Augmented Reality Technology to Facilitate Proficiency in Emergency Medical Procedures

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Abstract

Background: *Augmented reality (AR) conveys an experience during which the user's real-time environment is enhanced by computer-generated perceptual information; it is being investigated as a solution to enhance medical education and clinical practice. There is little literature on its utility for teaching emergency procedures.*
Methods: *A within-subjects trial was performed comparing traditional training to AR guidance for two emergency procedures. Lay-subjects and emergency medical technicians received video training and AR guidance for performing bag-valve-mask ventilation and needle-decompression. Subjects performed both procedures in a simulation setting after each training modality. Subject performance, acceptability and usability were analyzed.*
Results: *There was no difference in procedural performance between lay or EMT subjects for AR training, and no difference in subject-reported usefulness between the AR and control training.*
Conclusion: *AR mediated guidance for emergency medical procedures is feasible and efficacious. Subject performance after AR training was statistically undistinguishable from a didactic educational modality.*

Keywords: Augmented Reality, Emergency Medicine, Healthcare, Education

1. Introduction

Augmented reality (AR) is an emerging technology that is experiencing mounting interest in a variety of settings, including both medical education and practice-guidance (Azuma 1997; Munzer et. al., 2019). Augmented reality is defined as technology that meets three core requirements: (1) it combines real and virtual content, (2) it is interactive in real-time, and (3) it is registered in 3-dimensions (Azuma 1997). AR is channeled through a variety of wearable devices and has the potential to convey an interactive experience during which objects and surroundings present in the user's real environment are enhanced by computer-generated perceptual information (Munzer et. al., 2019). Over the last several years, impressive advances have been made in AR capabilities, allowing manufacturers to produce devices that are high-speed, portable, and economical and include consumer-

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friendly features such as high resolution, intuitive interfaces, integration with other technologies, and connectivity to the internet (Azuma 1997; Van Krevelen et. al., 2019). The improvement in features and accessibility has increased the practicality and feasibility of potential application of AR-assisted technology in many fields (Azuma 1997; Munzer et. al., 2019).

Within the scope of prehospital medicine, there may be numerous potential benefits of utilizing AR given the wide-breadth and scope of healthcare and its practice. There is the potential for real-time use for medical practice if practitioners can leverage virtual information and real-time patient information while uninterruptedly interacting with patients and providing care (Broach, et. al., 2018). First responders or rural providers may be able to transmit virtual representations of critically ill patients and receive step-by-step instructions for life-saving procedures in austere environments or at critical access facilities, thereby expediting the time from recognition of dangerous conditions to intervention (Munzer et. al., 2019). Such a strategy may allow "scope-shifting" of medical providers, expanding their practice to perform critical, time-sensitive tasks not normally encompassed by their traditional training in situations when a more advanced provider is not immediately available (Wilson et. al., 2013; Rojas-Muñoz et. al., 2020).

In the realm of education, AR technology could prove to be a practical tool for medical training for subjects in a variety of skills including anatomy and physiology, clinical practice, and procedural guidance given its integration of auditory, visual, and tactile stimuli (Dhar et. al., 2021; Ayoub et. al., 2019; Uruthiralingam et. al., 2020). Potential advantages of AR-mediated training include its provision of multimodal types of instructive stimuli for different types of learners, real-time availability, high level of interactivity, and ability to integrate with simulation equipment or real patients (Dhar et. al., 2021). Several previous studies suggest comparable or improved learning results when medical professionals utilize this technology for training purposes as compared to traditional in-person education (Aebersold et. al., 2018; Balian et. al., 2019; Rochlen et. al., 2017). These studies suggest that AR has the potential to serve as an effective primary training tool or enhancement for medical professionals.

The current literature is limited to medical professionals and students in healthcare training, and, to date, studies have not compared training results across different levels of baseline training, including non-medical lay-personnel. There is also a paucity of investigation pertaining to the feasibility of AR use for "just in time" training, during which subjects use the technology to learn and perform procedures for the first time in real time. Furthermore, prior studies have not extensively examined technology intended for out-of-hospital environments, an important potential application of AR technology. Thus, gaps continue to exist in evaluating the effectiveness of AR as a training modality to expedite proficiency in performing medical decision making and sophisticated procedures. Our study seeks to expand on the current literature by utilizing an AR device to train and evaluate non-physician providers and non-medically trained research subjects in emergent basic and advanced life support procedures and compare their performance using AR technology with traditional training methodologies.

