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User-Centered Design and Evaluation of ARTTS: an Augmented Reality Triage Tool Suite for Mass Casualty Incidents

Cassidy R. Nelson[1] Virginia Tech
Joseph L. Gabbard[2] Virginia Tech
Jason B. Moats[3] Texas A&M
Ranjana K. Mehta[4] Texas A&M

Abstract

In this work we present ARTTS: a head-worn Augmented Reality (AR) Triage Tool Suite containing an initial sorting tool, virtual assessment tool, and virtual triage tag to assist emergency responders in mass casualty incidents. The initial sorting tool can prompt novice responders through first-wave tasks to aid recalibration from shock to triage. The virtual assessment tool provides novice responders, potentially confused by the chaos, with a walkthrough of the SALT triage flowchart. Finally, current emergency medical triage processes leverage static paper tags susceptible to loss or illegible damage. ARTTS' virtual triage tags are dynamic, can be updated through responder interaction, and employ user interface emergent features based on individual patient conditions. This paper describes ARTTS' capabilities, as well as the applied user-centered design process including review of existing triage material, subject-matter expert interview transcripts, wireframing, application of usability and user-centered design principles, as well as iterative usability subject-matter expert assessments and design walkthroughs. The ARTTS user experience aims to enhance, not upend, existing triage processes. Finally, this paper provides a usability evaluation comparing ARTTS' virtual triage tag to a physical paper triage tag. Our tag achieved requisite System Usability Scale (SUS) scores and showed negligible differences to the paper triage tag on usability and mental workload.

Keywords: Augmented reality, triage, first responders, emergency response, mass casualty incident.

Index Terms: H5.2.2 [User Interfaces], H.1.2 [User/Machine Systems]: Human Factors; H.5.1 [Multimedia Information Systems]: Artificial, augmented and virtual realities.

1 Introduction

The World Health Organization (WHO) defines mass casualty incidents (MCIs) as "… an event which generates more patients at one time than locally available resources can manage using routine procedures… requir[ing] exceptional emergency arrangements and additional or extraordinary assistance," [1]. A critical component in MCI response is that of triage, or the assessment of treatment and evacuation priority of injured persons [2], with poor coordination leading to increased mortality [3] via delayed triage [4]. Delaying triage is detrimental as there's a 'golden hour' of trauma where treatment efficacy greatly impacts outcomes [5], where effective triage processes are needed to increase survival chances for all injured parties by assuring highest priority injuries are assessed first [6], and resources are managed effectively. As augmented reality (AR) is a novel technology that affords mobile, bare-handed, head-up interaction with information superimposed atop the real, physical world [7], we posit AR can provide the additional, extraordinary assistance necessary to enhance the triage component of MCI response. To that end, we present ARTTS, *a head-worn Augmented Reality Triage Tool Suite* containing an initial sorting tool, virtual assessment tool, and virtual triage tag to assist emergency responders (ERs) in mass casualty incidents (described in more detail in Section 4).

To create ARTTS, our design team coordinated with an emergency response subject matter expert (SME, specifically hereafter referred to as our primary SME) wielding nearly 30 years of experience in not only emergency services but also emergency response training. Further, we leveraged additional subject-matter expert interviews from ten ERs after each had exposure to select AR experiences designed to illustrate relevant AR capabilities (e.g., annotating a scene to mark hazards, viewing head-up data, interacting with hand-based menus, etc.). We then identified several broad areas where AR could enhance emergency response as well as specifically improve triage processes. From these areas, we ascertained requirements and developed ARTTS. Then, we conducted a user evaluation of the triage tag's user interface and usability with eleven ERs.

Initial sorting acts as a simple series of screen prompts to kick start triage activities by reminding novice ERs of the very first step of triage. These tasks are currently held only in ERs' memory, therefore relying on ERs' ability to recall process details and experiences/training while under duress. The *virtual assessment tool* (VAT) is more involved, housing the entire first wave triage decision tree that is also currently held only within a trained ERs' memory. ARTTS' VAT provides a "click-through" presentation of the Sort, Assess, Lifesaving Interventions, and Treatment/Transport (SALT) framework [8]. *Virtual triage tags* replace state-of-the-art physical, paper tags currently employed by ERs which are filled out with hand-written information by responders and attached to MCI patients to track recovery, treatment, evacuation, and triage efforts during MCIs. ARTTS' virtual triage tags denote personal patient information, injury type and severity, provided treatments, patient ID, patient triage order. and generally aim to overcome shortcomings of physical triage tags. For example, paper triage tags can become lost or illegibly damaged due to weather, feature a finite and small area in which to write, only allow unidirectional changes (worsening), [9] are static, and are difficult to see in the dark. Static refers to the paper tag's inability to automatically update themselves — they require constant manual responder input. Paper triage tags also do not provide a capability to prioritize patients within the same category [10] since the data contained on each tag cannot currently be aggregated or "rolled up" to a central server (for comparative analyses and summarized data views of the overall response), nor provide a physical space to manually denote additional prioritization. Finally, paper triage tags alone do not allow for advanced notice to hospitals. In our vision, ARTTS virtual triage tags will provide hospitals advanced notice of patient injuries prior to their arrival, thus permitting enhanced, adaptive, specialized preparation.

[1]email: cassidynelson@vt.edu
[2]email: jgabbard@vt.edu
[3]email: jbmoats@tamu.edu
[4]email: rmehta@tamu.edu

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This work contributes to the evolving body of knowledge related to using AR for emergency response by providing ARTTS, a list of general AR requirements and use cases for emergency response, specific AR-based triage requirements, a use case describing application of user-centered design and evaluation processes when integrating AR tools into existing occupational workflows, design principles for AR systems to support MCIs, and lessons learned from the evaluation that benefit other AR practitioners interested in fielding AR to non-technical user communities.

