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RESEARCH ARTICLE

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Elucidating cognitive processes in cardiac arrest team leaders: a virtual reality-based cued-recall study of experts and novices

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ABSTRACT

Background: Team leadership during medical emergencies like cardiac arrest resuscitation is cognitively demanding, especially for trainees. These cognitive processes remain poorly characterized due to measurement challenges. Using virtual reality simulation, this study aimed to elucidate and compare communication and cognitive processes-such as decision-making, cognitive load, perceived pitfalls, and strategies-between expert and novice code team leaders to inform strategies for accelerating proficiency development.

Methods: A simulation-based mixed methods approach was utilized within a single large academic medical center, involving twelve standardized virtual reality cardiac arrest simulations. These 10- to 15-minutes simulation sessions were performed by seven experts and five novices. Following the simulations, a cognitive task analysis was conducted using a cued-recall protocol to identify the challenges, decision-making processes, and cognitive load experienced across the seven stages of each simulation.

Results: The analysis revealed 250 unique cognitive processes. In terms of reasoning patterns, experts used inductive reasoning, while novices tended to use deductive reasoning, considering treatments before assessments. Experts also demonstrated earlier consideration of potential reversible causes of cardiac arrest. Regarding team communication, experts reported more critical communications, with no shared subthemes between groups. Experts identified more teamwork pitfalls, and suggested more strategies compared to novices. For cognitive load, experts reported lower median cognitive load (53) compared to novices (80) across all stages, with the exception of the initial presentation phase.

Conclusions: The identified patterns of expert performance — superior teamwork skills, inductive clinical reasoning, and distributed cognitive strategiesn — can inform training programs aimed at accelerating expertise development.

KEY MESSAGES

1. Novel combination of virtual reality simulation and cognitive task analysis provides a promising educational tool for identifying and addressing gaps in resuscitation team leadership skills, offering a valuable approach to competency-based medical education in critical care scenarios.
2. The consistently high cognitive load reported by team leaders, regardless of experience level, suggests a need for guidance on strategies to better distribute cognitive demands among team members during cardiac arrest resuscitations.
3. Experts demonstrate more advanced teamwork skills, inductive reasoning, and distributed cognition during cardiac arrest management, highlighting areas for focused skill development in novice leaders.

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Cognitive load; clinical simulation; virtual reality; medical education; emergency medicine

Introduction

Approximately 290,000 in-hospital cardiac arrests occur each year in the US, and nearly 80% of patients do not survive [1–3]. However, studies suggest that high-quality resuscitation training for clinical staff can significantly improve the odds of survival by 29–49% [4–8]. Despite these findings, gaps remain in how current training

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methods translate into improved clinical performance and patient outcomes. Traditional resuscitation training primarily emphasizes technical skills (e.g. chest compressions, rhythm recognition), yet real-world performance is influenced by a complex interplay of non-technical skills–cognitive, behavioral, and environmental factors that are often inadequately addressed in conventional training models [6,9].

Traditional methods, such as instructor-led courses and high-fidelity manikin-based simulations, present several challenges, including limited accessibility to simulation equipment, variability in training standardization, and constraints related to instructor availability and cost. Furthermore, these methods often struggle to replicate the dynamic, high-pressure environments in which resuscitations occur, potentially limiting the transferability of learned skills to clinical settings. These limitations of traditional training, combined with the high cognitive demands of resuscitation leadership, call for innovative approaches that can both replicate complex scenarios and measure cognitive processes.

Virtual reality (VR) has emerged as a promising modality for resuscitation training, offering unique advantages in both skill development and assessment [10–14]. VR-based training has the potential to bridge existing gaps by providing immersive, scalable, and standardized learning experiences aimed to support both technical and non-technical skills (e.g. communication, situational awareness) acquisition [15]. Its ability to create high-fidelity, high-pressure scenarios allows learners to engage in active decision-making and leadership practice in ways that traditional training methods may not fully support. Studies have shown that both technical and non-technical skills acquired within these virtual environments are comparable to those learned in other simulation environments [13,16].

Understanding these cognitive processes is particularly crucial because code team leadership extends far beyond technical skills. While traditional training emphasizes algorithmic approaches and protocol adherence, the cognitive demands placed on code team leaders represent a critical yet understudied aspect of resuscitation performance [17]. During cardiac arrest resuscitation, healthcare professionals must rapidly coordinate complex interventions under intense pressure, with the bulk of this cognitive challenge falling to the code team leader [18,19]. This suggests that cognitive load—the amount of working memory being used to process information—may reach levels that could hinder learning and performance [20].

The impact of cognitive load appears to vary significantly between expert and novice practitioners, suggesting an opportunity to use these differences to inform training design. Understanding how experts manage cognitive demands could provide crucial insights for developing more effective training interventions. For example, prior empirical research has demonstrated that structured role allocation between nursing and medical team leaders significantly reduces cognitive burden and improves team performance [21,22]. Concretely, when nurse team leaders manage logistical aspects and routine algorithmic components while medical team leaders focus on diagnostic reasoning, medical team leaders experience significantly lower cognitive load scores (measured by NASA Task Load Index [23]), enabling them to better focus on critical decision-making tasks [21,22]. This complementary leadership approach appears to enable medical team leaders to dedicate more cognitive resources to developing causal theories and differential diagnoses while ensuring consistent protocol adherence through nursing leadership [22]. Another study found that external stressors during simulated resuscitation scenarios significantly impaired team leaders' non-technical skills (communication and decision-making), suggesting that leadership and non-technical skills become particularly crucial during stressful stages of the resuscitation [17]. Yet, the extent to which cognitive load fluctuates during different stages of resuscitation and its impact on team cognition and performance remains unclear, particularly regarding the differences in cognitive load experienced by expert versus novice clinicians.

The differences in cognitive processing between expert and novice clinicians manifest clearly in their reasoning approaches during acute care situations [24–26]. While experts typically employ inductive (Type 1) reasoning based on well-developed schemas from prior experiences [27,28], novices rely more heavily on deductive (Type 2) reasoning processes [28,29]. This distinction has important implications for cognitive load management during resuscitation scenarios. Inductive (Type 1) reasoning is considered a scheme-inductive process in much of medicine in which schemas/heuristics are developed based on physicians' prior experiences [25,27,30]. As a result of their greater experience and larger set of schemas, expert physicians most often use inductive reasoning, making clinical reasoning a significantly more efficient process for them. Well-constructed schemas that have been developed through years of valuable experience are typically associated with more accurate diagnosis and treatments [30]. Norman and colleagues posit that deductive reasoning is a slower analytical reasoning approach compared to inductive reasoning, which is faster and more heuristic [28]. Novices are more likely to engage in these slower deductive reasoning processes because their heuristic patterns have not yet fully developed [28]. In resuscitation scenarios, expert team leaders might employ forward reasoning, quickly generating hypotheses based on pattern recognition from e.g. vital signs, clinical presentation, while less novice team leaders might engage in more deductive approaches to verify these hypotheses through specific data points and clinical findings. To effectively capture and analyze these complex cognitive processes, particularly within VR environments, specialized methodological approaches are needed [31]. This is where Cognitive Task Analysis [32] becomes particularly valuable as a research method.