2. Methods

2.1 Setting and Participants

Our investigation took place in a medical school affiliated with an urban academic tertiary care medical center. Two types of subjects were recruited: emergency medical Technician (EMT) subjects and lay subjects without prior medical training. EMT participants were recruited by an email distributed through local EMS agencies and were considered eligible if they were 18 or older and licensed active Basic Emergency Medical Technicians (EMT-Bs) with no higher level of licensure or training. Lay participants were recruited through local medical school staff, community listservs and word of mouth; they were eligible for inclusion if they were 18 or older and had no formal medical training or licensure. Non-English-speaking subjects, subjects with more extensive medical experience such as paramedics, nurses, or physicians, subjects under 18, and subjects unable to provide informed consent were excluded. All subjects received a small monetary reimbursement for their participation in the study. All study activities were performed over two separate days in a dedicated institutional simulation center. This study was approved by the Institutional Review Board of the affiliate medical school.

2.2 Procedure

This study was focused on the performance of two common emergency medical procedures: bag-valve-mask ventilation (BVM) and needle chest decompression. Bag-valve-mask ventilation is a method of ventilating an unconscious patient and providing "rescue breathing". The procedure involves using a chamber filled with oxygen and a fitted mask to force air into a patient through the mouth and nose.

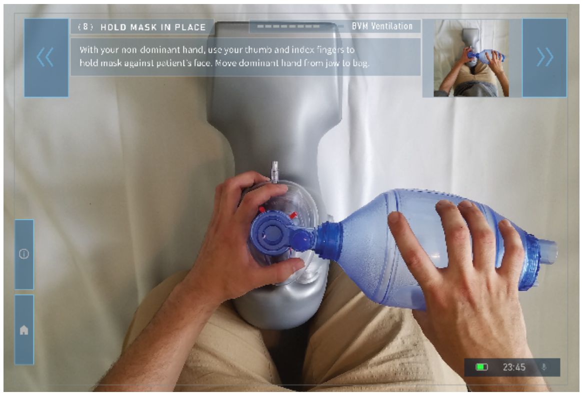
Needle decompression is a more invasive procedure whereby a practitioner inserts a needle into the chest wall of a patient to relieve built up air pressure that may be causing a collapse of the lung on the affected side of the chest.

In the state where this study took place, an EMT-B would be expected to be competent in performing BVM but would not be expected to be trained in needle decompression. A lay person would not be expected to be proficient in either and neither procedure would be a common component of a lay community first aid course.

All subjects participated in two types of training activities for the target procedures: a control condition video training and the investigational augmented reality (AR) condition. In the conventional "control training" activity, each subject watched a narrated lecture video for both medical procedures, performed by an experienced instructor who regularly teaches both skills to learners, demonstrating the steps to perform each task with visual aids. After watching the video, subjects were then asked to perform both the BVM and needle chest decompression procedures on simulation mannequins independently.

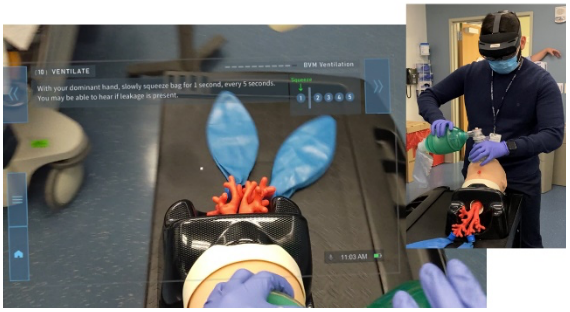
For the investigational AR training, we used human factors and user-centered design methods to design and develop a prototype heads-up display using the Microsoft HoloLens 2. This AR – based interface provides real-time training guidance on the targeted medical procedures and includes both voice command and eye tracking/hand gesture interaction mechanisms (e.g., say "next," or use the hand gesture "Air tap" after looking at the "next" icon, to move to the next guidance step). A key design consideration was to provide sufficient guidance to complete procedures, without detracting/obscuring attention in the visual field of view during medical care. The prototype consists of heads-up information display intended to provide stepwise guidance to the user through each stage of the studied medical procedures.

