to guide me through unfamiliar procedures. I normally get nervous with procedures I am inexperienced at, but this software was really helpful. <ul style="list-style-type: none"> · Great to practice procedure. · Super interesting tech. (Top tier, 10/10 interesting) · The AR software. Exceptionally interesting, enlightening, and calming
<p>Did you experience any frustrations?</p>	<ul style="list-style-type: none"> · No, it was very informative. I learned how to use the headset with ease. Great job! · The videos did not allow for fast-forwarding or rewinding, so a lot of time was spent on waiting for video to loop back to where I need to see specific detail. <ul style="list-style-type: none"> · Voice recognition failed frequently. · As an apple product user, I'm engrained with certain functions & methods to activate them. Therefore, adjusting to new methods (such as pinching, etc.) to make functions occur was annoying, but not impossible in such little time. <ul style="list-style-type: none"> · My lack of knowledge & familiarity of the device really. · Just instructions for the Cric insertion. The first step was not clear enough to give me confidence with starting the procedure. Some of the following steps were not clear as well. I would like more confidence when making cuts and tool insertions. · I was not very good at pinching/opening my hands/fingers during the tutorial to resize/move screens. I did not practice this during the actual scenarios though because I found voice commands easier to use. <ul style="list-style-type: none"> · Tech still in development, but great potential. · No, great time. · Nothing frustrating besides my own lack of clinical knowledge.

<p>Do you see this software being of value? How do you picture it being used?</p>	<ul style="list-style-type: none"> · Yes, this could be used in training and in combat. It gives a great real-life experience. · I definitely see it as a training tool first. Again, the concern is on how fast it could convey instruction during an actual emergency. However, with adjustment, I could see real-world application. <ul style="list-style-type: none"> · High value with simulation work. · Yes, the software is helpful for large-scale readiness training events where experts are limited. I hope to see it soon, to train new providers like myself. <ul style="list-style-type: none"> · I think this has a huge value in the future in my field, especially for clinical training and refresher skill verification. Would be of huge benefit to those medics/PAs/RNs who aren't in clinical settings, also where there's no skills labs available. · Yes, could be used in deployed environments and for frontline civilians (medical and non-medical). · Absolutely perfect for training & just-in-time refresher for patient care. But [users] must have prior experience/training before relying on this assistive tech. · Yes, in the field and education (For education, put in a virtual assessment for virtual documentation, with checkmarks to show what [instructors] went over). · In combat casualty care, [this is] absolutely beneficial. For individuals who are ignorant or rusty with clinical/surgical skills, this would be paramount for effective care in the field.
<p>Did you experience any increased stress?</p>	<ul style="list-style-type: none"> · I was a little stressed only because I've never done a Cric and it was my first time. However, if a second try is done, I think I would be a lot more comfortable. · Not really, and that might be a problem. Knowing that a real patient's life was not at stake had me focused on the instructions more than saving a life. <ul style="list-style-type: none"> · No · Yes, during lag times (where the video/instructions were ahead & behind in a step) I kept thinking the patient was dying. · I did. First, it's been years since I've done either task while being watched but trying to get used to HoloLens simultaneously to being watched. · Cric insertion. Not clear in the instructions. Concerned for patient regarding time to complete the procedure. Sometimes remembering instrument names since the correct tool is needed to follow steps. Concerned about time for the patient. <ul style="list-style-type: none"> · Just slightly when software home screen kept popping up when I was trying to focus on the procedure instructions. · Not really, frustrated at missing steps without prompts (in no-AR scenario) · A little bit, getting familiar with the tools! That was more individually based and not software driven.
<p>Did you experience any side effects or sickness?</p>	<ul style="list-style-type: none"> · None · None · No · No · No side effects or discomforts at all · None · N/A · No · No (Subject said he is "sensitive" to this and he felt nothing this time.) · Not at all

Interestingly, while participants recognized ARSAM's potential for real-time procedural guidance, a majority expressed strong support for its use as a just-in-time training tool. This aligns with growing evidence to support AR in medical education, where it has been shown to enhance procedural accuracy, improve user confidence, and increase knowledge retention during simulation-based learning [30]. Unlike active clinical use, training scenarios benefit from more lenient time constraints and allow users to

engage with the system without time-critical consequences or harm to patient safety. Additionally, participants expressed interest in just-in-time training applications-an approach increasingly endorsed for preparing providers in unpredictable or infrequent scenarios, such as those encountered during battlefield medicine or disaster response [31,32].

This study was a first step to understanding user satisfaction and engagement with the ARSAM application prior to evaluating

clinical performance. Given our findings, the next phase of development should prioritize interface optimization, system reliability, and instructional design tailored to reduce cognitive burden. Although the application is strongly tied to the hardware of choice in this study, it is important to note any potential limitations in device durability and stability, especially in non-hospital settings. Furthermore, future validation efforts should assess the impact of ARSAM on procedural accuracy, task completion time, and user performance under field or simulation conditions. Expanding testing to include combat medics and advanced practice clinicians in operational environments will be critical to ensuring clinical utility and field readiness.

Limitations

A limitation of this study was simulation fidelity. We aim to make this technology usable in high stress surgical, non-hospital, battlefield environments. However, our simulated surgical bay lacked the environmental stressors necessary to capture such high-pressure responses from participants. For example, there were no detrimental consequences if the procedure was not performed in a timely or accurate manner. The simulation environment also had comfortable conditions for the participant. This could conceivably result in more favorable usability metrics than if the technology had been tested in a synthetic battlefield setting. It may be more conducive to conduct future performance assessments of ARSAM in a fully immersive training scenario to accurately capture high-stress environmental responses in a repeatable fashion [33].

Software usability and user interaction were the primary focuses of this evaluation, as our development efforts were limited to software refinement. However, some of the feedback we received focused on the device, such as difficulty with voice and gesture recognition or the speed/volume of auditory instruction. Although the AR device's physical design and system limitations were outside of our control, we were able to make software adjustments to address some of these issues, such as enlarging buttons and disabling verbal instruction. Ultimately, we wanted to create an application that was device agnostic, with the recognition that each hardware device will have its own unique challenges.

Finally, our participant recruitment pool was limited to a single institution and included those both with and without medical expertise. While non-medical feedback helped in terms of improving usability, this cohort is not representative of our target user population and may have limited the amount of medically relevant feedback gathered. Future studies with a more relevant cohort will enable us to confirm clinical content accuracy, assess clinical performance, and conduct a secondary usability assessment.

Conclusion

Our study demonstrates the potential use of ARSAM in the performance of two emergency interventions. Although users found the clinical decision support software to be acceptable in its current state, feedback was obtained to increase usability and likelihood of adoption. User comments and survey data will direct improvements, bolstering its potential for real-time guidance.

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Author Contribution

SM, NC, AS developed the study design; SM, AW, NC, JR, DL, AS conducted the study, SM, NC, AW, AS collected and analyzed the primary data; SM, NS, NC, AW, JR, SC drafted the initial manuscript; SM, AW, NC, JR, DL, SC, AS provided key revisions and final edits.

Conflicts of Interest

None to declare

Disclaimers

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