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Comparing Capabilities of Simulation Modalities for Training Combat Casualty Care: Perspectives of Combat Medics

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ABSTRACT
Introduction:
Combat casualty care requires learning a complex set of skills to treat patients in challenging situations, including resource scarce environments, multiple casualty incidents, and care under fire. To train the skills needed to respond efficiently and appropriately to these diverse conditions, instructors employ a wide array of simulation modalities. Simulation modalities for medical training include manikins, task trainers, standardized patient actors (i.e., role players), computer or extended reality simulations (e.g., virtual reality, augmented reality), cadavers, and live tissue training. Simulation modalities differ from one another in multiple attributes (e.g., realism, availability). The purpose of this study was to compare capabilities across simulation modalities for combat casualty care from the perspective of experienced military medics.

Materials and Methods:
To provide a more complete understanding of the relative merits and limitations of modalities, military combat medics (N = 33) were surveyed on the capabilities of simulation modalities during a 5-day technical experimentation event where they observed medical simulations from industry developers. The survey asked them to rate each of eleven modalities on each of seven attributes. To elicit additional context for the strengths, limitations, and unique considerations of using each modality, we also collected open-ended comments to provide further insight on when and how to use specific simulation modalities.

Results:
Results showed differences among the simulation modalities by attribute. Cadavers, role play, moulage, and live tissue all received high ratings on two or more attributes. However, there was no modality that was rated uniformly superior to the others. Instead, modalities appear to have unique strengths and limitations depending on the training context and objectives. For example, cadavers were seen as highly realistic, but not very reusable.

Conclusions:
The study furthers our understanding of simulation modalities for medical training by providing insight from combat medics on the benefits, limitations, and considerations for implementing different modalities depending on the training context. These results may be helpful to instructors in selecting modalities for their programs.

INTRODUCTION

Tactical Combat Casualty Care (TCCC) training involves teaching a complex set of skills, including best practices for managing traumatic injuries, how to treat and evacuate multiple casualties in resource scarce environments, and tactical considerations for care under fire.[1] TCCC training has significantly improved survival rates for preventable combat deaths,[2] and recent research identified the need to improve training efficiency and provide additional training opportunities between deployments.[1,3,4] Simulation helps meet the varied needs of training for TCCC. There is mounting evidence that simulation helps improve medical practitioner knowledge and skills.[5,6] Practitioner-improved knowledge and skills may lead to improved patient outcomes such as decreased length of hospital stay and decreased morbidity and mortality.[2]

Simulation takes many forms or modalities,[7] from simple task trainers and role players (i.e., standardized patient actors), to high-fidelity manikins, cadavers, live tissue training, and computer-generated scenarios (i.e., serious games, Virtual Reality [VR], and Augmented Reality [AR]). The

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These data have not previously been presented. Additional data from the same study beyond the scope of this article were presented at the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC), held in Orlando, FL in November 2023.

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purpose of the training may also vary widely, including fostering knowledge of anatomy, developing psychomotor skills, improving decision making, patient assessment or diagnosis, and case management. Because each modality has different capabilities to approximate a medical task, the choice of the simulation modality for specific learning outcomes should take such capabilities into consideration. In some cases, the choice of modality for achieving a training objective may be straightforward. A simple box trainer, for example, is useful for developing a specific psychomotor skill, but not for case management. Alternatively, a high-fidelity manikin may not be appropriate for training in conditions where the simulator may be damaged, such as in a field training exercise. In many cases, however, multiple modalities could be used for a given purpose. For example, a task trainer, manikin, cadaver, and live tissue training could each be used to train the cricothyroidotomy procedure depending on the resources available and the skill level of the trainee.