In the remainder of this paper, we first provide the limited amount of related work we found on using AR to support emergency response and specifically triage. Section 3 describes our user-centered design methods, development process, and the ER standards anchoring ARTTS. Section 4 illustrates the proposed ARTTS interfaces with additional discussion. In Section 5, we outline the results of our usability evaluation conducted with actual ER personnel as well as design principles for AR systems. Lastly, section 6 delivers a conclusion encapsulating limitations and future work for ARTTS, as well as for AR in triage generally.

2 Related Work

As alluded to above, our review of the literature revealed opportunities to build upon the limited prior art, particularly in relation to AR support for initial sorting, SALT processes, and virtual triage tags. We did however find a few inspiring works of interest.

Fernández, Bernabe, & Rodriguez's [6] application leveraged Google Glass to provide decision support to first line responders through icon prompts for each step of the triage process. As a responder moves through the flowchart, a different icon glows, eventually leading to a category assignment. However, as the icons have no written prompts and novice responders may still struggle, particularly if the responders are not familiar with the symbology. This is compounded by the entire triage process, represented by icons, being always present. Sometimes the process requires that responders skip steps but this may be confusing for novice responders.

Vassell et. Al., [4], also leveraged Google Glass to capture triage tag identifiers, (they used QR codes instead of bar codes) and generate an incident commander view of patient locations and severity. However, their QR code identifiers completely replaced the entire physical tag, not just the bar codes. While incident command information is enhanced and the system allows responders to select a QR marker printed in a color associated to the patient's triage category, all other tag information is lost to first-wave responders. Moreover, the limited field of view and monocular viewing limitations of google glass suggest there is opportunity to explore AR interfaces that leverage current state-of-the art binocular displays with wider fields of view.

Nestler, Huber, & Klinker [11] propose a radio-frequency ID (RFID) enhancement to traditional triage tags but this primarily aids incident commanders in assessing general ground status (number of patients and their rough locations) and does not directly aid first-line responders.

Killeen et. Al., [9], proposed an addition to the physical tag via a digital version displayed on personal digital assistants (PDA's). Scanning the physical tag barcode pulls up the digital version. The digital tag also provides decision support by leveraging the Simple Triage and Rapid Treatment (START) triage protocol [12]. However, PDAs require both hands of the responder to hold the device and the stylus needed to interact with the device. Further, START is no longer the standard of practice protocol for triage [8].

Mizumoto et. Al., [10] created and leveraged a bio-sensor to afford dynamic data collection for triage-tag information population that can be viewed with video-passthrough AR via a tablet. Again, the device requires one or both responders' hands and leverages the START protocol. Moreover, the triage tag was replaced with a drastically limited version containing only five information categories, all of them providing quantitative data (i.e., heart rate, respiration, etc.). This approach arguably results in a loss of all qualitative data and in turn provides much less information than the traditional paper tag affords.

Uchiyama et. Al., [13], designed a different type of AR marker leveraging blinking LEDs, affording a greater allowable distance between responders and patients while still allowing access to patient data tags. Again, the triage tag was completely replaced with a digital tag containing only quantitative data, which could be viewed as resulting in drastically diminish informational capacity in comparison to paper triage tags. Additionally, this system leverages a mobile device and thus requires at least one responder hand to hold and use the system.

Other work with AR and triage focus on areas such as augmenting real-time data movement between incident commanders and responders [14], an AR training environment for MCIs in virtual hazards [15], providing advance status information enroute to MCI sites [16] or to hospitals [5], or supporting more limited triage associated with profoundly austere conditions and non-medically trained 'responders' or laymen [17].

3 User-Centered Methodology

In designing ARTTS, we first assembled a design team that featured several disciplines, including: human factors engineering, usability/user experience engineering, computer science, visual arts, and emergency response. We employed a UX design cycle [18] (also outlined in figure 1) and embraced a human-centered design [19] philosophy for all ARTTS framework elements. In summary, we first sought to understand users and their work needs, then created candidate design solutions, and then iteratively prototyped and evaluated these solutions; at each step putting human needs, behavior, and capabilities first [19].

Our primary SME provided insight via interviews as well as reference materials for training in triage [20], and for existing identified areas for AR support in policing (a first-responder occupation with overlap to emergency response) [21]. From these resources and a literature review of related work, we extracted a categorized list of ways in which AR could support emergency response (see list in Section 4). Our primary SME then reviewed the categorized list and helped us prioritize AR tools for triage according to impact, feasibility, and likelihood of adoption. We were careful to consider where and how AR could complement existing triage processes instead of upending them as SMEs indicated technology acceptance as a consistent hurdle in emergency response. Our remining user-centered design activities for this phase of work centered specifically on triage for MCIs. Wielding this adjusted list, we conducted a set of subsequent interviews with ten other SMEs asking about triage pinch points, how AR could alleviate them, and the requirements of any new system for adoption.

We then conducted a thematic content analysis using the qualitative transcript data and notes taken from the interviews with the ten additional SMEs. Consistently identified attributes were grouped and synthesized into work activity notes that we then organized into a work activity affinity diagram (WAAD). From the WAAD, we distilled user and flow data models [18] as well as personas in which to drive subsequent user interface design decisions. We leveraged the data models to capture system requirements for ARTTS.

