Applying Virtual Reality, Augmented Reality, and Artificial Intelligence for Immersive and Interactive CPR Training Assistants

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Abstract. With the advancements in Virtual Reality (VR), Augmented Reality (AR), and Artificial Intelligence (AI), medicine is witnessing a paradigm shift, especially in training methodologies for emergency procedures like Cardiopulmonary Resuscitation (CPR). This research collates recent findings on how these technologies can be utilized to provide more effective CPR training tools that could transform bystanders into effective first responders during out-of-hospital cardiac arrests. The study encompasses various aspects of these technologies, from their individual benefits in a training environment to their combined potential in real-time emergency scenarios. By analyzing the integration of VR/AR tools, AI's decision-making capacities, and conversational AI's real-time guidance, this paper sheds light on the future of CPR training and its potential implications for emergency healthcare.

I. INTRODUCTION

Cardiopulmonary Resuscitation (CPR) is a crucial intervention during cardiac emergencies, and its effective administration can often make the difference between life and death. Traditionally, CPR training has been in-person, focusing on manikins and instructors. However, with the rise of VR, AR, and AI technologies, there is a compelling case to be made for enhancing how we approach CPR training.

Given the prevalence of out-of-hospital cardiac arrests and the importance of bystander intervention, it is important to ensure that more individuals are trained in CPR and confident in their abilities to administer it effectively. With devices like Oculus Quest, HTC VIVE, Google Glass, and HoloLens, we are not limited to traditional training boundaries. These tools, combined with the cognitive capabilities of AI and the interactive potential of conversational AI like ChatGPT, herald a new era of CPR training—one where even untrained bystanders can receive real-time guidance during emergencies, potentially increasing survival rates.

II. VIRTUAL AND AUGMENTED REALITY IN CPR TRAINING

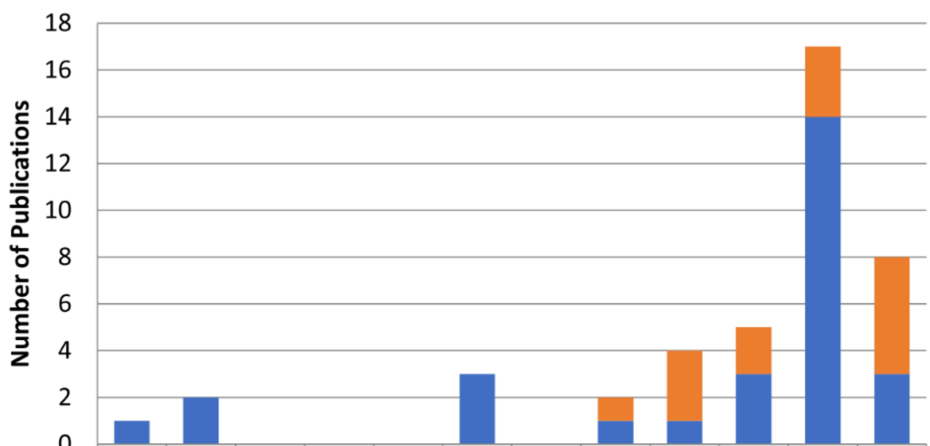
2.1. The Imperative of CPR Training. Cardiopulmonary Resuscitation (CPR) is a crucial emergency response during cardiac arrests. A notable research titled "The Construction of Lay Rescuers in Bystander CPR Classes'" underlines this importance. After observing multiple CPR classes, the study encapsulated three pivotal ways in which CPR training molds lay rescuers:

1. Imparting knowledge about the correct CPR procedure—from checking the patient's consciousness to initiating chest compressions.
2. Providing hands-on experience with manikins and invaluable feedback from certified trainers.
3. Instilling a sense of urgency and emphasizing real-world situations where bystander interventions have been life-saving.

Such training methods create a cadre of lay rescuers adept at intervening during cardiac emergencies, thereby augmenting survival rates during out-of-hospital cardiac arrests [1].

2.2. Barriers to Bystander CPR. However, as the paper "Barriers to bystander CPR in deprived communities: Findings from a qualitative study" points out, a significant barrier remains: the confidence of potential bystanders. Interviews with residents of underprivileged communities in central Scotland revealed that the main barrier to bystander CPR intervention was not just a lack of knowledge, but a lack of confidence [2]. Rooted in inadequate access to formal CPR training, bystander apprehension underscores the urgent need for innovative and accessible training methodologies.