Because simulation modalities vary widely on aspects such as sensory realism, anatomical and physiological fidelity, durability, deployability, and reusability, it may not be obvious which modality or combination thereof is preferable for a given purpose. At present, information about the most beneficial modality or combination of modalities is inconclusive. There is research comparing live tissue models versus other simulations.[8–10] However, comparisons of other simulations with one another are rare; for an exception, see Diaz et al.[11] A recent NATO technical report[12] stated that "although advances have been made in recent years in both simulation and immersive technologies, a single environment, linking realism, haptics and emotional connection remains elusive (pp. 3-11)." The report also concluded that there is no single dominant modality for training and that multiple modalities should be considered for achieving a given training outcome (pp. 3-9, 3-11).

To inform stakeholders on choosing the best modality (or combination of them) for achieving a specific training objective in various contexts, we conducted a study to compare simulation modalities quantitatively and qualitatively from the perspective of experienced combat medics. They were surveyed as part of a week-long technical experimentation (TE) event focused on medical tasks important for TCCC.

METHOD

Survey

A survey of subjective ratings of simulation modalities was created to analyze overall impressions of modalities for medical simulation by combat medics. This survey included 108 items focused on the role of modalities in combat casualty care simulation. There were eleven simulation modalities included in this study: Low-Fidelity Manikin, High-Fidelity Manikin, Low-Fidelity Task Trainer, High-Fidelity Task Trainer, VR, AR, Serious Games, Cadavers, Role Play (i.e., standardized patient actors), Moulage, and Live Tissue Training (LTT). Serious games are typically computer games or simulations designed for educational objectives rather than simply for entertainment.[13]

TABLE I. Likert-scale Survey Items Rated across Modalities

Item	Likert-scale Survey Items	Attribute Label
1	[Modality] is readily available to me.	Available
2	[Modality] can be used in most environments without being damaged or malfunctioning.	Portable
3	[Modality] is realistic and has similar anatomical dimensions, physiological reactions, and weight to that of human patients.	Realistic
4	[Modality] allows for practice of the critical Tactical Combat Casualty Care skills.	Practice TCCC
5	[Modality] causes an emotive response similar to that of human patients.	Emotive
6	[Modality] can easily be reused or reset for multiple training iterations.	Can Reuse
7	[Modality] leads to good learner engagement.	Engaging

The survey first defined the terms used throughout, consistent with the terms used throughout the TE event. The definitions were referenced from the DoD Modeling and Simulation Glossary (U.S. DoD, 2020). For each simulation modality, the survey asked evaluators to rate their agreement with statements on subjective items related to aspects of the modality for medical training (e.g., availability, see Table I). Following the rating of each modality in the quantitative section, we asked evaluators to provide open-response feedback on each modality in a qualitative section. The items allowed the evaluators to directly express their opinions about the effectiveness of various training modalities, as well as limitations and considerations for when and how to use each modality. Such judgments were not tied to any specific training devices exhibited at the TE event. The survey was given at the beginning of the TE event, and evaluators were asked to return the survey at the end of the week to allow for adequate time to respond to the items.

Participants

Medics ($N = 33$) were recruited from the U.S. military (Army, Navy, Air Force, Marines) as part of a TE event. Out of 33 participants at the TE event, 30 completed the survey evaluations and were included in the analyses. Participants were 100% male, and averaged 34.85 years of age (minimum 21, maximum 52, *SD* 7.74). Participants were experienced in medical procedures (minimum 3 years, maximum 30, mean