We further anchored our requirements and emerging conceptual designs with established national emergency response standards [8] and work artifacts [22]. For example, ARTTS' conceptual foundation is heavily informed by the Model Uniform Core Criteria (MUCC) for Mass Casualty Incident Training [23], further ensuring that ARTTS could be integrated in and potentially even used for training in the future.

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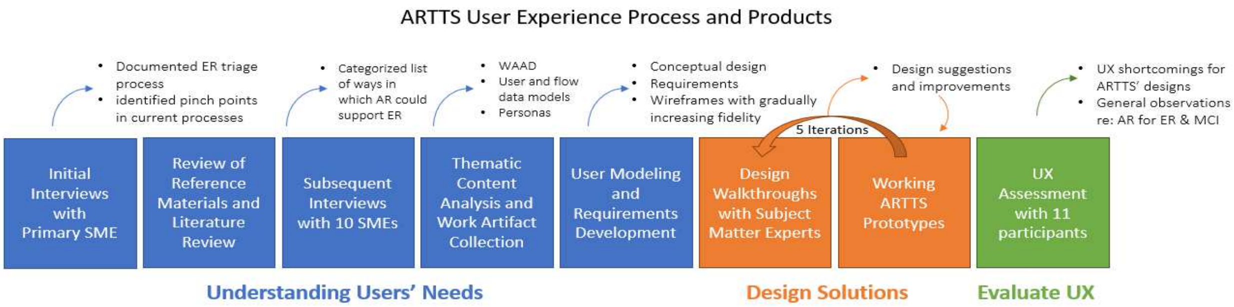

Figure 1: We employed a user-centered design and evaluation process to increase likelihood of ARTTS' adoption.

Wireframes (figure 2) helped quickly identify visual clutter and accidental emergent features for removal, as well as pinpoint areas for improvement for the transition from physical tag to virtual tag.

Finally, ARTTS has come to prototype fruition several times, with expert insight for each iteration evaluated via design walkthroughs with our primary SME for changes. In sum, the version of ARTTS presented in this paper underwent five design iterations.

3.1 AR Display Hardware

While mobile devices are smaller, cheaper, and more ubiquitous, SMEs identified it mission critical that ERs have their hands free to give medical interventions necessary for survival. In this vein, Coskun et. Al., [24] found that holding a device with one hand and using the other to interact with the device reduces device acceptance. Additionally, handheld tools can be easily lost as medical care requires the device to be pocketed or placed nearby and can also be dropped between patients.

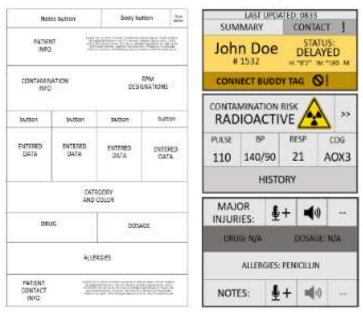

Figure 2: A comparison of an earlier iteration, lower fidelity wireframe (left) and a later, higher fidelity wireframe (right).

MCI events are typically chaotic, and potentially dangerous, until ERs have established an evacuation plan and the threat has ceased, which sometimes does not occur until after evacuations have been completed. As such, we chose a binocular optical see-through AR display to support stereoscopic viewing of near field objects (specifically the user interfaces associated with ARTTS' tools) and assist in preserving situation awareness as replacing or diminishing reality was not identified as a requirement [25]. With these requirements in mind, we chose to leverage the HoloLens 2 as the medium for ARTTS current delivery, and provide a sample of AR display tradeoff considerations in Table 1.

Table 1: Sample of AR Display Tradeoff Considerations

Requirement	Handheld AR	Headworn AR
Hands-free to give medical interventions	One hand required to hold display and see information; second hand required to interact; potential issues with arm fatigue	Hands required for gesture-based interaction only, otherwise hands are open and free.
Aid in scene processing	When device is being held up	Always integrated graphics in real
Visualization of real-time data	Viewed indirectly via video pass-through AR	Viewed directly with via optical see-through AR
Facilitation of data collection relevant to search and also future training	Can leverage integrated GPS, eye tracking not available without additional hardware	Can leverage integrated eye tracking, GPS often missing
Facilitation of communication between response teams	May not perform well under loud conditions and/or limited privacy without use of additional hardware (which can be lost, require charging, etc.)	Can employ integrated microphone and speakers proximal to users' mouth and ears for better channel quality and privacy
Suitable for use in chaotic environments	Handheld size has advantages, but can be easily dropped and misplaced	Headword size has disadvantages, but is less likely to be misplaced
Provide situational awareness (SA) support	Must first alert users via vibration or tone before AR visual SA support can be provided	Is already on' head, such that visual notifications and alerts can be attended to instantly
Support hazard avoidance and general wayfinding	Requires looking through handheld as a lens onto the world, as well as spatial mapping between phone view and real-world view	Provides a natural first-person point-of-view perspective of integrated AR and real-world

4 Initial Design Results & Discussion

4.1 ER Use Cases that can Benefit from AR

By reviewing the literature and engaging emergency response SMEs we identified the following emergency response dependent needs/uses. Use cases identified in the supplementary materials and/or in our literature review are noted with citations, all others were derived from primary SME discussions and SME interviews.