2.3. Virtual Reality: Oculus Quest and HTC VIVE. Venturing into the realm of technological solutions, the scoping review "The use of virtual reality and augmented reality to enhance cardio-pulmonary resuscitation: a scoping review" reveals a promising vista of possibilities. As shown in Fig. 1, the paper chronicles the surge in VR and AR research [3]. With devices like the Oculus Quest, users experience real-time instruction, feedback, and immersion in realistic environments. Personal research on VR tools like CPR Simulator, available on Oculus Quest, demonstrates how visual and auditory guidance, quiz-based reinforcement, and a user-friendly interface can make CPR training more intuitive and efficient. The tool is a revolutionary start, but it could be improved with the incorporation of an AR manikin and more realistic hand interactions for a more holistic training experience.



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
AR	0	0	0	0	0	0	0	1	3	2	3	5
VR	1	2	0	0	0	3	0	1	1	3	14	3

Fig. 1. Graphical representation of publications per year. Data collected June 2020 (adapted from [3]).

The paper "Virtual Reality Simulation Technology for Cardiopulmonary Resuscitation Training: An Innovative Hybrid System With Haptic Feedback" further explores VR's potential for CPR training. This research introduces a hybrid system that combines the tactile feedback of a manikin with VR's immersive experience. Utilizing tools like the HTC VIVE and the VIVE Tracker, the authors have reimagined CPR training, making it more accessible, reliable, and immersive.

A pivotal aspect of their work is the incorporation of the VIVE Tracker to ensure hands-on quality training in the CPR simulation. As illustrated in Fig. 2, the tracker captures the user's hand positions in the VR environment, enabling them to perform chest compressions freely. The software evaluates the compressions, measuring variables like rate, frequency, and hand placement on the manikin or victim's chest. A compression is deemed successful based on two crucial criteria: depth and recoil.

Fig. 2. HTC VIVE Tracker attached to a glove enabling accurate tracking without interference with CPR performance (adapted from [4]).

Fig. 3. 3D model of realistic human victim overlay the mannequin in VR space (adapted from [4]).

The authors integrated a real CPR half-torso manikin into the VR space to give users realistic feedback. As shown in Fig. 3, this was overlaid with a 3D human body model, ensuring users experienced an authentic tactile response while immersed in the virtual environment.

Beyond these innovative features, the application also boasts a range of other functions to enhance the training experience. These include infographics, audiovisual aids, 3D instructional characters, and multiple-choice questions accompanied by explanations. Users are presented with simulated virtual scenarios to emulate real-life emergencies, which are complemented by real-time feedback. As illustrated in Fig. 4, Fig. 5, Fig. 6, the experience is further heightened through gamification elements such as varying difficulty levels, a scoring system, and competitive leaderboards [4].

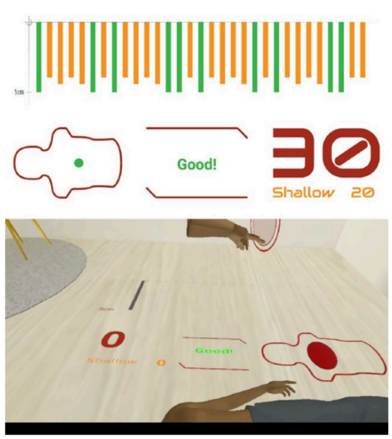


Fig. 4. Real-time feedback of CPR performance (adapted from [4]).

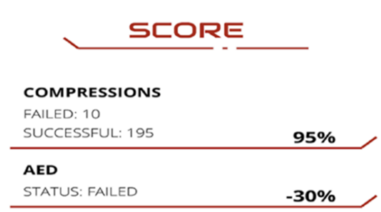


Fig. 5. Scoring system with informative feedback and assessment (adapted from [4]).

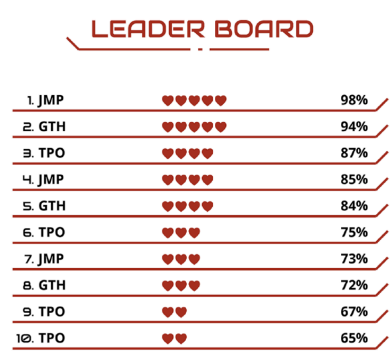


Fig. 6. Leaderboard for gamification and engagement (adapted from [4]).

This holistic approach to CPR training harnesses the best of both physical and virtual realms, introducing a new standard for medical training simulations.