TABLE II. Mean Ratings to Likert-scale Items of Attributes by Modalities

Modality	Available	Portable	Realistic	Practice TCCC	Emotive	Can Reuse	Engaging
Interrater reliability	0.96	0.97	0.96	0.96	0.95	0.86	0.95
Low-fidelity manikin	**4.13**	3.80	2.43	3.13	*1.70*	3.77	2.50
High-fidelity manikin	3.07	2.37	3.27	3.93	2.50	3.17	3.47
Low-fidelity task trainer	3.83	3.87	2.60	3.77	*1.57*	**4.13**	2.90
High-fidelity task trainer	2.80	2.77	3.17	3.73	2.37	3.37	3.33
Virtual reality	*1.87*	2.87	*1.93*	2.10	2.27	3.87	2.87
Augmented reality	*1.47*	*1.87*	2.17	2.50	2.41	3.79	3.07
Serious games	*1.53*	*1.97*	2.37	2.33	2.10	3.63	3.03
Cadavers	2.80	2.60	**4.43**	**4.20**	3.30	2.33	**4.13**
Role play	3.80	**4.43**	**4.70**	3.83	**4.13**	3.30	**4.27**
Moulage	**4.31**	**4.52**	3.55	3.97	3.41	**4.24**	**4.07**
Live tissue training	3.21	3.86	3.21	**4.69**	3.97	3.00	**4.66**

Note. *N* varies from 29 to 30. Reliability estimates based on the assumption of random (sampled) evaluators. Evaluators rated each of 11 modalities (e.g., VR, cadavers) on each attribute. The color heat map indicates stronger agreement in green and stronger disagreement in red (for grayscale, means greater than 4 are shown in **bold face**; means less than 2 are shown in *italics*).

11.92 years, *SD* 6.91), and the majority (76%) were medical instructors. The majority (55%) had experience as a medic treating casualties in a combat environment. A University of South Florida Research and Integrity Compliance Officer designated the project Not Human Subjects Research (NHSR) and thus exempt from IRB review.

Procedure

The survey was completed by participants throughout the weeklong TE event in which industry developers exhibited medical training devices to the participants in exchange for feedback from the participants on those devices. During the TE event, developers chose to present simulations relevant to combat casualty care. As described in Bailey et al.,[14] evaluation checklists tallying capabilities of simulations were devised for 12 TCCC tasks, and these were completed by the participants for relevant simulations after attending a developer presentation. A total of 27 simulations were presented during the event, with a mix of tasks and modalities. The development of the evaluation checklists and a summary of their resulting data have been presented elsewhere[14] and are beyond the scope of the research presented here focusing on subjective views of simulation modalities.

Analyses and Results

Paper and pencil responses to the surveys were entered into Excel spreadsheets by the research team and analyzed with R and SPSS. Analyses included analysis of variance (ANOVA) for testing mean differences across modalities by attribute followed by post-hoc tests for differences in specific modalities where overall tests were significant.

Interrater Reliability of Ratings

Before reporting the details regarding the modalities, it is important to establish the interrater reliability of the data in order to support the credibility of the findings. The reliability estimates[15] for the mean ratings were all substantial, with all but one greater than 0.90 (Table II).

TABLE III. Analysis of Variance of Modalities by Attribute

Item	Attribute	*df*	*F*	*p*	Std. Err.
1	Available	10, 287	31.98	<0.01	0.20
2	Portable	10, 286	34.62	<0.01	0.18
3	Realistic	10, 287	31.56	<0.01	0.18
4	Practice TCCC	10, 287	26.96	<0.01	0.17
5	Emotive	10, 287	22.62	<0.01	0.20
6	Can Reuse	10, 287	8.47	<0.01	0.21
7	Engaging	10, 287	23.68	<0.01	0.16

Note. The table reports the details of each ANOVA, where *df* means degrees of freedom, *F* means the overall *F* test statistic, *p* means the likelihood of results as or more extreme than those obtained given the null hypothesis of no difference, and Std. Err. means approximate standard error of the difference in means.

Mean Evaluations of Modality by Attribute

The average subjective ratings to each attribute for the simulation modalities are shown in Table II. On each of these Likert-scale items, evaluators rated their agreement with the statements on a scale from 1 ("Strongly Disagree") to 5 ("Strongly Agree"). The color heat map in Table II indicates stronger agreement in green and stronger disagreement in red (for grayscale, means greater than 4 are shown in bold face; means less than 2 are shown in italics).