The Cognitive Task Analysis (CTA) is a specialized methodological approach used to examine the complexity of cognitive processes involved in performing intricate tasks. During resuscitation, cognitive processes significantly influence team performance [33,34], yet these processes are often challenging to measure using existing methods like observation and self-report surveys. Consequently, they remain poorly characterized and underrepresented in training programs designed to enhance resuscitative care [35]. CTA techniques help to elicit the behavioral and cognitive processes utilized in complex tasks. They encompass a broad range of methods that support training and education, system design, safety, error analysis, and the development of tools such as decision support systems [32]. By employing CTA, we can clarify the cognitive processes engaged during cardiac arrest resuscitation, laying the groundwork for expertise development. This not only equips educators with a more comprehensive understanding of decision-making techniques among learners, but also informs the creation of targeted improvement strategies for cardiac arrest training by elucidating these essential processes. While CTA has been successfully applied in other high-stakes medical scenarios such as cardiac surgery [36] and anesthesiology [37], its application to cardiac arrest resuscitation, particularly in combination with VR simulation, represents a novel approach. While the core principles of CTA have been applied to real-world or manikin-based resuscitation training, the VR environment offers distinct advantages. It facilitates direct, unobtrusive data collection by capturing participants' speech, video recordings, and metadata related to key care team actions (e.g. intubation, medication administration) and linking this data to changes to the patient's clinical state. These data are seamlessly gathered through the VR headsets and Unity engine, significantly enhancing the granularity of the analysis.

In this study, we chose to focus on critical decisions, communications, pitfalls, and strategies for two main reasons. First, these components have been previously validated as key cognitive processes in high-acuity team situations, including both cardiac surgery and resuscitation teams, where researchers have effectively differentiated expert performance through analysis of these elements [36,38]. Second, these elements represent the fundamental cognitive processes that CTA is uniquely positioned to reveal, as they form the tacit knowledge base of expertise that is difficult to capture through traditional observational or survey methods.

In summary, this study addresses three critical gaps in current resuscitation training. (1) The limited understanding of cognitive processes that differentiate expert from novice performance during resuscitation, (2) the lack of validated methods for measuring these processes in high-fidelity scenarios, and (3) the need for evidence-based approaches to accelerate expertise development. By combining VR simulation with CTA, we aim to elucidate the cognitive processes of expert and novice code team leaders, particularly focusing on decision-making patterns, communication strategies, and cognitive load management. These insights can inform the design of more effective training interventions that target both technical and cognitive aspects of resuscitation leadership, potentially accelerating the development of expertise and, ultimately, improving patient outcomes.

Research questions and hypothesis

The inclusion of both experts and novices allowed us to identify beneficial cognitive patterns in experts that could be targeted for training and development. We used a mixed methods approach to enable us to extract and identify the nuanced differences between these two groups, providing a comprehensive understanding of cognitive processes during cardiac arrest management. Through this approach, we sought to answer the following research questions:

1. How do the decision-making processes of expert code team leaders differ from those of novices during simulated cardiac arrest resuscitations?
2. What are the key communication patterns exhibited by expert code team leaders, and how do these compare to novice communication behaviors?
3. What common pitfalls are observed among novice code team leaders, and how might these be mitigated through training?
4. What cognitive load management patterns are reported by novice and expert code team

leaders, and how could these insights serve as targets for training novice team leaders?

We hypothesized the following: Expert code team leaders would report distinct cognitive and communication patterns compared with novices, specifically greater use of inductive clinical reasoning (e.g. collecting and analyzing assessment data before considering diagnosis) and distributed cognition strategies (e.g. recapping, soliciting input from team member), resulting in more effective team coordination and task management.

Materials and methods

This mixed methods study employed CTA to examine the cognitive processes and communication patterns of expert and novice clinicians during VR-based cardiac arrest simulations. Video-based recall was used to allow clinicians to accurately revisit their actions and reasoning during the simulation, enhancing memory retrieval and providing rich contextual insights. Deductive thematic analysis was used to analyze post-simulation interviews with participants due to the use of four predetermined themes (i.e. critical decisions, critical communications, pitfalls, and strategies) essential to team-based critical event management [39,40]. Specifically, thematic analysis was employed because it enabled the identification of key patterns directly relevant to the research questions, making it easier to compare responses between experts and novices. This study was approved by the University of Michigan Medical School Institutional Review Board (reference number: HUM00193383). Verbal informed consent was obtained prior to the start of the study. Verbal consent was chosen as the preferred method due to the remote nature of the post-simulation interviews conducted via Zoom (Zoom Video Communications Inc.), educational focus of the research, and the minimal risk posed to participants. All data collected from simulations and post-simulation interviews were stored in a password protected server.

Conceptual framework

This study was conducted within a post-positivist research paradigm [41], emphasizing the systematic comparison of expert and novice performance and the collection of quantifiable cognitive load data to draw conclusions and minimize the subjectivity of the research process. The study was grounded in three complementary frameworks that align with this post-positivist stance:

- Cognitive Load Theory (CLT): This framework, developed by Sweller et al. [20] provided the foundation for understanding how participants manage cognitive resources during complex tasks. CLT helps explain differences in performance and strategy selection between experts and novices based on their varying cognitive load capacities and management strategies.
- Cognitive Task Analysis (CTA): Based on Klein's Critical Decision Method for eliciting knowledge [42], CTA served as both a theoretical lens and methodological approach. This framework guided our examination of the cognitive processes underlying expert performance, helping identify critical decisions, communications, and strategies employed during simulated cardiac arrest management.
- Expertise Development Theory (EDT): Drawing from Ericsson's deliberate practice framework [43] this theoretical perspective informed our analysis of the differences between expert and novice performance, particularly in how domain expertise influences decision-making patterns and cognitive load management.

The above three frameworks complement and extend one another while directly informing our methodology. CLT provides the foundation for understanding human cognitive architecture and guided the design of our VR simulation scenarios by incorporating progressive complexity levels and reducing extraneous load through intuitive interfaces in the VR environment. CTA offers the methodological tools to systematically analyze cognitive processes, shaping our interview protocol and the systematic coding of cognitive processes during cardiac arrest management. EDT bridges these approaches by explaining how observed differences in cognitive load management and decision-making strategies emerge through deliberate practice and experience, while also informing our sampling strategy and the criteria used to differentiate expert from novice performance.

Study design and setting

We conducted a mixed methods study using CTA [38]. We specifically employed a mixed methods approach to understand the cognitive processes involved in simulated cardiac arrest management, revealing nuanced differences between experts and novices. The qualitative insights illuminated decision-making factors, while the quantitative data enabled effective comparison of these distinctions. This methodological choice grounded in our theoretical frameworks helped us systematically examine decision-making processes, communication patterns, and cognitive strategies cognitive load across participant groups.

Figure 1 shows a summary of the methodological approach and procedures used in this study. The study setting, a large academic medical center's clinical simulation center, was chosen for its established expertise in cardiac arrest simulation training and availability of state-of-the-art VR technology, providing for the explicit needs of this study. We used VR for this study because it offers standardization and consistency in scenarios, ensuring that all participants experience the same conditions. Additionally, VR environments can offer a significantly more immersive experience compared to traditional simulation methods, aiding students in the suspension of their disbelief.

Sample

We employed convenience sampling due to the specialized nature of cardiac arrest team leadership and the intensive time commitment required for VR simulation and CTA interviews. After VR-based ACLS training sessions, we approached individuals who acted as team leaders to participate in the CTA study. The sample size of 12 participants aligns with established guidelines for CTA studies, which typically recommend a minimum of three to five experts are needed to identify cognitive processes [44,45]. Participants were categorized into two groups (Experts and Novices) based on specific cardiac arrest management experience. Expert status was defined as having: (1) current ACLS instructor certification, and (2) minimum of 5 years of experience leading cardiac arrest teams. Using these criteria, our expert group included seven ACLS instructors with experience leading cardiac arrest teams as paramedics ($n=1$), nurses ($n=4$), emergency medicine physicians ($n=1$), and family medicine physicians ($n=1$). Experts (five females, two males) had a mean clinical experience of 24 years. Novices were defined as clinicians with prior ACLS training but little to no prior experience leading cardiac arrest teams. This group included five junior residents with prior ACLS training but limited team leadership experience. Novices' specialties were in emergency medicine ($n=1$) and family medicine ($n=4$). The novice group (three females, two males) included second-year ($n=3$), third-year ($n=1$), and fourth-year ($n=1$) residents.