2.4. Augmented Reality: Google Glass and HoloLens. Augmented reality, blending the boundaries between the virtual and the real, introduces another dimension to traditional training methods. As underscored in the study, "Augmented Reality in Emergency Medicine: A Scoping Review" AR can overlay critical patient information in real-time, enhancing the provider's efficiency [5]. This sentiment is further echoed in the "Feasibility of Augmented Reality in Clinical Simulations: Using Google Glass With Manikins" study. Medical students aided by Google Glass showcased enhanced accuracy during simulated medical procedures. As depicted in Fig. 7, most students endorsed the continued integration of Google Glass technology in clinical simulations [6].

Measures		Mean (SD)
Simulation Design Scale		
	Objectives and information	4.65 (0.18)
	Support	4.85 (0.04)
	Problem solving	4.53 (0.30)
	Feedback/guided reflection	4.85 (0.14)
	Fidelity (realism)	4.67 (0.12)
Student Satisfaction and Self-Confidence in Learning		
	Satisfaction with current learning	4.67 (0.13)
	Self-confidence in learning	4.35 (0.60)

Fig. 7. Medical students' mean responses on the Simulation Design Scale and Student Satisfaction and Self-Confidence learning surveys, on a scale from 1 (strongly disagree) to 5 (strongly agree) (adapted from [6]).

Additionally, the study "Adherence to AHA Guidelines When Adapted for Augmented Reality Glasses for Assisted Pediatric Cardiopulmonary Resuscitation," explores the potential of AR glasses in improving CPR adherence to the American Heart Association (AHA) guidelines. The research tested ten pediatric residents using AR glasses (Google Glass) against another ten using traditional pocket reference cards for CPR guidance. Based on AHA guidelines, the AR application provided real-time images, diagrams, a countdown clock for chest compressions, and automatic calculations for treatment and defibrillation doses. The findings were telling: residents using the AR glasses reduced errors by 53%, and cumulative defibrillation dose errors decreased by 37% [7]. In essence, AR glasses demonstrated a substantial potential to enhance CPR training's efficiency, adherence, and accuracy in line with AHA standards.

Another groundbreaking application, HoloCPR, discussed in the paper "HoloCPR: Designing and Evaluating a Mixed Reality Interface for Time-Critical Emergencies," offers an AR interface for CPR training, overlaying instructional steps on a physical manikin. The authors evaluated this tool's effectiveness by engaging forty-two participants in a study. Participants were tasked with executing CPR on a physical manikin guided by HoloCPR, with their performance metrics, including accuracy and response time, duly measured. For comparison, a control group relied on standard 2D instructions on a separate device, such as a tablet. The comparative evaluation elucidated that the HoloCPR users had better response times, accuracy, and overall performance, as illustrated in Fig. 8 and Table 1 [8]. This solidifies the potential of AR in training bystanders more effectively.

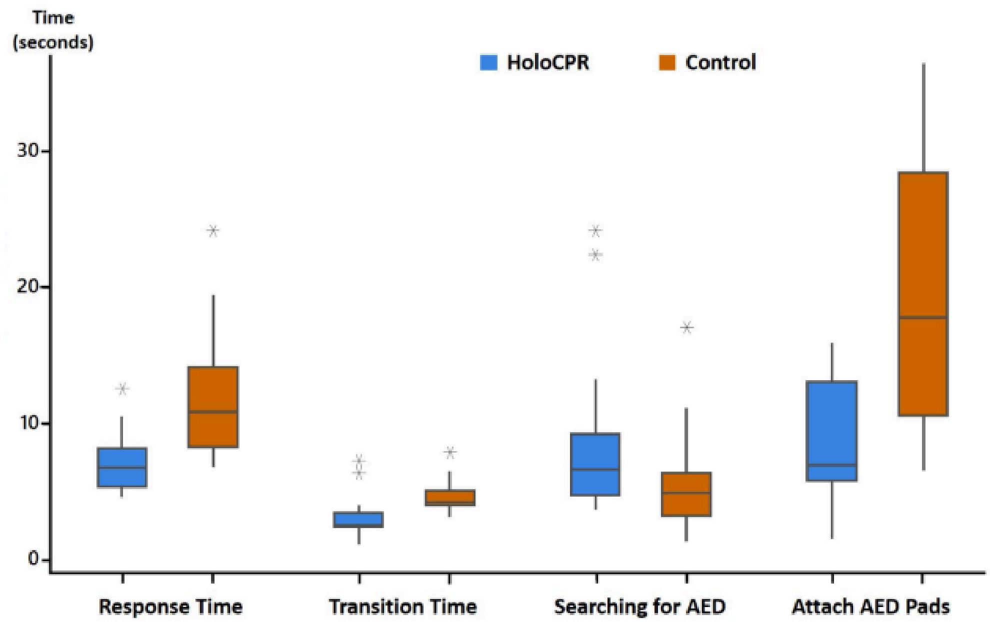


Fig. 8. Response time, transition time, time spent searching for the AED, and time taken to attach AED pads across both conditions (adapted from [8]).