We tested mean differences among the modalities separately for each attribute. Because the same evaluators provided ratings for each modality and attribute, repeated measures ANOVA was used to model the ratings. Following a significant overall *F* test, Tukey HSD post-hoc tests were used to identify significant differences among specific modalities. Because there are many modalities and attributes, only summary statistics for the ANOVAs are presented here along with an approximate standard error of the difference in means

TABLE IV. Modalities and Representative Qualitative Responses

	Benefits	Limitations	Considerations
Low Fidelity Manikin	"Good for things like hoisting or illustrating pt [patient] movement techniques." "Their low complexity and high availability make them a good option when better training methods are unavailable."	"Setting up and resetting takes a lot of time." "Low fidelity manikins are lacking in creating emotive response and realistic feedback" "There are 'mannequinisms' [sic] that have to be verbally told to students.."	"They can be augmented with moulage to increase skills practice" "Low fidelity manikins provide feedback when needing to do basic medical training and demonstrate simple TCCC techniques. Anything more advanced requires high fidelity manikins and beyond that LTT"
High Fidelity Manikin	"High fidelity does provide a lot of feedback" "High fidelity manikins are the best with tracking for vitals and realistic hands on advanced care for prolonged use."	"Too fragile and way too expensive." "High fidelity manikins require an instructor versed in the complexity of the operation. They have best application in… dedicated simulation facility. They are typically too much of a hassle to keep at a unit." "High fidelity manikins do a poor job of replicating human response. Also fragile [sic]" "There are a lot of different manikins. Not all can do the things we want… I like to see manikin attachments that can do escharotomy or fasciotomy. A big plus is having urine output. Money is the biggest issue. Warranties are a plus."	"High fidelity manikins are always an instructor training intensive event. Prep, employment, manual inputs, and rehab are all key steps to maintaining and properly utilizing the manikin. Far too often instructors rotate or leave, taking their manikin knowledge with them. Additionally, the struggle between high fidelity and durability are always at odds with each other. Realistic skin means easy to damage or tear. Durable skin means tough, unrealistic IV, chest tube or wound packing training scars." "Companies need faster times to repair them. I've seen mannikins take almost 6 months to come back for repair."
Low Fidelity Task Trainer	"handy tools to teach specific skills where time and resources are constrained. They can be implemented at the operational units. Not a primary teaching medium but great to have as a backup."	"Typically they are built very well for a specific task and cannot train any other task. These lead to rooms full of task trainers that are one trick ponies. However, they have a place in initial training and learning."	"They are a tool but not the whole toolbox"
High Fidelity Task Trainer	"can really improve student learning"	"The reset time is often too long or costly."	"Useful when combined with manikin/human pt role player"
VR	"VR/AR all has its place for pre-test or pre-LTT. It allows the tudent to try different things, make mistakes and learn. None of them replace task trainers, high fidelity manikins or LTT." "Seems promising for driving decision making in complex/ challenging scenarios and checking knowledge in respect to drug knowledge Etc."	"I would not use VR to train psychomotor skills and I am unsure whether using VR to train novice EMTs/Medics without the benefit of prior skills training would be helpful or extremely harmful. Will be watching tech in this area with interest." "VR is poor as a procedural skills trainer requiring tactile input/feedback"	"We are quick to evaluate VR/AR harshly at first glance but there are a few points to keep into consideration: technology is in its infancy, in its current state it is not possible to effectively train medical tasks involving psychomotor skills, it is effective in training skills involving a high degree of decision-making"
AR	"AR/VR allow for cognitive training and decision-making"	"Can't beat LTT" "Same limitations as VR"	"Similar to VR it has a place and better ability for tactile inclusion. Still more geared toward cognitive decision making at this time"
Cadaver	"Cadavers are best suited for task requiring accurate clinical surface anatomy [surgical skills]. Perfused cadavers should be used for junctional and difficult bleeds." "Cadaver use is almost as critical for realistic training as LTT…I believe should be mandated at all upper level training."	"Main issue: longevity of training, limited iterations" "Cadavers are great at A&P, but lack feedback during surgical skills." "No vital signs, respirations, etc."	"The cost to utility ratio for these seems very low. The value of 'first cut/first procedure' on cadavers is inestimable but probably not worth 4K when there are lower cost alternatives which yield similar results. This being said, if money is no object I would like the option to train with cadavers all the time."