For the AR training condition, subjects were oriented to the hardware/software of the HoloLens prototype. They were coached through a calibration module and then instructed in how to use the experimental AR software. Subsequently, subjects were instructed to utilize the "just-in-time' AR modules to perform BVM and needle chest decompression procedures on simulation mannequins. Figure 1 and 2 illustrates the first and third person view of the AR training technology.



With your non-dominant hand, use your thumb and index fingers to hold mask against patient's face. Move dominant hand from jaw to bag.

Figure 1. First Person Perspective of the AR Software's user interface



With your dominant hand, slowly squeeze bag for 1 second, every 5 seconds. You may be able to hear if leakage is present.

Figure 2. First and Third Person Perspective of the AR Software/Hardware in use

Upon presentation to their study appointment, participants were randomized to begin with either the video-lecture control training or AR HoloLens training. All participants participated in both the control training and the AR training.

Subject completion of each medical procedure (BVM, Needle Decompression) was video recorded for later in-depth scoring. After completion of each procedure, subjects completed a corresponding set of survey materials regarding the training they received prior to the procedure. At the end of the study, materials were collected, and participants completed a demographics survey. In summary, each participant received two types of training. Conventional control training, delivered in the form of a pre-recorded video lecture and just-in-time guidance delivered via AR on a Microsoft HoloLens. Following each type of training, participants performed two medical procedures (BVM and needle decompression).

2.3 Measures

After each task for the two training types, subjects were instructed to fill out a usability and usefulness questionnaire pertaining to their experience with each type of training. This questionnaire consisted of four questions: (Q1) “Was the training you received conveyed to you in an effective and usable way?”; (Q2) “Was the training you received useful to you?”; (Q3) “Would you opt to use this method of training again?”; and (Q4) “How well do you feel you performed the medical tasks?”. Each question was rated on a seven-point scale, where a 1 = “not at all (*usable, useful, likely or unlikely to use again*)” or “very poor performance”, and 7 = “extremely (*usable, useful, likely to use again*)” or “excellent performance.”

Four expert evaluators who are board-certified emergency physicians observed the procedures and reviewed supplementary video footage of subjects completing each simulation task. Task performance was scored according to a predetermined validated rubric used for scoring practical examinations of EMS personnel (Massachusetts Office of Emergency Medical Services, 2019; National Registry of Emergency Medical Technicians, 2020). These rubrics awards 1 point each for each required psychomotor task performed correctly in support of the intended medical procedure such as setting up or operating a piece of equipment, rendering simulation care to a patient, or simulating the evaluation of the impact of an action. A “passing” score varies by local jurisdiction protocol and overall subject performance across a testing cohort. Each task was scored by 1 evaluator. Evaluators were blinded to EMS/lay status but not to the training method used for the procedure. Scores were reported as a percentage of possible total points achieved.

2.4 Analysis

All data were transcribed into Redcap, a secure online electronic database (Harris et. al., 2009). We analyzed the usability and usefulness questionnaire data, as well as the evaluator scoring data using a mixed-factor repeated measure ANOVA with Simulation Type (BVM, Needle-Decompression) and Training Type (AR, Control) as within subject factors, and Participant Type (EMT, Lay) and Training Order (AR first, Control first) as between subject factors. For post-hoc comparisons of statistically significant model effects (at $\alpha = .05$), adjustments for multiple comparisons were made using Bonferroni’s correction due to its power and robustness with small sample size (Field, 2009). All statistical analyses were completed using JASP version 0.16.1.

Sample size was chosen based on project resource constraints and a review of guidelines for studies using similar methods (i.e., comparative usability study) that suggest a sample size of between 8-25 (varying depending on study complexity), for detection of usability issues and group differences (Spyridakis and Fisher, 1992; Nielsen and Landauer, 1993; NIST, 2015; FDA, 2016).

3. Results

3.1 Demographics

We enrolled *N*=40 subjects in this trial, divided evenly into lay and EMT-basic cohorts (*n*=20 per group). Subject demographics as summarized in Table 1.