Study materials and tools

Multi-user virtual reality cardiac arrest simulation environment

The VR simulation immerses a team of four clinicians in an in-hospital rapid-response scenario, where they collaboratively manage a cardiac arrest patient following a ST-elevation myocardial infarction (STEMI). After receiving handoff from a bedside nurse non-player character (NPC), participants must work together to stabilize the patient's evolving arrhythmias and clinical condition over a 10- to 15-minute session (Figure 2). The simulation integrates voice recognition and motion capture for enhanced realism and engagement. Prior to the session, participants completed a 10-minute interactive tutorial to familiarize themselves with the VR environment and controls.

Initial design of the VR simulation design was guided by a conceptual framework integrating several

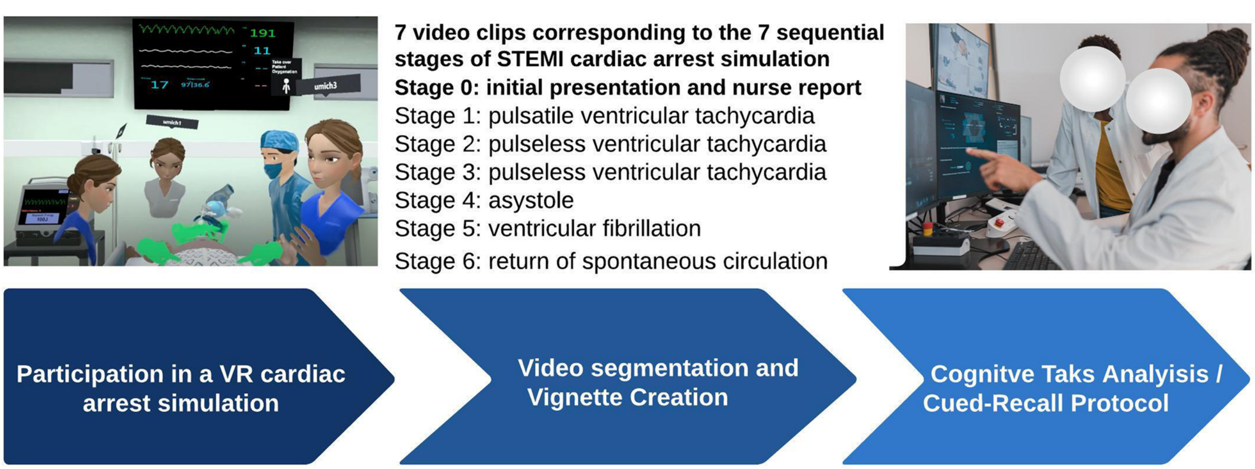

Figure 1. Methodological steps and procedures used in this study.

Figure 2. A screenshot of the virtual reality cardiac arrest simulation environment used in this study.

educational theories. The theory of deliberate practice was used to structure learning objectives around progressive skill acquisition to enhance competency in high-stakes settings [46]. Adult learning theory informed scenario design to ensure self-directed, clinically relevant learning experiences to promote engagement and retention [47]. CLT [20] and situated cognition [48] guided the embedding of decision-making processes within an authentic, high-stress team environment, facilitating knowledge transfer to real-world clinical practice.

The VR simulation program was developed and tested using a systematic, process-driven approach to ensure instructional effectiveness, user engagement, and clinical relevance. To ensure content validity, subject matter experts (SMEs) conducted a structured review using a modified Delphi method [49]. This process included iterative feedback and consensus-building to assess accuracy, clinical relevance, and alignment with learning objectives [49]. Additionally, scenario design adhered to evidence-based guidelines for in-hospital cardiac arrest management including the 2020 AHA ACLS guidelines [50] and the 2021 European Resuscitation Council (ERC) guidelines [51]. These guidelines provided a validated framework for scenario content, ensuring alignment with current resuscitation science and best practices.

Prior to this study, the VR simulation and tutorial underwent 217 aggregate hours (over 700 person-hours) of pilot testing, involving nurses, physicians, and students. Testing focused on usability, content validity, reliability, and instructional effectiveness. Testing followed an iterative process, with user feedback guiding periodic refinements to enhance functionality and educational outcomes. The tutorial design was also informed by CLT principles, carefully managing cognitive load by introducing clinical tasks, VR controls, interaction mechanisms with virtual objects and the environment in a structured sequence that builds from simple to complex operations.

Measurement tools

Cognitive task analysis interview protocol. We used video vignettes (cued-recall protocol) of each stage of the cardiac arrest to guide the semi-structured interviews with participants based on the CTA methodology described by [36]. We used a phenomenological approach [52] to extract the cognitive characteristics (e.g. processes, communications, self-reported cognitive load) of cardiac arrest management and compared them between novices and experts.

First, participants reviewed a video clip of one stage of their simulation, then using an interview guide, the facilitator prompted participants to comment and reflect on this video clip (e.g. 'Can you describe for me what is happening in this clip?'; 'I saw your team [observation]', 'What was going through your mind at the time?'). These open-ended prompts were designed to allow the participants to externalize their thinking and assess their own performance to uncover their rationale for observed behavior. These interviews focused on uncovering key decision points (e.g. 'Identify and describe all moments in which you need to make a decision during this stage'), communications (e.g. 'Identify and describe critical communications that occur during this stage'), pitfalls (e.g. 'What problems may occur during this stage?'), strategies (e.g. 'What strategies do you use to solve and/or prevent problems during this step?'), and their perceived cognitive demand. This is a common technique used in CTA to generate an inclusive and exhaustive list of cognitive elements.

Cognitive load assessment. Following the Diaz protocol [36] the perceived cognitive load was assessed by asking participants to report their mental demand during each stage of the cardiac arrest scenario using a visual analogue scale from 1 (minimum demand) to 100 (maximum demand) (e.g. 'How mentally demanding is this stage for you?' and 'What is your estimate for the mental demand experienced by each team member?' This approach builds on Paas's [53] widely validated self-report cognitive load measurement, which has been extensively used in educational research [54]. This instrument consists of one item in which learners report their 'perceived amount of mental effort'. While Paas [53] originally used a 9-point scale, subsequent validated adaptations have successfully employed 100-point scales [55] and continuous scales [56], supporting our measurement approach.

Data collection procedures

Pre-simulation phase. A total of 12 standardized VR simulations were conducted, each with one participant assuming the role of team leader (seven with an expert, and five with a novice as team leader). All simulations were conducted using the HP Reverb G2 Omnicept head-mounted display [57] within the simulation lab of the University of Michigan. Prior to the simulation, participants were provided with a basic orientation to the VR hardware, controls, and interaction through a virtually guided scenario.

Simulation phase. To effectively complete the simulation, the team must designate individual roles and responsibilities such as chest compressions, airway management, defibrillator management, and medication administration. Participants were given the option to select their preferred role in the simulation. For each simulation, participants assumed the team leader role, while the other three roles were typically filled by fellow residents or research staff. The virtual patient's condition changes in real-time in response to actions taken by the team. Participants were tasked with communicating dynamically and exchanging information regarding the patient's clinical status under realistic time pressure and rapid workload changes. Each of the 12 simulations used the same scenario storyline of ventricular tachycardic cardiac arrest due to a STEMI. This scenario consisted of seven stages, signaled by changes in the patient's cardiac rhythm or clinical condition.