(continued)

TABLE IV. (Continued)

	Benefits	Limitations	Considerations
Role Player	"Role players who understand what they are trying to emulate mixed with good moulage is the best training aid." "Best used for simple trauma with alert and oriented patients. Additionally, best for any scenario driven by physical exam"	".. they require extensive planning and coordination." "Role players are only as good as their motivation. They also are limited in feedback, procedures that can be done safely, and moulage available." "no invasive interventions and are time/labor/cost intensive to procure/prepare/train"	"Actor fatigue is a real thing" "The verbal feedback of well trained role players allows for improvisational engagement."
Moulage	"Moulage when done right can be a great tool to add to role players or manikins."	"moulage is not a viable option, since most people can't apply it properly… doesn't allow for realistic bleeding or wound packing."	"Moulage can be applied to anyone but requires a lot of expertise to be realistic." "Cleaning and reset have always been a major issue"
LTT	"LTT is pivotal to a medic's training. Being able to work on a live patient that bleeds and breathes is not replicable even with the best role players and moulage." "LTT provide skill practice in one area that no other simulation can hold a candle to. That is hemorrhage control. Once that need is met by an alternative, LTT will become obsolete." "LTT is the only or first time many medics are able to interact with a 'real' patient. This helps break down psychological barriers for some"	"Anatomy inaccuracy is the only major drawback" "Principal downsides, cost, no ability to facilitate/procure animals for training without oversight. Many interventions must be performed in ways which are often times not reminiscent of human interventions."	"A combination of AR/VR, high fidelity manikins, and LTT is the appropriate way to move forward." "LTT is a great model that currently cannot be reproduced. LTT should be used after proper pretraining has been conducted. Videos, reading, simulation, task training and quizzes should all be exhausted prior to LTT." "Limited LTT and mostly role players is the best training combination"

for each attribute. The standard errors can be used by the reader to explore the significance of any differences of interest in Table II.

Subjective ratings of modalities differed significantly for each attribute (see Table III). Several specifics are worth noting in comparing the modalities. AR, VR, and Serious Games were rated as currently less available than other modalities by the evaluators and were also considered less suitable for practicing TCCC. For portability of simulation modalities, low-fidelity manikins, task trainers, LTT, role players, and moulage, were rated as more portable than other modalities. In terms of realism, role players and cadavers were rated as more realistic overall. LTT and role players were rated as more capable of producing an emotive response. Cadavers were rated as less reusable than other modalities, except LTT. Finally, the most engaging modalities were LTT followed by cadavers, moulage, and role players.

Qualitative Responses

The survey provided space for comments for each modality, which often explained the reason for a given rating. Table IV lists representative comments for benefits, limitations, and considerations of each simulation modality to provide insight on the quantitative analyses. We chose for presentation comments that were clear and representative rather than presenting redundant comments. We also included comments that presented a unique idea so that the list is intended to be comprehensive for the study participants. Note: Serious Games are not included in the table because the only comment on that modality was that it is "best used for decision making."

DISCUSSION

To provide a more comprehensive picture of the relative benefits of simulation modalities for medical training, experienced military medics provided evaluations of eleven different modalities by seven different attributes and open-ended comments on each modality. The mean ratings in Table II provide a snapshot of the current state of such technology for training TCCC. The descriptions in Table IV provide qualitative detail and elaboration for each modality. To the best of our knowledge, the current results present the most comprehensive comparison of simulation modalities to date. Several features of the results are worth noting.