Table 1. Subject Demographics
Characteristics of study population (n (%))

	All	EMS	Lay
Age			
Mean	34.5	32.3	36.7
Median	28	28	28
Range	18,67	20,57	18,67
SD	14.1	10.81	16.52
Gender			
Male	24 (60)	14 (70)	10 (50)
Female	15 (38)	5 (25)	10 (50)
Nonbinary	1 (2.5)	1 (5)	0 (0)
Certification			
Lay	20 (50)	NA	20
EMT-Basic	20 (50)	20	NA
Race			
White	36 (90)	19 (95)	17 (85)
Asian	3 (7.5)	1 (5)	2 (10)
Black/African American	1 (2.5)	0 (0)	1 (5)
Native Hawaiian/Pacific Islander	0 (0)	0 (0)	0 (0)
American Indian/Alaska Native	0(0)	0 (0)	0 (0)
Ethnicity			
Hispanic/Latino	2 (5)	2 (10)	0 (0)
Non-Hispanic/Latino	38 (95)	18 (90)	20 (100)

3.2 Subject-Reported Usability Questionnaire

For questions related to usability, usefulness, and likelihood to use the training again (Q1-Q3), there were no statistically significant main effects or interactions of Participant Type or Training Order. For self-appraised performance ratings (Q4), there was only a statistically significant Subject Type main effect (F(1,36)=5.440, *p*=.026) such that EMTs (4.39) rated their own overall performance significantly higher than Novices (3.56) rated their own overall performance (*t*(19)=2.332, *p*=.026, *d*=0.373). See Table 2 for a summary of the Usability questionnaire results for all effects.

Our primary interest for this analysis focused on the effects of training type. See Table 3 for a summary of marginal means for each training condition. There was no effect of training type on overall ratings of usability, usefulness, or likelihood of using the training again (Q1-Q3). There was however a statistically significant effect of training type on participants' self-assessed performance ratings (Q4), such that they rated their performance higher when performing tasks with AR training than when performing them with Control training. There was no interaction of Participant Type and Training Type, indicating this effect did not differ across participants. For the significant interaction of Task and Training Type for all questions, the only meaningful difference from post-hoc analysis was for Q4. There was a significant interaction between Training Type and Task, such that self-assessed performance was greater for AR versus control training for the Needle-D task (*t*(19)=3.532, *p*=.005), but there was no difference between ratings for the BVM task (refer to Table 4 for ratings).

However, there was a statistically significant phenomenon whereupon subjects had greater ratings of self-assessed performance when using the AR training (4.58) compared to the control training (3.45) if they used the control training first (*t*(19)=3.568, *p*=.006). The opposite effect for control training in subjects who used the AR guidance first was not observed (t(19)= -0.274, *p*=1).

Table 2. Usability Questionnaire Results Summary *P-values reported for all model effects.*

Effects	Usable	Useful	Use again	Self-rated Perf.
Within-subjects effects				
Task	.003	.026	.003	<.001
Task*Subject Type	.027	.185	.003	<.001
Task*Training Order	.027	.445	.905	.190
Task*Subject Type*Training Order	.501	.341	.287	.516
Training Type	.957	.191	.352	.028
Training Type*Subject Type	.033	.227	.262	.341
Training Type*Training Order	.026	.038	.017	.011
Training Type*Subject Type*Training Order	.103	.110	.063	.080
Task*Training Type	< .001	.001	.020	.006
Task*Training Type*Subject Type	0.148	0.774	0.252	0.693
Task*Training Type*Training Order	0.235	0.255	0.753	0.666
Task*Training Type*Subject Type*Training Order	0.235	0.391	0.916	0.279
Between-subjects effects				
Subject Type	0.968	0.453	0.922	0.026
Training Order	0.777	0.707	0.58	0.787
Subject Type*Training Order	0.968	0.168	0.871	0.664

Table 3. Usability Questionnaire Ratings – Marginal Means by Training Type. *Overall ratings for the AR and Control training for all questions. Question rated on seven-point scale, where a 1 = "not at all (usable, useful, likely)" or "very poor performance", and 7 = "extremely (usable, useful, likely)" or "excellent performance."*

Train Type	Usable	Useful	Use-Again	Self-rated Performance
Contr	5.11	4.68	4.41	3.72
AR	5.13	5.00	4.78	4.23

Table 4. Usability Questionnaire Q4 – Self-Rated Performance – Marginal Means by Task and Training Type. *Mean ratings by Task and Training Type. Question rated on a seven-point scale, where a 1 = "very poor performance", and 7 = "excellent performance."*

Task	Train Type	Self-rated Perf.
BVM	AR	4.493
	Control	4.415
NdD	AR	3.974
	Control	3.015

Both subject cohorts were more likely to reuse both types of training (Q3) for BVM (4.76) than needle decompression (4.43) (*F*(1,36)=10.498, *p* = 0.003) and EMT subjects rated the BVM training (5.38) more usable (Q1) than the needle decompression training (4.88), across training types (F(1,36)=5.341, p=.027).