Post-simulation interviews. Each participant was interviewed within two to four days after completion of the simulation in a 1:1 format via Zoom (Zoom Video Communications Inc.) and Descript (version 78.2.5, Descript Inc., San Francisco, CA) was used to record and create transcripts of the interviews. Interviews were scheduled in the days following the simulation session to ensure 1:1 interviews with each participant and to help accommodate participants' limited availability on the day of the simulation. Data was coded and maintained in an electronic spreadsheet (Microsoft Corporation, Redmond, WA, USA). Interviews lasted 65 min on average (ranging from 59 to 71 min), including time spent reviewing video segments.

Data analysis

Following the interviews, all participant responses elicited during the interviews were entered into a comprehensive database. Responses were divided into those from experts versus novices, separated by the stages of the code simulation. Deductive thematic analysis was used to analyze the data, using four predetermined themes essential to team-based critical event management [39,40] and based on the CTA interview protocol: critical decisions, critical communications, pitfalls, and strategies. A coding framework was developed from the predetermined themes. Two members of the research team (SR and IS) with emergency medical experience developed the coding framework after familiarizing themselves with the data that was derived directly from the CTA interview recordings. Coders conducted all coding together to improve consistency and reliability, and reduce bias. Any discrepancies between the coders were resolved through discussion, until consensus was reached. The codes for each unique response were numerical in value and corresponded to their respective domain (i.e. D1… D*n* for decisions, C1…C*n* for communications, P1…P*n* for pitfalls, and S1…S*n* for strategies). By utilizing these shorthands, we were able to better understand the trends between the experts and novices. Subthemes emerged within each of the four predetermined themes, and were reviewed by additional members of the research team (BH, JC, MC), with backgrounds in emergency medical care, to validate findings. This was an inclusive list approach aimed at documenting all thought processes mentioned to capture their full breadth and depth. The frequency with which each subtheme was mentioned in each stage was coded in order to calculate rates. Lastly, the reported cognitive load for each stage was divided by participant level (expert or novice) and averaged amongst participants in each group. The Consolidated Criteria for Reporting Qualitative Research checklist [58] was used to ensure methodological robustness and thorough documentation (Supplementary Appendix 1).

Reflexivity statement

Our research team's diverse composition and expertise directly influenced our approach to data collection, analysis, and interpretation. The primary interviewer, a learning health scientist with a PhD in computer-supported collaborative learning, brought extensive mixed-methods research expertise while maintaining objectivity through the absence of supervisory relationships with participants. This positioning helped create an environment where participants could freely share their decision-making processes without concerns about evaluation or judgment. Our research team combined diverse expertise across emergency medicine, learning health sciences, computer science, and human factors, which enhanced the rigor and depth of our analysis. This interdisciplinary approach allowed us to examine the data from multiple perspectives. Critically, all team members involved in data extraction were Advanced Cardiovascular Life Support (ACLS) certified, ensuring a foundational understanding of resuscitation protocols that informed our analysis. To minimize disciplinary biases, we implemented several strategies: (1) regular team meetings to challenge individual interpretations, (2) structured cross-checking of coding between team members from different disciplines, and (3) explicit discussion of how our different backgrounds might influence our interpretation of the data.

Results

This study aimed to identify and compare the cognitive processes employed by expert and novice clinicians during cardiac arrest resuscitation in a VR environment, with particular attention to decision-making patterns, communication strategies, and cognitive load management. The CTA revealed 250 unique cardiac arrest resuscitation cognitive processes. Descriptive analysis revealed these processes were distributed across the following main domains: decision points (48 expert, 45 novice), critical communications (23 expert, 20 novice), pitfalls (46 expert, 33 novice) and strategies (77 expert, 44 novice). Within these domains, our thematic analysis found considerable overlap between expert and novice groups, with 86 subthemes (34.4%) being unique to one group. Thematic saturation analysis, defined as no new codes emerging from three consecutive interviews, was achieved within the decisions, pitfalls, and strategies domains after interviewing 5 novices and 7 experts. However, critical communications lacked saturation within the novice group due to limited and inconsistent responses. Research team consensus resulted in not pursuing saturation in this domain primarily due to the limited input provided by novices in this domain.

Table 1 shows the cognitive processes grouped according to the seven stages of the cardiac arrest simulation, and includes only the subthemes with two or more responses within the decisions and critical communications domains. For each stage, the table is divided into subthemes that are: (i) shared between novice and expert groups and (ii) subthemes that are unique to only one of these groups. An interactive dashboard was developed to allow exploration of all the CTA findings and can be viewed online via https://mteam.vercel.app/

Decision-making patterns

Critical decisions

Several subthemes were mentioned at least three times more frequently by either the novice or expert group involving clinical decision making. During stages 1, 2, and 5, (ventricular tachycardia (VT) with pulse, VT without pulse, and ventricular fibrillation), treatment considerations (e.g. performing cardioversion, compressions, and medications) were mentioned three times more frequently among novices, while assessment findings (e.g. pulse, airway, EKG) were mentioned more frequently by experts (frequency ratio 3:1). In stage 7, there were three times more post cardiac arrest interventions mentioned among experts compared to novices, such as ordering an EKG, administering IV fluids, and inducing hypothermia. During stages 3, 4, and 6, several experts considered potential reversible causes of cardiac arrest (e.g. hyperkalemia), which were not mentioned by novices in any of these phases. As one expert put it:

Table 1. Expert and novice subthemes with two or more responses.

Stage	Decisions (D)		Critical communications (C)	
Stage 0. Nurse report	Both groups		Both groups	
	D1. Is the patient stable? (2), [5] D2. What are the potential causes of the arrest? (3), [3] D4. Verify airway, breathing, and circulation (6), [2]		No shared mentions	
	Experts	Novices	Experts	Novices
	D9. What is the cardiac rhythm? (5) D3. What resources are available? (3) D8. Which advanced cardiac life support algorithm should be followed? (3)	D18. What are the current and past vitals? [6] D49. Who is on my code team? [2] D12. What roles are the team members going to fill? [2]	C2. Verbalize next steps (3) C5. Ask the nurse any remaining questions (3) C6. Ensure direct and specific closed loop communication (2)	NA
Stage 1. V. Tach with pulse	Both groups		Both groups	
	D19. Does the patient have a pulse? (6), [5] D1. Is the patient stable? (4), [4] D9. What is the cardiac rhythm? (8), [4] D4. Verify airway, breathing, and circulation. (4), [6]		No shared mentions	
	Experts	Novices	Experts	Novices
	D7. Should we start compressions? (2)	D13. Should we use electrical therapy? (5)	C11. Communicate with team members (3) C10. Confirm vitals (2)	C4. Assign team member roles [2] C2. Verbalize next steps [2] C23. Ask team members to assess the patient [2]
Stage 2. V. Tach no pulse	Both groups		Both groups	
	D9. What is the cardiac rhythm? (6), [3] D19. Does the patient have a pulse? (4), [3]		No shared mentions	
	Experts	Novices	Experts	Novices
	D12. Which team member should perform each task (6) D13. Should we perform cardioversion? [6] D26. Are the compressions and ventilations appropriate? [5]	D23. Should we administer medication? [5] D7. Should we start compressions? [3] D2. What are the potential causes of the arrest? [3]	C2. Verbalize next steps (3)	NA
Stage 3. V. Tach no pulse	Both groups		Both groups	
	D9. What is the cardiac rhythm? (4), [3] D2. What are the potential causes of arrest? (4), [3] D13. Should we perform cardioversion? (6), [3]		No shared mentions	
	Experts	Novices	Experts	Novices
	D26. Are the compressions and ventilations appropriate? (7) D19. Does the patient have a pulse? (6) D23. Should we administer medication? (5)	D29. When should we check a pulse next? [2] D35. When should we administer the next round of epinephrine? [2] D30. What medication should we administer? [2]	C6. Ensure direct and specific closed loop communication (2) C15. Ask for team feedback/ suggestions (3)	NA
Stage 4. Asystole	Both groups		Both groups	
	D38. What are the next steps in the advanced cardiac life support algorithm? (3), [3] D9. What is the cardiac rhythm? (5), [5]		No shared mentions	
	Experts	Novices	Experts	Novices
	D23. Should we administer medication? (5) D19. Does the patient have a pulse? (5) D13. Should we perform cardioversion? (4)	D48. Should we administer amiodarone? [4] D23. Should we administer epinephrine? [3] D13. Is the rhythm shockable? [2]	C19. Communicate timing of interventions (2) C15. Ask for team feedback/ suggestions (3)	NA
Stage 5. V. Fib	Both groups		Both groups	
	D9. What is the cardiac rhythm? (8), [6]		No shared mentions	
	Experts	Novices	Experts	Novices
	D26. Are the compressions and ventilations appropriate? (3) D35. What time should epinephrine be administered? (2) D39. Is the ET tube correctly placed? (2)	D13. Is this rhythm shockable? [3]	C6. Ensure direct and specific closed loop communication (2) C2. Verbalize next steps (2)	NA