Metric	**HoloCPR**	**Control**
Time to react	7.04 seconds	11.96 seconds
Time to find AED	8.61 seconds	5.77 seconds
Time to attach AED pads	8.98 seconds	19.41 seconds
AED pad placement	17.65% incorrect	18.7% incorrect
Time to transition to next steps	3.17 seconds	4.65 seconds
Staying on track with procedure (7 steps)	1 deviation (2 additional steps)	3 deviations (additional rounds of chest compressions or rescue breaths)
Hand position	41% correct Of the 48% that started with the wrong form, 30% corrected their form	12.5% correct Of the 87.5% that started with the wrong form, none corrected their form

Table 1. Response time, AED phase time, transition time, and adherence to proper procedure (adapted from [8]).

2.5. Conclusion of the Section. As CPR remains a crucial emergency intervention, leveraging the capabilities of VR and AR for its training can bridge the current confidence and accessibility gap. These technologies can transform bystanders into effective first responders through immersive, interactive, and real-time guidance, ultimately increasing the chances of saving lives during cardiac emergencies.

III. ROLE OF ARTIFICIAL INTELLIGENCE IN HEALTHCARE

3.1. Why AI? Artificial Intelligence (AI) has rapidly transitioned from a futuristic concept to an essential tool in various sectors, especially healthcare. A seminal research titled "A systematic review of trustworthy and explainable artificial intelligence in healthcare" underlines the motivations behind integrating AI into the medical domain. Firstly, AI possesses the potential to revolutionize patient care. With its recent advancements, AI can aid in more accurate diagnostics, predict patient needs, and optimize treatment plans. Additionally, AI acts as an invaluable support system for healthcare providers. It can streamline administrative tasks, offer clinical recommendations, and even provide mental health interventions, amplifying the efficacy of the healthcare system.

However, a set of prerequisites is necessary to genuinely integrate AI into clinical practice. The same research enumerates seven requirements to deem an AI system as 'trustworthy': human oversight, stringent data governance, technical robustness, accountability, complete transparency, an inherent bias-free nature, and an alignment with societal well-being [9].

3.2. Why Explainability? With the increasing complexities of AI models, a pertinent question arises: How do these models make decisions? The paper "To explain or not to explain?—Artificial intelligence explainability in clinical decision support systems," delves into the essence of this question. It underscores the importance of 'explainability' in AI-powered Clinical Decision Support Systems (CDSS). Understanding the rationale behind AI recommendations is critical when decisions can be life-altering.

For instance, the study highlights an AI-based CDSS designed to detect out-of-hospital cardiac arrests from emergency calls. While the system could identify such events faster than human dispatchers, it was often disregarded due to a lack of trust from previous inaccuracies. Without explainability, AI's decisions remain binary—either alerting or remaining silent—with the same level of confidence irrespective of the situation [10]. Such unwavering decisions, without context, can be detrimental, especially when incorrect. Explainability, therefore, acts as the bridge fostering trust between AI and its human counterparts.

3.3. Framework for Creating XAI. For AI to be genuinely beneficial, especially in a nuanced domain like healthcare, its operations and decisions should be interpretable by its human users. The paper "Explainable artificial intelligence for mental health through transparency and interpretability for understandability," introduces the Transparency and Interpretability for Understandable Models (TIFU) framework, which aims to create an interpretable AI. As elucidated in Fig. 9, the TIFU framework proposes a balance between the accuracy of the AI model and the readability of its explanations, ensuring AI's utility for the average user. It is a guide to ensure that the explanations generated by AI align with the clinical requirements and patient needs [11].