Setting the stage (first waves of response. Establishing crisis extent, setting up evacuation points, finding patients)

- Facilitation of quick data collection and effort-free use

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- Aids in scene processing
- Can implement a specific decision tree system for reporting

Communication

- Recording patient status
- Updating patient status
- Visualization and real-time editing of real-time data [26]
- Facilitation of interdisciplinary communication between specialists [26]
- Able to identify areas already searched [26]
- Facilitation of data collection relevant to search and also future training [26]
- Tracking of location, activity, and status of other responders [21]
- Integration of civilian data [27]
- Triage support [3], [5]
- Facilitation of communication between response teams across multiple disaster events [3]
- Survivor treatment support [3], [5]
- Streaming of patient information (video and audio) to be viewed by hospital responders [5]
- Advanced hospital notice

Decision making

- Evacuation progress summary
- Resource inventory
- Resource allocation tracking
- Jolting stunned responders back to triage
- Lessen cognitive load for novice responders in remembering triage process
- Visualize non-physically visible structures (pipes underground, etc.) [26]
- Lessening of cognitive load associated with personal information tracking [26]
- Support via third party with more complicated data that's been synthesized to provide guidance [26]
- Situational awareness support [26]
- Expert advice in real time from expert not physically responding [5]

Navigation/wayfinding

- Hazard avoidance
- Direct to points of interest [26]
- Further information about points of interest (type of point, distance, direction relative to user) [26]
- Map displays to support navigation [21]
- Thermal/Infrared [21]
- Advanced optics for zoom [21]

Threat detection

- Quick sharing of dangerous / damaged areas to fellow responders during response [26]
- Real-time intelligence about crimes/criminals in an area [21]
- Integration of substance sensors to notify of contamination [21]
- Friend identification worn by responders and picked up by helmet [21]

Training

- High training transfer ratio between device and actual use
- Quickly instituted
- Easy to train in-house (within a station. No third-party institutions needed)

4.2 General System and User Interface Requirements

Through work activity notes we identified three primary user types: novice responder, expert responder, and incident commander. *Novice responders* are ERs with limited experience, particularly in relation to MCI's. This limited experience renders novice responders more vulnerable to becoming stunned. Comparatively, *expert responders* define ERs with moderate to extensive experience, again particularly in relation to MCI's. This relation to MCIs is critical as the sheer scale of MCIs make these incidents profoundly different from typical, small patient pool response. Finally, *incident commanders* are responsible for higher-order aspects of emergency response including managing operations, resource allocation, and making decisions regarding risk/reward for search and rescue of hazardous environments. Incident commanders are not on the front lines and are instead typically located in a communication hub overseeing all incoming streams of data to inform decision making and using the afforded communication channels to communicate those decisions quickly to front line responders.

Current pinch points are mostly associated with evacuation status and consistent communication regarding patient status. It can be difficult for responders to quickly determine evacuation status due to the sometimes staggered physical placement of patients across an MCIs geographic area, particularly if those patients are not mobile and need ER support to move. Furthermore, as triage happens in waves with patients exchanging hands rapidly and often, consistent communication is difficult regarding concerns like administered care and last checked status. Each successive wave of triage builds upon previous iterations. Later waves also allow responders to spend more time with patients, gather more detailed information, and provide more definitive care. More specifically, first-wave responders spend around less than two minutes with each patient to ascertain rough estimates of patient status. ERs then attend to patients in triage order to provide care beyond basic life-saving interventions and gather further information. Thus, continuity of care is the primary concern in relation to consistent communication across triage waves.

Though current paper triage tags are immensely helpful, we deduced that AR could amplify their effectiveness by recording, communicating, and updating patient status (automatically and via responder interactions), supporting stunned responders limited ability to recall triage process details, decision support via data aggregation across multiple patients, demarcating and avoiding hazards, providing evacuation progress summaries, furnishing resource allocation status, and for training.

There are nuanced interactions between responder types and AR needs. For example, incident commanders need a more holistic understanding of triage efforts than novice and expert responders on the front lines. Our initial version of ARTTS centers on aiding front-line responders, particularly novices. However, expert responders also stand to benefit from ARTTS through its support of consistent communication and enhanced capacity to track evacuation and triage status. Finally, as SMEs identified novice responders as susceptible to becoming stunned, novice responders require more molecular, specific AR support.

SMEs indicated that any AR system will need to be at least bare-handed (with hands-free options preferred), usable in day or night conditions, easy to use, reliable, and create a shared digital environment for all responders. *Bare-handed* means that responders do not need to physically hold a tool to use the interface.

A *shared digital environment* means that responder A should be able to see and update a triage tag created by responder B, and that an incident commander can view a summary of triage information generated by responder A and B (and more). Additionally, AR-based triage must afford enhanced informational continuity across triage waves.

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A *triage category* refers to both an assessment of the patient's current medical condition and delineates the order in which patients must be attended to and evacuated. Best practice standards utilize the Sort, Assess, Lifesaving Interventions, and Treatment/Transport (SALT) framework [8], so ARTTS does as well. Black refers to deceased patients, grey is for patients identified as expected to expire, red for patients who are in critical condition that can potentially be saved but need medical intervention in a hospital, yellow for patients who can receive stabilizing care in the field but will need hospital follow up, and green for patients experiencing minimal injuries (if any).

Visual elements leverage the Mixed-Reality Took Kit's (MRTK) standard dark blue backgrounds and white text seeking to mitigate limitations of the AR display's additive light model [28] and afford visibility in brighter conditions, as well as aesthetic consistency across tools. We used Nielsen's heuristics [29] to anchor our interface design efforts to ensure that ARTTS has an aesthetic and minimalist design, flexibility of use, employs recognition over recall, prevents errors, and exhibits internal consistency [29]. We also used gestalt principles to chunk information groupings within the virtual tag to ease visual search [30]. Moreover, we greatly expanded the salience of the assigned triage category by highlighting the entire informational box containing patient name, thus creating an emergent feature and supporting parallel search [30]. Flexibility of use was further attained via multiple interaction types, basing the virtual triage tag on the physical tag, and by providing access to process flow charts.