(*Continued*)

Table 1. Continued.

Stage	Decisions (D)		Critical communications (C)	
Stage 6. ROSC*	Both groups		Both groups	
	D2. What are the potential causes of the arrest? (5), [4] D41. Did we achieve return of spontaneous circulation? (2), [3]		No shared mentions	
	Experts	Novices	Experts	Novices
	D43. What post-arrest care should be administered? (4) D44. Should we cool the patient? (3) D19. Does the patient have a pulse? (3)	NA	C22. Communicate to team members that ROSC has been achieved (2)	NA

(#) Expert subthemes.
[#] Novice subthemes.
NA: No subthemes with two or more responses.
*ROSC: return of spontaneous circulation.

> Let's go through our H's and our T's everybody. Get everybody involved in this resuscitation. It's not just my code. It's our code. So [does] anybody have any ideas? Let's go through those H's and those T's everybody because we have two minutes to do nothing but CPR. So we can talk for two minutes now, and work through this.
>
> So you can invite the input… I want them [trainees] to know that this isn't just cookbook medicine. We're detectives. Now we need to figure out what got us here. – Expert 4

Team communication processes

Critical communication

Teamwork-related critical communications were mentioned more frequently among experts than novices during stages 0–4. These included statements such as ensuring closed loop communication, asking for feedback and suggestions, and recognizing the team's limitations. However, among novices there were limited shared responses within the critical communications domain. Novices had only three shared subthemes across all stages of the scenario (Table 1). This led to no shared subthemes between experts and novices within this domain. The limited focus on team communication among novices was apparent in comments made during interviews, where some expected the team members to be self-directed. The comment from one of the novice's below illustrates this point:

> The team members kind of decided amongst themselves who was going to do what, which I probably could have been more clear about. – Novice 1

Pitfalls and strategies

Both novices and experts described numerous pitfalls and offered strategies to address them for every stage of cardiac arrest management. Many pitfalls mentioned across both groups involved issues associated with omitting an indicated intervention such as repeating vital signs or failing to intubate the patient. Affective-related pitfalls were also noted across both groups. These included issues such as having high stress levels, self-doubt, and not trusting team members to perform assigned tasks.

Both groups had difficulty identifying effective strategies to address the described pitfalls. Most strategies addressing procedural pitfalls involved simply performing steps that may accidentally be omitted, such as checking a pulse or intubating the patient. When considering affective–related pitfalls, there were very limited strategies with only one expert mentioning the use of a checklist to reduce stress and cognitive load during stage 0.

Teamwork and team communication was a common theme mentioned by experts in both pitfalls and strategies. A total of 41 experts mentioned pitfalls and 44 mentioned strategies associated with teamwork or team communication. In comparison, only 20 novices mentioned pitfalls and 5 mentioned strategies related to teamwork or team communication. Clarifying team member roles was commonly referred to as an important strategy for both novices and experts. Commenting on the role assignment, one of the experts said:

> Since we don't [start the simulation] with predefined roles as a team, those team roles have to be rapidly negotiated. – Expert 3

The most common strategies offered by the experts to address the pitfalls they observed during the simulation included recognizing team limitation, creating an environment where team members can speak up, and knowing team member names with closed-loop communication.

Cognitive load management

Self-reported cognitive load

Descriptive statistical analysis was used to examine cognitive load (CL) patterns. The median CL for each role was calculated using the median of medians approach (each stage representing the median score of all participant scores; see Figures 3 and 4). Comparative analysis showed the team leader role had the highest reported median CL across all stages with a score of 80 in both groups. The team leader role had the highest reported median CL across all stages with a score of 80 in both groups. Challenges involving confidence and stress associated with the leader role were frequently mentioned among novices during interviews. For example, one novice said:

> … I wish I was the compressor instead. I was like can I trade roles? Can someone else be the team leader? There was a lot of remorse. I think listening to my own voice, obviously that is my stress voice. – Novice 1.

Role-specific cognitive load patterns

Mann–Whitney *U* tests revealed that overall self-reported median CL levels were consistently higher among novices than experts across the different stages ($U = 43.0$, $p = 0.019$), with the largest difference reported in the airway management role (median CL of 53 for novices vs. 30 for experts). When examining total CL (all roles) in each stage, the median total-team CL reported by novices was lower than the median total-team CL among experts during Stage 0 (initial

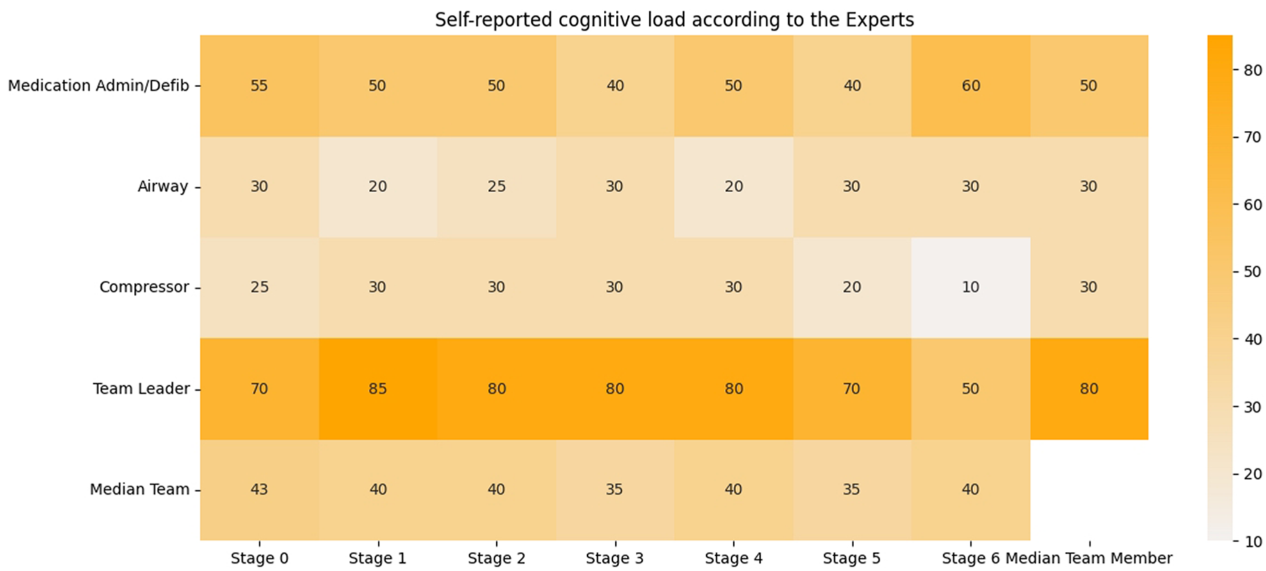

Figure 3. Heatmap of self-reported cognitive load median values according to the experts per stage.