For the statistically significant Task-Subject Type effect for self-appraised performance ratings (*F*(1,36)=5.440, *p*=.026), EMT subjects self-rated their overall performance significantly higher than lay participants rate their own performance for both BVM (*t*(19)=3.842, *p*=.002) and needle decompression (*t*(19)=4.527, *p*<.001) and EMT subjects self-rated their performance on the BVM more highly than on needle decompression (*t*(19)=6.735, *p*<.001). There were no meaningful post-hoc analysis results for the Task-Training Order and Training Type-Subject Type significant effects for Q1.

3.3 Evaluator Assessment of Subject Performance

For the evaluator assessed performance scores (percentage of possible total points achieved), the statistically significant effects for overall performance (all tasks) were the Task main effect (*F*(1,36)=38.410, *p*<.001), Subject Type main effect (*F*(1,36)=9.321, *p*=.004) and Task-Subject Type interaction effect (*F*(1,36)=5.723, *p*=.022). All subjects scored more highly on the BVM task (62) than the needle decompression task (47) and EMTs had higher scores (62) than Lay subjects (47). EMT scores for the BVM task were significantly higher than scores for EMT needle decompression (*t*(19)=6.074, *p*<.001) and both Lay subjects task performance scores (BVM: (*t*(19)=3.815, *p*=.002; NdD: (*t*(19)=5.584, *p*<.001)). No other significant effects were found. Table 5 summarizes overall subject performance scores for both subject and task types by training type and the order in which they completed training (control training first versus AR training first).

Table 5. Subject Performance
Mean score percentile achieved by subjects, divided by task, training and subject type

Task	Train Type	Sub Type	AR or Contr First	Mean Score (%)	SD
BVM	AR	EMT	Contr	67	27
			AR	65	29
		Lay	Contr	57	22
			AR	48	29
	Control	EMT	Contr	75	15
			AR	81	10
		Lay	Contr	57	26
			AR	46	23
NdD	AR	EMT	Contr	49	13
			AR	47	20
		Lay	Contr	45	13
			AR	39	22
	Control	EMT	Contr	51	14
			AR	56	19
		Lay	Contr	43	20
			AR	42	15

4. Discussion

This study yields preliminary evidence to support the potential of AR to be employed as a novel modality for training and real-time practice guidance in the little-investigated realm of emergency medical procedures. Such a strategy has the potential to be highly useful in numerous settings that currently suffer from a critical shortage of highly skilled medical providers including austere, and rural environments, as well as combat situations. This project also uniquely offers groundwork evidence that completely novice learners can use AR to successfully perform highly technical medical procedures.

AR has gained attention as a relatively new modality for training and practice guidance with great potential in a variety of fields, including medicine. It holds the advantage of offering portable, “just-in-time” delivery of content and multimodal stimulus for a variety of learners. Because the technology integrates computer generated information with the environment of the user, it can provide a vivid, detailed projection of a desired task which may allow those using it to perform procedural and cognitive processes successfully even if the user is novice to them. Leveraging AR technology to task-shift advanced procedures and medical decision making to additional personnel may expand the availability of critical medical procedures.

Overall, subjects rated the AR usability and usefulness, and their likelihood to use these training modalities again equally to the standard training, suggesting that AR was perceived by both lay and professional subjects as being comparably acceptable to traditional training. Lack of familiarity with the AR hardware and software did not appear to pose a significant barrier to either cohort, and subjects were able to quickly adapt to and learn the use of the AR technology to successfully perform the require simulation tasks. Additionally, both subjects with no medical training and those with a baseline certification were able to successfully interface with the AR guidance, suggesting that the AR technology can be feasibly used across learners with a variety of foundational knowledge and experience.

When comparing procedure type, subjects preferred BVM over needle decompression across both the control and AR training in their ratings of usability, usefulness, or likelihood to use again. There are several possibilities for this finding including the relatively simplicity of the BVM procedure versus the needle decompression or the less invasive nature of this procedure. The fact that this procedure is a core skill required for EMT certification and therefore very familiar to that cohort likely increased "comfort" with the procedure. All these factors may have impacted the observed ratings.