Our design efforts resulted in three main (but four total possible) interaction techniques: poke, ray-cast, and voice, with touch-pinch used for special interaction (e.g., grabbing the side of an interface window to 'physically move' the window location). These give responders flexibility of use redundancies and afford bare-handed use. Interactions can be used to select items and toggle between the triage tag and the SALT walkthrough interfaces. As ray-casting and poke interactions will still require responders' hands, voice provides a truly hands-free interaction option where possible. The range of interactions also ensures ARTTS elements can be utilized in near menu—within arm's reach—and distant menu contexts when necessary. Gaze was considered for this purpose as well, but early pilot testing revealed inconsistent effectiveness, thus violating the requirement that the system be reliable.

All ARTTS elements can all be easily moved and resized, which is the only way the touch-pinch interaction is currently utilized. ARTTS elements can 'follow' responders or be pinned to the physical world. Follow refers to a body-relative AR user interface element, meaning that the tag is anchored to the responder's body. Pinning the tag toggles ARTTS into a world-relative AR user interface element, anchoring ARTTS into a physical world location [31]. To summon any ARTTS tool responders need only hold up their palm with fingers closed in a flat position (leveraging MTRK's hand menu features).

In the following sections we present ARTTS' three main AR tools in the order we would expect them to be used in the field. All tools can be accessed via the 'toolbox' featured in figure 4.

4.3 Initial Sorting Prompt

SMEs indicated that arrival to an MCI scene can be overwhelming. Moreover, the sheer scale of the chaotic scenes can stun responders into inaction, as stressful events can potentially alter memory retrieval [32] and result in cognitive impairment [33]. From our discussions with our SME and the literature in training, we know that repeated study of materials mitigates retrieval inhibition the least, with repeated retrieval practice resulting in more enduring memories and enhanced retrieval [32]. Meaning, novice responders are potentially unable to retrieve critical process details quickly and accurately as the only real mediator for this effect is previous experience.

Stakes are high in MCI response with each second being critical. Thus, to improve response efficiency and support novice responders we created an on-demand AR-based initial sorting prompt (figure 3). This prompt is uncomplicated and only utilizes the very first step of the SALT triage process. The instructional language is simple, and a check list is used to track progress. Initial sorting can be an initial kick to reorient responders back to the triage process. The interface is deliberately simple with outlines around each selection option to aid visual scanning [30].

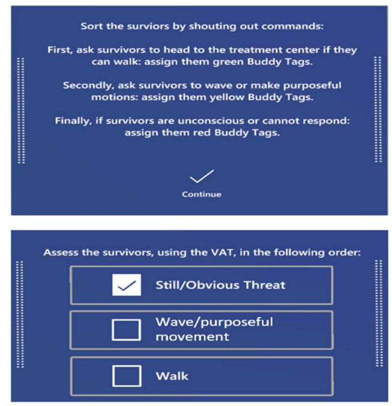

Figure 3: Initial sorting prompts. The first prompt (top image) is used upon arrival to the scene, while the bottom image acts as a prompt and progress checklist.

The initial sorting tool employs poke, ray-casting, and pinch interactions. To ensure consistency, it uses the same aesthetic as all ARTTS elements.

4.4 Virtual Assessment Tool and ARTTS Tool Selection and Management

Sometimes a simple early kick is not enough. Should an ER need more aid they can leverage additional support via the Virtual Assessment Tool, or VAT.

VAT serves as an interactive alternative to the current static SALT flow chart and provides an AR-based "click through" experience to yield a decision tree that would otherwise need to be internalized (and recalled) by responders under duress. By design, the VAT complements the Initial Sorting Tool, by supporting the "ALT" processes defined by SALT (with the Sorting Prompt Tool supporting the "S" in SALT).

As responders select items in response to VAT's interface prompts (see figure 4, top image, where top two prompts are selected), the system tracks the appropriate paths through the SALT flowchart, eventually resulting in a final triage assessment. The assessment outcome then automatically populates a new virtual triage tag for the relevant patient with the appropriate data (leaving other areas like allergies blank for the time being). We designed this experience to minimize the number of interactions necessary. Though we could eliminate all interactions through a show/hide interaction by simply presenting the entire SALT flowchart as a static image, we felt this would increase mental workload and visual search time resulting in non-

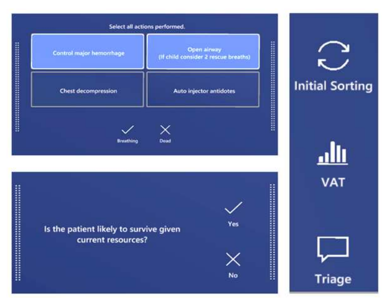

Figure 4: VAT prompts and tool manager. Top and bottom images are sample prompts provided by VAT. The right image is the overarching tool manager.

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adoption of the tool. Additionally, we felt this was another opportunity to leverage gestalt principles as well as AR's visualization and interaction capabilities to improve existing processes and artifacts.

Figure 5: Current state of the art, physical triage tag [22]

4.5 Virtual Triage Tag

We designed ARTTS' virtual triage tag using a physical tag work artifact (figure 5) created by Evacu-Aid [34] thus ensuring user familiarity by migrating design elements to minimize upending of current processes. Further, the virtual triage tag adheres to current best standards of practice (SALT). The virtual tag (figure 6) is chunked to minimize visual search time [30] into three major sections found in the left column: general information, physical condition, and additional information

General information provides characteristics of the patient such as name, height, weight, as well as overall triage status and time of last assessment. Overall status follows traditional naming and color coding to allow ERs to quickly identify patient condition (once specified by previous waves).