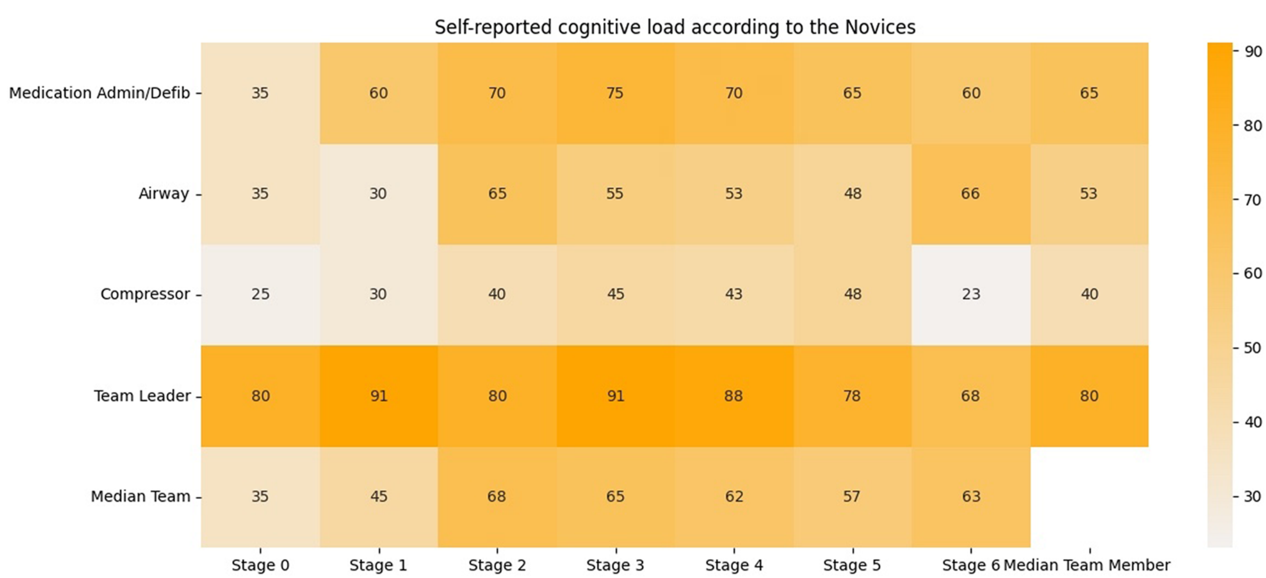

Figure 4. Heatmap of self-reported cognitive load median values according to the novices per stage.

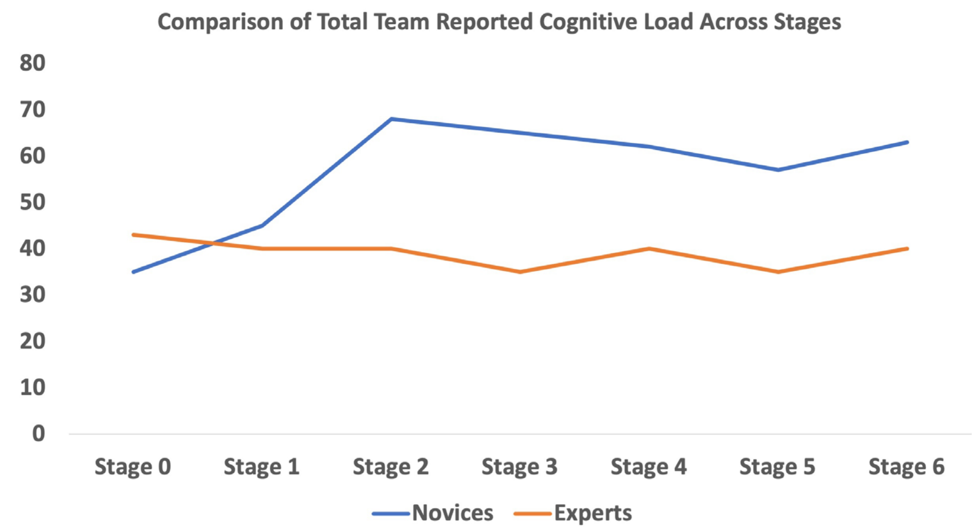

Figure 5. Line graph comparison of total team reported median cognitive load across all stages.

presentation and nurse report). However, this switched during stage 1 (Ventricular tachycardia with a pulse), where novices began reporting a higher CL than experts, which continued higher throughout the rest of the simulation (Figure 5).

In summary, our analysis revealed three key distinctions in how cognitive processes and expertise manifest during simulated cardiac arrest resuscitation. First, experts demonstrated more advanced inductive reasoning patterns and proactive information gathering, while novices relied more heavily on deductive approaches, testing treatment hypotheses before gathering complete assessment data. Second, experts exhibited more efficient team coordination capabilities—actively soliciting team feedback, verbalizing planned steps, and establishing clear workflows—while novices struggled with basic team communication, showing no consistent patterns in their communication approaches and often expecting team members to be self-directed. Third, experts demonstrated more efficient cognitive load management, strategically front-loading mental effort during initial patient assessment to reduce cognitive burden in subsequent phases. However, both groups experienced peak cognitive demands in the team leader role, suggesting opportunities for distributed cognitive load strategies. In the following section, we discuss these findings in detail, ground them in the existing literature, and discuss how they could serve as targets for training novice team leaders.

Discussion

This study used an innovative VR-based simulation to uncover cognitive processes during simulated team-based resuscitation. Our findings revealed three key differences between expert and novice performance that have important implications for practice, education, and further research. First, the study results confirmed our hypothesis that experts would demonstrate superior clinical reasoning through inductive approaches and strategic information gathering, while novices would rely on less efficient deductive reasoning patterns. Second, experts showed mastery of team coordination through consistent communication strategies and proactive leadership, whereas novices reported minimal shared understanding of critical team interactions. Third, experts demonstrated more efficient cognitive load management, strategically front-loading mental effort during initial patient assessment to reduce cognitive burden in subsequent phases—a critical skill for reducing medical errors during complex resuscitations [21,22]. These findings show that expertise in resuscitation develops through the integration of systems—where clinical knowledge combines with efficient information processing, deliberate team coordination, and strategic cognitive resource allocation [6]. These findings provide new insights that could inform instructional design, assessment targets, team performance improvements, and error reduction, though more research is needed to determine generalizability and identify optimal applications. We further discuss these key findings related to decisions, communication and teamwork, cognitive load, and their implications for clinical practice and training.

Decisions

During stages 0 through 2 within the decision domain, novices were more likely to consider the appropriateness of a treatment prior to considering assessment findings. This was identified during our thematic analysis through statements such as, 'Should we cardiovert the patient?' Novices would then make statements indicating they need to perform an assessment to determine the need for the treatment they are questioning. However, experts focused on performing various assessments, and later made absolute statements about treatment such as, 'We need to cardiovert the patient'. This suggests that novices used a deductive reasoning approach during these stages, where they form an initial hypothesis then collect assessment data to validate that hypothesis [59]. This pattern aligns with established research showing that inductive reasoning characterizes expert clinical decision-making in familiar scenarios, while deductive reasoning typically manifests in novices or during complex cases [25]. The temporal dimension of these reasoning patterns becomes particularly evident in resuscitation scenarios, where experts demonstrate faster decision-making coupled with higher certainty in their actions. This speed and efficiency in expert reasoning stems from well-developed pattern recognition capabilities and a structured clinical knowledge base. These findings add to the body of literature by supporting previous studies identifying the use of deductive reasoning processes among novices. This may guide the development of new instructional strategies aimed at transitioning novices toward inductive reasoning during resuscitation or support current strategies such as schema-based instruction. For instance, specific simulation-based strategies (e.g. advocacy-inquiry model [60,61]) can be used while harnessing schema-based instruction methods aimed at shifting clinicians to inductive reasoning processes, particularly during debriefing sessions.