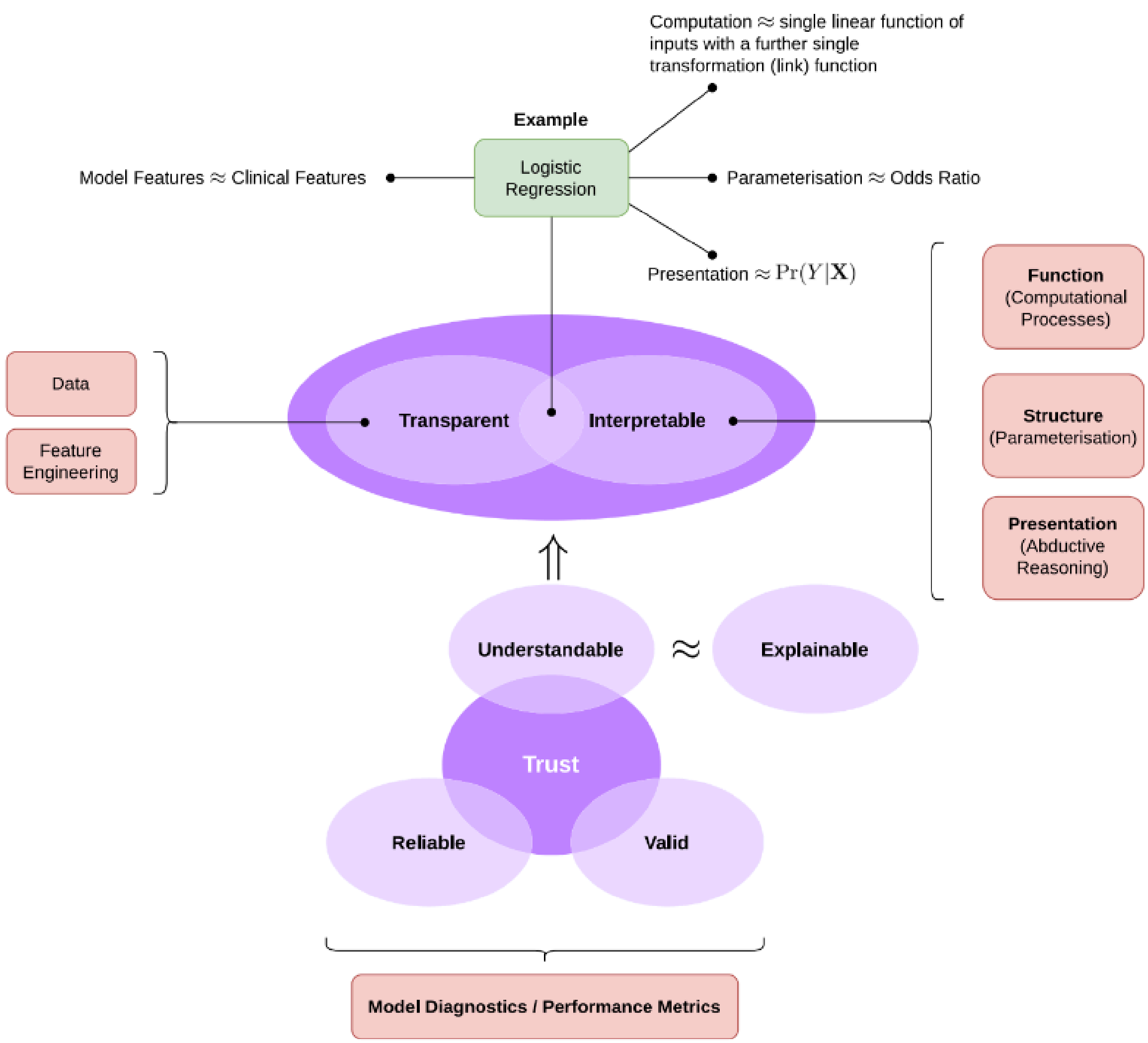


Fig. 9. The transparency and interpretability for understandable models (TIFU) framework emphasizes "explainability" in models through a balance of transparency and interpretability. For instance, logistic regression is highlighted as a model that epitomizes both of these qualities (adapted from [11]).

3.4. XAI Methods. Delving deeper into the realm of XAI, the research titled "A Review on Explainable Artificial Intelligence for Healthcare: Why, How, and When?" categorizes the XAI methods into three broad spectrums. These are:

1. **Local Methods:** Explains the decision made by the AI for a specific instance or input.
2. **Global Methods:** Explains the AI model's general decision-making logic and structure.
3. **Model Introspection Methods:** Explains the AI model's inner structure and parameters.

Each method offers insights at different granularity levels, from a focused explanation for a single decision to an overarching view of the model's functioning. The challenges of XAI in healthcare, as highlighted by the paper, are primarily the complexity of healthcare data and the often multifaceted nature of medical decisions, where a definitive 'truth' or 'correct decision' is hard to define [12].