Physical condition data is gathered on responders' first inspection of patients. The triage tag supports collection of pulse, blood pressure (BP), respiration, cognitive status, as well as injury type and location if applicable as these areas are core to triage category delineation. We used insights from our expert interviews to define the specific quantitative values employed for status delineation.

Lastly, *additional information*, allows responders to elucidate qualitative details on patient injury severity that cannot be easily quantitatively captured such as critical information needed for effective medical intervention including major injuries, allergies, and other notes. Allergies creates a quick check for critical allergies identified by SMEs such as latex, penicillin, and sulfa. The major injuries and notes sections host voice recordings created by first wave responders completing early assessments. These voice recordings are available for aural playback and can also be displayed as text through voice-to-text. Each entry in the tag is timestamped, while voice-to-text entries are additionally stamped with responder identity (responders log in to each headset, thus allowing for their entries to be coded with their information).

In the virtual triage tag, triage category is presented in the first chunk (instead of at the bottom like the physical tag), and the triage category color coding fully surrounds critical demographic information for patients. Responders can quickly delineate the assigned triage category by the color saliency, but status has also been redundantly encoded with explicit status labeling in the same visual area. As black appears transparent in optical see-through AR, we used two distinct shades of grey to represent the printed tags black and gray colors. Any potential problems perceiving differences between the two shades of gray is minimized by the aforementioned capacity to complete parallel search due to dual encoding [30].

Figure 6 features ARTTS' fully expanded virtual triage tag. The items in the right column, the body chart and voice-to-text boxes, can be separately toggled open or closed by selecting the small person-silhouette and major injury ellipses respectively shown in the main tag (or by saying "show/hide body chart" and "show/hide major injuries/notes"). When opened, the right-side panels slide open to the side of the main tag instead of replacing the main tag. This was an indicated preference found through design walk-throughs with our primary SME that affords all data is visible when desired, and collapsible when not.

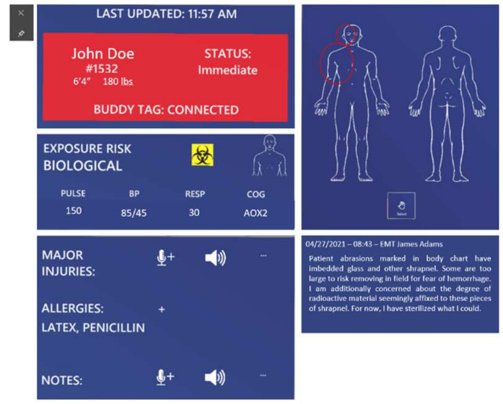

Figure 6: ARTTS' fully expanded AR-based virtual triage tag

Instead of using a pen or pencil to mark physical areas of concern and injuries, responders can use ray-cast or poke interaction techniques to mark up the virtual triage tag's body chart. When marking the body chart, responders can toggle between a circle and eraser tool. The circle tool allows ERs to place a circle (allowing for customized placement) onto any part of the body chart. Early designs included an eraser tool to remove any circles with one poke action, however the modal interface was found to be more cumbersome than simply allowing users to simply reselect existing circles to remove them.

Pulse, blood pressure, respiration, and cognitive data can be entered with voice or via poke and ray-cast interaction with a virtual keyboard. Future iterations will limit the numeric data areas to a numeric key pad. Finally, the digital nature of the triage tag allows for bidirectional patient status changes. The traditional paper tag only affords category changes if the patient worsens, while the virtual tag allows for patient status improvements to be documented as well without losing the patient's category assignment history.

5 Triage Tag Evaluation Results & Discussion

Eleven emergency responders (3 female, 8 male; Age range 20 – 67, avg. 43.8) participated in a usability evaluation of the triage tag, the most complicated element of ARTTS, so that we could ascertain the virtual tag's usability and associated mental workload. None of the responders had any experience in AR and ten had experience with physical triage tags. UX studies have been found to not need large sample sizes, with Rex & Pyla describing that empirical evaluations with at least three to five users can often identify 80% of usability issues within an system [18]. Equipped with this, we feel that eleven participants are sufficient for our initial purposes.

Figure 7: Participant using the virtual triage tag.

Participants were first given AR user interaction familiarization tasks designed to train participants on poking, ray-casting, scrolling, and moving the tag. Participants were trained in poke interactions by being asked to poke a random layout of ten virtual boxes labeled 1-10 in ascending order. This was done 8 times, yielding 80 pokes. This process was repeated for ray-casting. For scrolling, participants were asked to scroll through a list (in near range, so like a 'poke touch' interaction) to find a specific fruit and then click on it

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when they saw it, yielding 8 scroll tasks. Finally, participants were asked to ray-cast a cube from one location to another within a designated cube (far field), yielding 8 object movement tasks.

Upon completion of familiarization, participants are then given either a paper or AR triage tag (order of which was counterbalanced across participants) and walked through a set of benchmark tasks built such that all interactions are completed more than once and to give participants a good overview of tag usage. Example tasks included “add latex to the allergy list”, “record a pulse of 120”, “update the patient status”, etc. These benchmark tasks varied only in the specifically requested interaction styles to achieve the task.

After completing the benchmark tasks, participants were asked to fill out a System Usability Scale (SUS) survey [35] and a Raw Task Load Index (RTLX [36]—NASA TLX [37] without pairwise comparisons to mitigate survey fatigue) [36]. Then participants were given a new set of benchmark tasks, comparable in difficulty, on the remaining tag modality, with the same surveys completed afterwards. The AR triage tag did have some unique questions associated with it. The first was the short form version of the User Engagement Scale [38] used for application assessment. The second was a self-reported assessment of their comfort in their AR interaction skills (1-10, 10 being the most comfortable.), as well as whether they felt their AR interaction skills improved with time (yes or no).