Critical communications

Although shared subthemes between novices and expert groups were common within the decision domain (total of 17 across all stages), the critical communications domain did not have any shared subthemes between the two groups with two or more responses. Much of this was due to novices having limited and inconsistent responses within their group when compared to more consistent responses offered by experts (Table 1). During interviews, novices struggled to provide meaningful input pertaining to critical communications. Few responses were given by them for each stage. When responses were given, they were not consistent among participants. For instance, within the critical communications domain, only a single stage (Stage 1) had subthemes that were consistent between at least two novice participants.

These are concerning findings as communication breakdowns are common causes of medical errors [62–65]. We believe this is likely due to limited training of non-technical skills in resuscitation instruction. Gordon and colleague [66] highlight the need for non-technical skills training, including communication, to enhance patient safety. This systematic review found that while there are various training programs available, many clinicians still lack adequate training in effective communication within teams, particularly in emergency settings. Although the concepts of communication and teamwork have been components of the ACLS standards since 2005 [67], the instructional design of these training sessions focuses more on technical skills [6]. Communication instruction in these sessions focuses more on *how* to communicate (e.g. closed-loop communication), rather than *what* critical things need to be communicated [6]. This makes experience a more important factor in effective communication. In this study, experts consistently shared similar responses with one another in this domain. These shared responses were likely due to similar experiences in cardiac arrest management that led to the identification of what critical items need to be communicated within the team. Additionally, experts may have acquired supplemental training focused on non-technical skills during their time as clinicians. These findings support the incorporation of more team communication principles in simulation-based education, emphasizing both how and what needs to be communicated during cardiac arrest management.

Teamwork

Experts considered teamwork-related matters more often than novices across all stages. During post-simulation interviews, we discovered that across all seven stages, experts were more likely to mention teamwork-related pitfalls and offered more strategies directed at addressing those issues. Among pitfalls and strategies offered by experts, there were several more comments addressed at promoting safety and quality of care among the team than comments made by novices. These included strategies such as encouraging team member feedback and recognizing team limitations. Experts also emphasized improving the overall operation of the team. This included using strategies such as familiarizing themselves with their team member's names and establishing an efficient workflow within the team.

Although the importance of effective teamwork among healthcare teams has been well-established in the literature [19,68,69], medical schools continue to place greater emphasis on individual performance [70]. Expert physicians emphasizing teamwork considerations more often was an expected finding of this study and aligns with research into novice and expert performance and perceptions within healthcare teams. Ghaderi et al. [71] examined the difference between expert and novice surgeons when preparing for challenging cases. The study noted that expert surgeons had a stronger focus on team communications aimed at addressing logistical issues that could arise during surgery. This strategy of communicating with teams to prevent specific issues from arising was observed across several stages of the scenario. For instance, experts more frequently mentioned that they verbalized planned steps with the team and used multiple strategies to elicit feedback from team members (e.g. fostering an environment that encouraged team members to speak-up and directly asking for feedback from their team). Although novices proved more hesitant to ask for direct feedback during the simulation, in the post-simulation interviews many novices acknowledged the value of soliciting or receiving feedback from other team members (e.g. 'I find it really helpful because there's so much to think about as the team leader [that] whenever people give you input and ask you 'do you want to do this?' I think that is all very helpful'. –Novice 2). Much like the differences we noted in critical communications, these findings are concerning as teamwork related issues are common causes of medical errors and poor outcomes [72–74]. This suggests that novices are not well prepared to function within these teams, thereby limiting their ability to effectively and safety managing a cardiac arrest. We believe that experts are likely utilizing teamwork principles that were learned through both additional training and experience managing cardiac arrest teams. This further supports the importance of incorporating more team communication and coordination principles into cardiac arrest training. This could help better prepare novice physicians to manage cardiac arrest teams, potentially leading to reduced errors and improved patient outcomes.

Cognitive load

The median reported CL across all seven stages was higher in novice physicians when compared to experts. However, when considering reported CL for each stage, experts reported a higher CL during stage 0, and a lower CL in all subsequent stages when compared with novices. During stage 0, participants received a report from the nurse. When examining subthemes in clinical decisions and critical communications during stage 0, experts considered overall more factors than novices. This included asking the nurse additional questions, confirming the accuracy of the report, and identifying available resources. Synthesizing this information and frontloading cognition to develop an actionable plan for patient care likely resulted in the higher reported CL by experts in stage 0. This in turn, may have contributed to the lower CL reported in all subsequent steps. Although we did not expect this, it is a significant finding as it implies that novice physicians do not dedicate necessary mental effort when receiving a report during patient hand-off. These findings may be a result of limited initial training in patient handoff or overestimation of handoff skills. For instance, one study found that none of the house staff in a residency program had received formal training in handoffs during medical school [75], consistent with findings that only 8% of U.S. medical schools provide formal instruction on handoffs [76]. This lack of training is further compounded by findings that residents often overestimate their handoff effectiveness, highlighting a significant gap in self-awareness and skill [77]. The impact of this could be significant as patient hand-offs are associated with high rates of error [78,79]. Further investigation is necessary to identify the reasons why novice physicians dedicate less mental effort during this phase.

During Stage 1, direct patient care begins. Novices begin reporting a higher total CL than experts during this stage, which persists throughout the rest of the simulation. This higher reported CL by novices is likely due to lack of familiarity with algorithms and team management strategies, failure to recognize and distribute cognitive load between team members, and lack of anticipation of status changes and next steps in management, all of which are commonly utilized by high-performing experts. Rasmussen's 'Skill, Rule, and Knowledge' is an information processing classification system that posits that unskilled individuals are more likely to engage in knowledge-based behavior, which can result in higher mental workload [80]. Experts are more likely to engage skill-based behaviors when they engage with a familiar environment and task (e.g. cardiac arrest management). This type of behavior is characterized by more heuristic thinking, resulting in lower cognitive demand [81].

The impact of higher CL reported by novices in stages 2 through 6 were noticed throughout the task analysis. Novices were more likely to report high stress levels as a potential pitfall. Studies have shown that high stress can contribute to cognitive overload [82], and potentially impair performance [83–85]. Additionally, stress can narrow attention, resulting in the individual focusing their attention on one aspect of the task [86]. We noticed this phenomenon among novices, as they focused much of their decisions and communications on actions aimed at routinely following the cardiac arrest algorithm. Although experts had these same considerations, they were more likely to consider other factors, such as the underlying cause of cardiac arrest and whether the patient had a clinical response to specific interventions that were administered.

Our study found that the airway role had the biggest difference in median CL between groups, with novices reporting a 76.67% higher median CL than the experts. Upon further examination, we noticed that there was a large increase in reported cognitive load among novices (median CL of 30–65) between stages 1 and 2. When examining the same stages among the expert group, there was a smaller increase between stage 1 and 2 (median CL of 25–25). In stage 2, the patient becomes pulseless and requires CPR. However, there were no changes in airway interventions during this stage among novices, as they were already ventilating the patent. There were no notable subthemes regarding airway among novices during this stage. Previous studies have found that the airway role sometimes carries higher cognitive load requirements than other roles, especially when advanced airway procedures are required [87,88]. In this study's simulations, the decision to perform endotracheal intubation occurred at various stages, not necessarily during stage 2. Further investigation is required to determine why novice team leaders perceived that airway role had a significant increase in CL during this phase, as our findings do not explain this phenomenon.