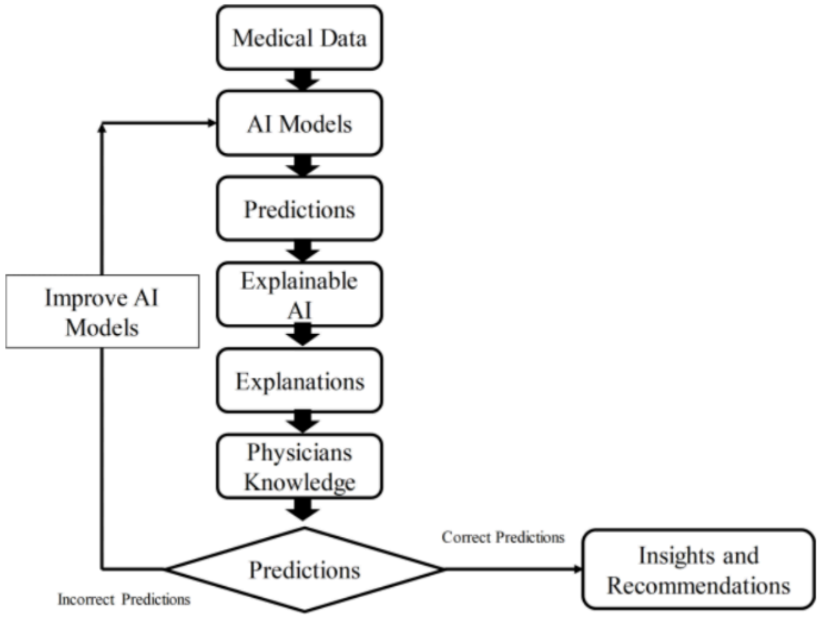


Fig. 10. An overview of the XAI system step by step (adapted from [12]).

3.5. Conclusion of the Section. As healthcare increasingly gravitates towards digital transformation, the role of AI becomes more pronounced. However, for AI to be a genuine ally in clinical scenarios, its decisions must be understandable, transparent, and rooted in the ethos of patient care. Advances in frameworks like TIFU and XAI methods enable a collaborative future for AI and healthcare professionals.

IV. CONVERSATIONAL AI IN MEDICINE

4.1. Introduction to Conversational AI. As Artificial Intelligence (AI) and healthcare converge, a new frontier emerges: Conversational AI. Conversational AI refers to technology that enables machines to simulate human-like interactions, often through voice or text-based dialogue. It combines natural language processing, machine learning, and a structured knowledge base to create an interaction that can offer advice, answer queries, and provide guidance in real-time. Conversational AI has the potential to revolutionize healthcare by providing quick and accurate responses in life-or-death situations.

4.2. "ChatGPT, can you help me save my child's life?". Among the pioneering studies in this field is the paper titled "'ChatGPT, can you help me save my child's life?' - Diagnostic Accuracy and Supportive Capabilities to lay rescuers by ChatGPT in prehospital Basic Life Support and Paediatric Advanced Life Support cases – an in silico analysis". The research investigates the capabilities of ChatGPT, a state-of-the-art conversational AI, in providing diagnostic and supportive assistance in prehospital Basic Life Support (BLS) and Paediatric Advanced Life Support (PALS) cases.

The researchers undertook an in silico analysis of ChatGPT's performance across 22 distinct BLS and PALS cases, creating 132 unique scenarios or prompts. The analysis aimed to assess ChatGPT's potential as a diagnostic tool lay rescuers could consult during emergency medical situations.