An initial assessment of data normality showed some concerns for overall SUS scores. A continuous fit evaluation displayed a right skewed (-2.21) curve with a leptokurtic kurtosis (6.077). These scores are both well outside what is considered a normal range of ± 1 for each [39], indicating non-normality. Interquartile range (IQR) evaluation showed one score well below the Q1 cutoff of 65. Huber M-Estimation was also used to estimate center and spread of this data with a default K Sigma of 4, ensuring an appropriately conservative evaluation of the data. Huber’s evaluation also pinpointed the same datapoint as an outlier. Thus, this outlier was excluded from our analysis. This exclusion yielded a new skewness (.13) and kurtosis (-.48) which is centered within that aforementioned ± 1 normality range.

Overall, ARTTS’ virtual triage tag received an average SUS score of 74.5. This is above the recommended average of 68 [40], thus simultaneously assuaging any immediate major concerns with the interface while also revealing there is room for improvement. The paper tag had a higher SUS score, but a matched pairs evaluation found this difference to be statistically insignificant.

Regarding mental workload as measured by the RTLX (out of 21): mental demand (9.8), physical demand (4.7), temporal demand (8.2), and frustration (5.5) were all below 11 (or moderate) for the virtual tag. Physical demand was the least concerning with a low average score of 4.7 (out of 21). Conversely, the biggest concern is that participants reported an average score of 15.5 (out of 21) for their perceived failure in accomplishing the task using the virtual tag. The paper tag had non-significantly lower results for the overall TLX score and across all dimensions except physical demand ($p > .01$), which is not surprising given that our tested tag required hands interaction.

Finally, we administered a short form version of the User Engagement Scale [38] to provide a deeper evaluation of the virtual tag and overall experience with AR. With 1 being strongly disagree and 5 being strongly agree, the subscale of perceived usability has a mildly positively leaning average of 3.67, further supporting the SUS result that the virtual tag has average usability while still having room for improvement. Focused attention had a similarly middling score of 3.33. More positively, aesthetic appeal of the tag yielded an average score of 4, with a perceived reward factor of interacting with the tag receiving a 4.67. All participants reported feeling highly confident in their AR skills and like their ability to interact in AR got better over time.

In summation, the virtual triage tag has held its own as compared to a physical, paper version of the triage tag in terms of user perception in the context of our study. I.e., the virtual tag did not significantly negatively diverge from the paper tag as indicated by our SUS comparisons. Though any change inherently yields a degree of process upending, these non-significant differences in SUS scores speaks to a degree of success in our goal to minimize upending existing triage processes. However, future iteration is warranted to maximize the tag’s effectiveness and to minimize any negative tradeoffs with the paper tag. The core areas for future focus will be on the physical fatigue facet and in helping provide user feedback to indicate success in tag interaction.

5.1 Design Principles

From a qualitative perspective, we noted several design principles for AR in MCIs, as well as UX findings that may be of interest to other AR practitioners.

Responders are sifting through several information streams and have to move quickly at first, eventually slowing in subsequent waves. Further, ERs are likely in dangerous environments when actively responding to an MCI. This means that AR applications should minimize visual search, afford different response strategies [41], and not subtract from ER situation awareness. These can be achieved using gestalt principles like common region, ensuring applications allow for a range of fidelity in each use, and by minimizing the graphical footprint while providing quick toggle on/off of said graphics. Our triage tag uses *common region* to chunk similar information and input types. Further, the tag has some quick response data (simple numbers) and longer response data (verbal notes) to support shifting ER strategies.

Graphics and applications should leverage Nielsen’s heuristics [29] to further facilitate efficient and pleasant use, while critically ensuring reliability of the system through error prevention and easing recovery from errors. Designers should further consider the selected hardware’s pros and cons carefully. We chose a HWD based on ER feedback and what we felt were worthy trade-offs for a feasible future of AR. Hardware should be reconsidered on a case-by-case basis for the intended use case. Finally, graphical elements should be robust enough to handle as wide a range of bright environments as possible, with visual redundancies for any colors that may be washed out on either end of the light spectrum.

More specifically, participants found poking much easier than ray casting, suggesting that user interfaces should be placed closer to users for easy access. Our triage tag is representative of likely the largest single UI that can be effectively used quickly via touch without more detailed practice and training and given today’s AR head-worn displays’ field of view.

Second, we noticed that scrolling through menus and large fields of vertical text (e.g. notes) proved to be difficult for some participants. We observed that some participants engaged in an “exaggerated scroll motion”, that is, physically lifting their arm above the head in to accomplish an effective vertical scrolling. ERs need reliable and fast interactions. Further, we observed that during scrolling or selection at distance, both of which used a pinch, participants sometimes did not separate their fingers enough and would lower their hand before the “pinch release” was recognized by the system (resulting in undesired continued scrolling or an untended non-release of a UI selection, respectively). Thus, practitioners may consider a “paging” mechanisms instead (e.g., buttons with “next” and “prev”) to poke through subsets of lists or text entries instead of scrolling a continuous list.