The role with the highest reported cumulative CL was the team leader. This higher cognitive load was reported by both novices and experts. These findings are consistent with previous research examining CL among team roles. Brown et al. [89] examined the differences in cognitive workload between team leaders and CPR providers during pediatric cardiac arrest management using a simulation-based approach. The study found team leaders reported higher cognitive load than other members of the care team. This high cognitive demand placed on team leaders raises concerns that cognition is not being effectively distributed among team members. Some strategies have examined ways cognition could be offloaded. Pallas et al. [21] examined the use of a separate nursing team leader during cardiac arrest management to oversee more 'technical' tasks such as the timing of CPR cycles, monitoring chest compression quality, and prompting medication administration. The study found that the use of the nursing team leader reduced CL of both the team leader and the overall team. Our findings support that the use of such strategies like this should be considered as a way to reduce the cognitive demand placed on the team leader during cardiac arrest management. The higher cognitive load experienced by novices highlights an urgent need to integrate cognitive load distribution and decision-making frameworks into current resuscitation training programs. Our work adds to the growing body of literature advocating for simulation-based education that incorporates non-technical skills training, particularly in cognitive and interpersonal skills such as communication and teamwork. These results not only inform instructional design but also pave the way for interventions aimed at accelerating the transition from novice to expert performance.

In summary, this study utilized a VR-based simulation to explore cognitive processes in team-based resuscitation, revealing distinct differences between novice and expert clinicians. Experts demonstrated a greater reliance on inductive reasoning and effective teamwork strategies, leading to better task management and coordination, while novices tended to use deductive reasoning and exhibited higher cognitive load throughout the simulation. Novices lacked awareness of critical communications, highlighting deficiencies in non-technical skills training. Additionally, experts prioritized teamwork and shared strategies for improvement, while novices were less prepared for collaborative efforts. The findings emphasize the need for enhanced training in communication, teamwork, and cognitive load distribution to aid the transition from novice to expert performance in clinical settings. Future research should further explore scalable methods for incorporating CTA findings into training curricula, investigate the longitudinal impact of such interventions on real-world outcomes, and evaluate the transfer of non-technical skills from virtual to clinical environments. Research examining different team arrangements would be valuable for determining whether various team compositions result in differences in cognitive tasks, cognitive load (including cognitive distribution), and team communication. This could facilitate the development of more tailored training programs for specific resuscitation teams. Additionally, comparative studies examining VR versus traditional simulation modalities could further elucidate the unique benefits of immersive technologies in medical education (90), and identify differences in cognitive load, communication and decision making among resuscitative teams.

Limitations

We used a convenience sampling of clinicians in this study from a single institution and the relatively small sample size may limit the generalizability of some of the findings of this study. For instance, novices at other institutions may receive more training on team communication, resulting in more consistent responses in critical communications. Saturation was achieved in three of the four domains. However, we did not achieve saturation in the critical communications domain among novices due to limited and inconsistent responses. The study team chose not to recruit further novices because saturation was not likely achievable due to very limited responses being provided by novices in this domain. This may impact the study results, as achieving saturation may have provided subthemes similar to the expert group, demonstrating little difference between groups in this domain.

We did not record team members with previous experience working with one another. It is likely that the team leaders in the expert group had previous experience with some members within their team, which is less likely among the novice group. This may have impacted results of the CTA and cognitive load differences between groups by introducing bias among the expert group, such as social desirability or acquiescence bias. Additionally, novices were mostly family medicine residents. This is a significantly different group composition than found among experts, who were more diverse and consisted of specialties with stronger backgrounds in emergency medicine. This may also impact the differences in the CTA and cognitive load we identified between groups. For instance, emergency medicine physicians likely have more experience specific to the management of cardiac arrest, leading to more competence and comfort managing these scenarios. As participants reflect on the simulation and self-report cognitive load in each stage, the source of cognitive load (e.g. knowledge gap in rhythm recognition vs. dealing with information overload) may be different between the groups.

As with many similar qualitative studies, the subjective nature of the interview and time between simulation and interview could also contribute to recall bias (although this was likely minimized by having participants watch videos of the scenario to aid in recall), leading to potential omission, exaggeration, or misrepresentation of details. This could lead to inaccurate conclusions drawn from the results. Additionally, because the researchers abstracted data directly from video recordings of the interviews, they were not blinded to the participant's expertise (e.g. novice versus expert) which may have contributed to an expectancy bias. These pre-existing expectations or personal hypotheses may have impacted how the initial coding framework was developed, as well as the coding process and identification of subthemes, by shaping the perspective of the coders and other members of the research team who reviewed the final subthemes. The use of a VR simulation, although high fidelity, may also add confounders due to the factors involved in navigating the novel interface. These confounders may have impacted trends noted in cognitive load and differences in subthemes between groups. Previous studies reported inconclusive results when comparing induced cognitive load in VR (head-mounted displays) with in-person manikin-based, augmented reality, and screen-based simulation environments [91–93]. However, research has indicated that familiarity with VR environments can reduce cognitive load when users are engaging with complex tasks [94]. Since we did not compare previous experience with VR between groups, it is possible that expert groups may have previous training experience with these environments resulting in decreased cognitive load when engaging with these complex tasks. This would lead to a difference in cognitive load during direct patient care, which was observed in our study, as novice clinicians reported higher cognitive load once direct patient care began in Stage 1.

The parameters of the qualitative methods used in this study, specifically that only subthemes mentioned two or more times were considered, may also overlook subtle or unique perspectives and may overemphasize common observations at the expense of individual perspectives, which may also play important roles in team performance. For instance, it was noted in stage 1 that novices reported cognitive load that surpassed the experts and peaked in stage 2. Various subthemes that were not commonly shared among novices may have provided insight into why some individuals in this group reported a higher cognitive load during these phases.

Conclusion

This study highlights notable differences between novices and experts in the cognitive processes used during cardiac arrest management. The varied responses among novices, particularly concerning critical communications, indicate a potential area for targeted training to improve consistency and reliability of team-based instruction, with the goal of accelerating the learning curve for critical leadership skills. The higher cognitive load associated with team leadership presents a challenge for both novice and experienced clinicians and highlights concerns of a limited emphasis on distributed cognition among team members during cardiac arrest management. Additionally, the tendency of novices to rely on deductive reasoning compared to the more inductive approaches of experts suggests a shift in reasoning patterns that may develop with experience. Experts' focus on teamwork and communication underscores the importance of these elements in effective cardiac arrest management. These insights enhance our understanding of the cognitive demands faced by medical professionals and pave the way for improved educational interventions and adaptive strategies. By targeting these specific areas, we can bridge the performance gap between novice and expert clinicians, ultimately improving outcomes in high-stakes medical situations.

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Ethical approval

This study was approved by the University of Michigan Medical School Institutional Review Board (reference number: HUM00193383). Verbal consent was chosen as the preferred method due to the remote nature of the post-simulation interviews conducted via Zoom (Zoom Video Communications Inc.), educational focus of the research, and the minimal risk posed to participants. Verbal consent from participants was obtained and recorded using the Zoom video conferencing platform. This study adheres to the Declaration of Helsinki.

Author contributions

VP, JMC, AS, and MC conceived the study and obtained research funding. VP, JMC, and MC supervised the data collection. VP, JMC, and MC undertook recruitment of participants. VP, BH, SR, and IS analyzed the data. BH and VP drafted the manuscript, and all authors contributed substantially to its revision. VP takes responsibility for the paper as a whole. All authors have read and approved the final work.

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Data availability statement

Available upon reasonable request. Please contact the first author Vitaliy Popov, PhD via email: vipopov@umich.edu

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