There was also a phenomenon of increased perceived usefulness of training with the AR training when it was accessed after the control training. Subjects were globally more confident in their performance after using the AR technology if they accessed control training first, suggesting that having "just-in-time" guidance with stepwise visual stimuli improved their comfort levels with performing the procedures. However, if subjects received AR training first followed by control training, there was no difference in perceived performance or usefulness between the two training types.

These findings may suggest evidence of the superiority of the AR guidance with regards to establishing self-perceived proficiency of task performance over control training. They may also suggest that the optimal training modality may in fact be a hybrid of AR and traditional training, whereupon users receive baseline training for target tasks remote to their actual performance, then AR "just in time" guidance in real time when performing them at a future date.

EMT subjects achieved higher task scores across all tasks, which is expected given their professional experiences and the fact that the BVM task is standard to their scope of practice. They likely also had some increased comfort with the clinical evaluation environment used in simulation, as they are required to perform in a monitored practical exam to attain initial licensing. Interestingly, the statistical significance of this phenomenon is lost for the BVM task when only the AR-guided tasks are considered. There is also no statistically significant difference between subject type performance on the needle decompression task, which was most likely to be unfamiliar to all subjects. The achieved scores were also within a narrower range across all subjects than with the BVM tasks. These findings suggest that even lay subjects with no medical training can achieve tasks with comparable success to health professionals when provided with adequate training. Both cohorts achieved higher scores with the BVM task than the needle decompression, which is likely explained by the factors discussed previously.

There was also no statistically significant difference between the scores achieved by either subject type when task scores were compared between control and AR training. Training order did not have a significant interaction with this finding, thus suggesting that the AR technology may be as effective as control training for fostering proficiency in the investigated tasks and could potentially be used as a substitute for control training or as a supplement to subjects who received traditional training long in advance of needing to perform the procedure. It also suggests that people with no medical background can be successfully prompted to perform tactile medical procedures and achieve success comparable to medical providers with the use of AR technology, opening numerous avenues for task-shifting to new populations in low-resource environments such as austere settings or disaster situations.

Our study is limited by a smaller sample size and a within-subjects model. It may have been underpowered to detect comparative differences in subject or training-type useability ratings and task performance. This study also investigated only two procedures that required a limited range of cognitive and tactile skills from subjects. All simulations were performed in a highly controlled medium fidelity environment with comfortable subject positioning and lighting as well as limited external stimuli. The control training was performed using a pre-recorded video. While this ensured standardization of the training material delivered, it lacks some potentially beneficial aspects of true in-person training including the opportunity to ask questions and receive personalized coaching or observed hands-on education. When participating in the control module, subjects performed all simulations immediately after undergoing training rather than a future time remote to the initial training which likely impacted subjects' recall of the procedures.

A larger randomized control model assigning subjects of comparable experience level to either AR or control training would more rigorously validate the efficacy of the AR training. Additional procedures with different levels of cognitive and tactile difficulty also may be investigated to determine whether the performance of AR software is dependent on the type and/or complexity of techniques being practiced. Going forward, we anticipate that investigations in field and/or high-fidelity environments are warranted to determine whether AR technologies are usable and effective in realistic practice environments, especially in high stimulus environments such as austere or combat settings. Ultimately, such research may serve to guide examination of policies and guidelines related to “scope of practice”, licensure, and credentialing as technology-enabled task shifting may allow for medical providers to perform more sophisticated clinical procedures safely and effectively beyond the scope of their traditional roles (Sabet Sarvestani et. al., 2021). Additional consideration will also need to be given to the pros and cons of AR versus video-mediated training with regards to its cost, practicality, and appropriateness for the setting in which it is employed.

In conclusion, our investigation demonstrates that AR mediated, “just-in-time” guidance for select emergency medical procedures has potential to be as effective as more traditional didactic-based educational method for non-physician providers, and our findings reveal that AR training may generate greater self-appraised performance by learners. These observations, coupled with AR’s potential for real-time remote interactions and the ongoing rapid advances in AR technology, suggest that there is significant potential for this modality in education. Further study is needed to rigorously evaluate AR technology via randomized control trials utilizing high fidelity-simulation (and eventually in-situ) settings to validate its efficacy as a means of developing provider, and potentially even lay-person, proficiency in unfamiliar emergency medical tasks and procedures.

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