Participants also found numerical data entry on the standard Holens/MRTK keyboard tedious, which suggests that a numpad (and redundant voice capability) may be a more effective input mechanism when there is a need to specify numerals. In a similar

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fashion, we also noticed that for entering blood pressure, we needed an input mechanism that matched the domain-specific ecological mental model [42] for blood pressure readings. So, for example, instead of entering systolic blood pressure and diastolic blood pressure as separate fields, we simply added a "/" to the numpad to allow for blood pressure to be entered as "120 / 80". Participants also did not reposition the virtual tag as much as we thought they might (i.e., in order to see the virtual tag better or to poke interact) and instead moved their body to more convenient viewing locations. Lastly, the HoloLens would often lose tracking when participants placed their head down low to the ground and turned their head to the side in order to listen to a supine patient breathing. Upon returning their head to a normal position, tracking would resume however the ARTTS' UIs would sometimes shift to a slightly different position. Practitioners should be wary and careful about ensuring tracking is consistent and reliable.

6 Conclusion

Our review of literature, training materials, and expert interviews identified several opportunities for AR support in emergency response. SME priority rankings for MCI triage guided our team to focus on recording, communicating, and updating patient status, supporting stunned ERs, and decision support.

Our analysis of interview transcripts suggests that AR systems for ERs need to support bare-handed interaction when possible, minimize the need to use hands in general, be visible in day and night conditions, are easy to use, are reliable, and create a shared digital environment to support multiple user roles (ERs, incident commanders, and in the future healthcare professionals receiving patients at hospital facilities). The team identified optical see-through AR as ideal to ensure reality is truly augmented (not replaced) and situation awareness is preserved.

Our current triage tag received middling to good scores on most tested facets. Though the paper tag trended more positively across these dimensions, these differences between the tags were not significant except for in relation to physical demand.

ARTTS supports standard recording of patient status similarly to the original physical tag. However, ARTTS data recording is augmented by the ability to update the tag and track provenance of updates, and the ability of the virtual triage tag to be accessed by any ER at any time and location. Moreover, the option to send data to hospitals in advance is an additional promising improvement that we hope to explore in future work. ARTTS global sorting and VAT interfaces further augment the ER experience by providing prompts to guide early triage requirements.

6.1 Limitations

Regarding interactions, ARTT'S uses speech-to-text which has its own limitations, especially in the context of loud environments like what might be found in MCI's. The HoloLens 2 allows for shifting of the sound sensitivities to afford better speech command intelligibility, but these may still be overwhelmed depending on the MCI. Additionally, standard problems with AR in bright, sunlit outdoor settings are still present. ARTTS does not currently provide a fully hands-free alternative to move the interfaces panels in space (one must touch-pinch), thus requiring the system be in the near field and only moved within the near field. Further, our current study focused on physical interactions and did not include voice commands, which may have been a mitigation strategy for fatigue.

We concede that there are limitations to HWDs in relation to their feasibility due to limited battery life, network connection, and limited effectiveness in outdoor and bright settings. However, mobile devices have long been available to responders and are outlined as not feasible via SME interviews. As HMD technology continues to develop, we foresee them quickly surpassing mobile devices in contexts where users need their hands free.

This work includes a small sample size of only eleven. While we feel eleven was sufficient for our purposes, more is preferrable. Further, participants were limited to one session of using the triage tag. As all participants indicated that interactions got easier with time, some perceived usability issues may be a result of not having enough familiarity with the tag itself because while it is heavily inspired by the original paper tags, there are still some changes that would require re-training if used in the field. Further, while our virtual tag did not negatively diverge from the paper tag, we concede this also means that these comparisons do not make clear any obvious 'gains' to be had from implementing AR in the field as the scores for the virtual tag were not significantly more positive. Simply replacing the paper tag with an AR version does not inherently yield meaningful change. We believe, however, that the gains of our tools are more likely to be realized elsewhere. Namely, in the field vis-à-vis additional and dynamic systems support offered by our virtual tag that are not available via paper medium. Our virtual tag could yield improved evacuation efficiency, more effective patient triaging, better resource management, and many other higher order benefits not evaluated by this study.

6.2 Future Directions

Moving forward, we envision ARTTS being integrated with ER-based system architectures such as Panacea's Cloud [3] or a Cloud-Fog [17] to support possible functions like the provision of advanced hospital notice. More work is needed in terms of in-situ usability evaluation strengthened via formative user evaluations in realistic MCI triage settings to obtain quantitative measures of effectiveness relative to the traditional paper triage tag and mental recall required for initial sorting and SALT. Studies regarding technology acceptance, VAT access versus strictly recall during response, and the effectiveness of initial sorting in reorienting stunned ERs should also be completed.

Future work in the AR triage space should not only build upon the areas focused on by ARTTS, but also consider possible solutions for the other identified use case areas not touched on by ARTTS such as wayfinding, hazard avoidance, evacuation progress summaries, resource allocation areas, and training.

Further, future work should endeavor to include more participants to ensure normality can be better assessed. Any future studies should include more training on the triage tag itself (not just on AR interactions) to ensure there is not a confounding effect with learning the new orientation of tag elements. The AR triage tag appears to need further iteration to bring the usability from 'average' to 'excellent' and to improve users' perceived performance. Finally, it is critical to assess whether these non-statistically significant differences have large practical implications, particularly in the context of actual field work. Future evaluation should consider ARTTS in at least a more intensive training scenario. This is particularly true as some of the core benefits of ARTTS that might make it favorable to a paper tag despite increases in some facets of mental workload were not well displayed in a controlled evaluation setting (like how paper tags are damaged by rain and mud, etc.). In short, as with many emerging applied AR endeavors, the ARTTS UX and associated hardware need to be stress tested in more field-like scenarios to better prepare it for adoption by ERs. Finally, we intend to evaluate the higher order gains of ARTTS like improved evacuation times and more efficient triage processes.

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