No	Scenario	Expected Diagnosis Keyword	Expected /Unexpected Therapy Keyword
1	**UPPER AIRWAY / FOREIGN BODY ASPIRATION** This case is about a 2-year-old child with breathing difficulties after aspiration of a Lego brick and showing the universal choking signs with her hands around the neck. Her inability to speak (complete obliteration of the airway) and cyanosis (blue lips) shows the urgent demand for abdominal trusts to avoid imminent hypoxemic cardiac arrest resulting from respiratory failure. **Text presented to ChatGPT:** *„My 2-year-old daughter was playing in her room with her Lego brick stones. Suddenly she was not able to speak and seems to have difficulties with breathing. She is able to communicate but cannot speak. Her Lips are blue, and she holds her neck with both hands. She is anxious. What is the likely diagnosis? And what can I do?"*	Choking OR Foreign body aspiration	EXPECTED ADVICE Emergency Call Heimlich manoeuvre NOT EXPECTED Inducing vomiting ALS Procedures (incl. Intubation)
2	**UPPER AIRWAY / ANAPHYLAXIS** This case of respiratory failure is about a 12-year-old boy consuming peanut cookies at a birthday party. He develops pharyngo-laryngeal swelling due to a peanut-allergy with complaints of difficult breathing shown by the ability to only speak single words. High pitched sounds on inspiration indicate inspiratory stridor. Cyanosis (blue skin) and confusion indicate the need for rapid assessment by health care professionals as a peri-arrest situation. **Text presented to ChatGPT:** *„My 12 year old son is at a birthday party. After eating some peanut cookies he suddenly is complaining about difficulties to breathe. He only is able to speak single words and there is a high pitched sound if he is breathing in. His skin is slightly blue and his seems to lose consciousness. What is the diagnosis? What can I do?"*	Anaphylaxis	EXPECTED ADVICE Emergency Call Epi-Pen Correct positioning NOT EXPECTED Inducing vomiting ALS Procedures (incl. Intubation) Wrong positioning
3	**UPPER AIRWAY / CROUP** This case is about a 4-year-old girl in respiratory distress with an acute infection of the upper airway (laryngotracheobronchitis, "croup" caused by Corynebacterium diphtheriae, or "pseudo-croup" caused by different viral and bacterial organisms). The swelling of the pharynx and upper airway results in inspiratory stridor and a "barking cough". **Text presented to ChatGPT:** *"My 4-year-old daughter is not feeling well. She suffered from fever this evening up to 39,6 Degrees Celsius. Now she complains that breathing is very difficult. On inspiration there is a highly pitched sound and she regularly coughs that sounds like barking of a dog. Her skin is ok, she moves normally but is slightly anxious. What is the diagnosis? What can I do?"*	Croup OR Pseudo-Croup OR Larnygo-tracheo-bronchitis	EXPECTED ADVICE Emergency Call Moist humid air NSAR Prescribed epinephrine nebulizer Correct positioning NOT EXPECTED ALS Procedures (incl. Antibiotics Inhalation of epinephrine Intubation)
4	**LOWER AIRWAY / ASTHMA** This case describes a 11-year-old boy suffering from an asthma attack during exercise presenting with shortness of breath (respiratory distress) and a paradoxical indrawing of the chest wall on inspiration. **Text presented to ChatGPT:** *„My 11-year-old son is at sports event. After a sprint he complains about short breath. And we hear a highly pitched sound when he exhales. Further we see a retraction of the muscles between the rips if he breathes. He is not feeling well. His skin is wet, and he is exhausted and anxious. What is the diagnosis? What can I do?"*	Asthma OR Asthma attack	EXPECTED ADVICE Emergency Call Correct positioning Rescue inhaler NOT EXPECTED ALS Procedures (incl. Intubation, Antibiotics)

Fig. 11. Some cases presented to ChatGPT and GPT-4 with the expected/unexpected advice and diagnoses (adapted from [13]).

4.3. Key Findings. Several findings from the study underscore the capabilities of ChatGPT in emergency scenarios:

1. **Emergency Medical Services (EMS) Alerts:** ChatGPT advised calling the EMS in 94 of 132 scenarios (71.2%)
2. **Emergency Detection:** The AI could correctly identify 12 out of the 22 cases (54.5%) as emergencies.
3. **First Aid Advice:** ChatGPT provided valid first aid guidance in 83 of 132 scenarios (62.9%)
4. **Diagnostic Accuracy:** Correct advice was significantly lower than 95%