First, no modality appears uniformly superior or inferior to the others. Rather, most of the modalities appear highly rated on some attributes, but not on others. For example, cadavers were rated as very realistic and very useful in training TCCC skills but were also considered not very portable and not very reusable. The computer intensive modalities (AR, VR, and serious games) were rated poorly on availability and realism but were rated more highly on reusability.

Second, different modalities might be chosen for training depending upon the context and the importance of a particular attribute for that context. Both role play and moulage had four attributes with mean ratings greater than four on a five-point scale. For both role play and moulage, one of the high ratings was for portability, suggesting that these may be good candidates for training in austere environments. Several open-ended comments suggested that medics considered role play plus moulage provides the best training for engagement with a patient, although others noted that both have drawbacks as well (role players experience fatigue, invasive procedures cannot be practiced, and proper application of moulage requires special skill). Live tissue training received high ratings (means greater than 4.5 on a 5-point scale) for both practicing TCCC and engagement, suggesting that this modality might be a good candidate for learning difficult TCCC techniques. Several open-ended comments suggested that evaluators considered live tissue to be an essential part of training, although many also mentioned that live tissue should only be used after other skill acquisition and that anatomical differences between the model and a human were an issue.

Limitations

Although the current report is comprehensive, it does not include important attributes such as the cost of acquisition and the cost of deployment (maintenance, technicians needed to operate, etc.), nor did the survey assess political or ethical attributes connected to some of the modalities (e.g., animal rights, biohazards, etc.). The sample size was limited, and it is possible that participation in the TE event itself may have altered the medics' opinions in some unknown ways. Additionally, because we recruited participants at an existing TE event, we were not able to stratify data collection to reflect the demographics of the combat medic population, so characteristics such as average age and gender are not necessarily representative of current combat medics.

As the earlier quote about the placement of LTT in the medics' skill development sequence indicated, the choice about what simulation is best suited for skill development may depend upon the current skill level of the trainee. For example, open-ended comments suggested that low-fidelity task trainers were seen as appropriate for novice learners, whereas LTT and cadavers were viewed as appropriate for training those with more experience after other training resources had been utilized.

The survey did not ask the participant to envision a specific context (e.g., austere environment, specific learner level) when responding. Rather, all the responses were general or overall opinions. Thus, there is room for gathering more nuanced evaluations of the modalities for specific trainee populations and training contexts. Finally, the data are based on medics' opinions rather than training outcome data. Studies comparing the performance of groups of trainees assigned to training by two or more different modalities would certainly be welcome.

CONCLUSION

Combat medics evaluated the quality of eleven simulation modalities for training combat casualty care using seven attributes to provide quantitative comparisons among the modalities. The medics also commented on the strengths, limitations, and unique considerations of each modality to allow more qualitative comparisons. Although no modality dominated the others, the results provide a more complete understanding of the modalities' relative merits. The study results may also be helpful in selecting one or more modalities for a given purpose depending upon the instructor's judgment of the important modality attributes along with the training context and the level of trainee skill.

DECLARATIONS

The authors declare no conflicts of interest.

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CONFLICT OF INTEREST STATEMENT

None declared.

CLINICAL TRIAL REGISTRATION

Not applicable.

INSTITUTIONAL REVIEW BOARD (HUMAN SUBJECTS)

A University of South Florida Institutional Review Board Research and Integrity Compliance Officer designated the project Not Human Subjects Research (NHSR) and thus exempt from IRB review.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC)

Not applicable.

INDIVIDUAL AUTHOR CONTRIBUTION STATEMENT

S.K.T.B., M.T.B., C.C.R. collected the data and drafted the original manuscript. S.K.T.B. and M.T.B. analyzed the data. S.K.T.B., M.T.B., F.B., D.L., L.L., Y.O. designed this research, reviewed, and edited the manuscript. All authors read and approved the final manuscript.

DATA AVAILABILITY

The data that support the findings of this study may be available on request from the United States Special Operations Command. Contact the corresponding author for more information.

INSTITUTIONAL CLEARANCE

Approved.

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