Case	Typ	Case-Description	Correct Diagnosis	Alternative Diagnosis	Correct Call for Help	Correct Advice	ALS Advice	Disclaimer	Safety
1	R	Choking	100%	60% (50%/66%)	100%	40% (100% / 0%)	0%	40% (100%/0%)	40% (100%/0%)
2	R	Anaphylaxis	100%	0%	100%	66% (100%/ 33%)	0%	33% (50%/0%)	100%
3	R	Croup	100%	0%	67% (33% / 100%)	83% (66%/100%)	0%	50% (100%/0%)	67% (33%/100%)
4	R	Asthma attack	100%	16.7% (33% / 0%)	67% (33.3%/100%)	100%	0%	33% (66.6%/0%)	67% (33%/100%)
5	R	Bronchiolitis	100%	83% (67%/100%)	67% (33.3% /100%)	67% (33%/100%)	67% (67% / 67%)	50% (100%/0%)	17% (33%/0%)
6	R	Pneumonia	100%	50% (67% / 33.3%)	100%	100%	0%	50% (100%/0%)	100%
7	R	Opioid Intoxication	100%	0%	100%	17% (33% / 0%)	0%	66.7% (100% / 33.3%)	17% (33.3%/0%)
8	R	Intracranial Pressure	100%	83% (67%/100%)	100%	33% (33%/33%)	0%	50% (100%/0%)	33% (33%/33%)
9	R	Duchenne Muscle Dystrophy	100%	33% (33%/33%)	100%	17% (0%/33%)	0%	50% (100%/0%)	17% (0%/33%)
10	S	Non-Hemor-rhagic Shock	100%	100%	0%	100%	0%	67% (100% / 33%)	0%
11	S	Hemorrhagic Shock	100%	0%	100%	100%	83.3% (100%/ 67%)	50% (100%/0%)	83.3% (100%/ 67%)
12	S	Septic Shock	66.7% (33%/100%)	100%	17% (0% / 33%)	83% (67%/100%	0%	50% (100%/0%)	17% (0% / 33%)
13	S	Anaphylactic Shock	100%	16.7% (33%/0%)	100%	100%	0%	50% (100%/0%)	100%
14	S	Neurogenic Shock	100%	67% (33%/100%)	83% (100%/67%)	83% (100%/67%)	0%	50% (100%/0%)	83% (100%/67%)
15	S	Arrhythmia (supraventricular tachycardia)	100%	67% (100%/33%)	17% (0%/33%)	33% (33%/33%)	33% (67%/0%)	50% (100%/0%)	0%

Fig. 12. A snapshot of the results and analysis of ChatGPT and GPT-4's responses (adapted from [13]).

4.4. Real-World Implications. The broader context of the study results suggests promising conclusions for the future use of ChatGPT in healthcare. Despite ChatGPT's inconsistent performance, even professionals such as emergency call center operators, telephone triage nurses, and general practitioners often have an accuracy rate below 95% in emergencies, sometimes below a 60% threshold in sensitivity or specificity. Remarkably, ChatGPT already surpasses these human benchmarks in emergency scenarios. Given that this is an initial evaluation without specific prior training, the results hint at a vast potential for ChatGPT in handling real-world emergencies as it continues to evolve through future research [13]. Moreover, the ability to instantly access an AI tool like ChatGPT during emergencies, particularly for laypersons, could be transformative. Accurate guidance could bridge the crucial time gap between the onset of a medical emergency and professional medical intervention, potentially saving countless lives.

4.5. Conclusion of the Section. Conversational AI's emergence in the medical domain promises a new paradigm of patient care, support, and intervention. The research on ChatGPT's performance in BLS and PALS cases imagines a future where AI might assist medical professionals and empower laypersons to act effectively during medical emergencies. As technology advances and conversational AI models like ChatGPT receive more specialized healthcare training, AI may become a viable first response in healthcare.

V. CONCLUSION

As technology and healthcare converge, we stand on the precipice of a new era in medical intervention, training, and support. Integrating VR, AR, and AI into healthcare marks an evolutionary stride, challenging us to reconsider our understanding of medical training, patient care, and emergency response.

Building on what we have explored, introducing VR and AR into CPR training can redefine our pedagogical approaches, making medical training more accessible and immersive. By reducing barriers to training, especially in deprived communities, and enhancing the fidelity of simulated environments, we open opportunities for individuals to become adept lay rescuers. Having a well-informed bystander present during a cardiac emergency can make a life-or-death difference.

Beyond diagnostic assistance, the integration of AI into healthcare opens a new frontier where trust in machine intelligence is essential. As AI tools become more transparent by explaining their decisions, we envision a future where human-machine collaboration in clinical settings is not only beneficial but indispensable. Imagine an untrained individual, guided by a combination of AR glasses and conversational AI, administering life-saving procedures with precision until professional medical help arrives.

Nevertheless, while the promise is vast, so is the responsibility. Integrating VR, AR, and AI into medicine demands rigorous validation, continuous refinement, and an unwavering commitment to patient safety and ethical considerations. As we harness the power of these advancements, we must also cultivate a culture of continuous learning and adaptability among healthcare professionals and laypersons alike.

Our exploration into the nexus of technology and medicine is not just about leveraging cutting-edge tools, but about reimagining the ethos of healthcare. It is about building a world where every individual can be empowered by technology to make informed, effective, and timely decisions in the face of medical emergencies. The fusion of VR, AR, and AI in healthcare is poised to democratize emergency response, saving lives on a global scale.

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