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Short paper

Identifying high cognitive load activities during simulated pediatric cardiac arrest using functional near-infrared spectroscopy

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Abstract

Aim: To identify specific activities associated with high cognitive load during simulated pediatric out-of-hospital cardiac arrest (POHCA) resuscitation using physiological monitoring with functional near-infrared spectroscopy (fNIRS).

Methods: We recruited teams of emergency medical services (EMS) responders from fire departments located throughout the Portland, OR metropolitan area to participate in POHCA simulations. Teams consisted of both paramedics and emergency medical technicians (EMTs), with one paramedic serving as the person in charge (PIC). The PIC was outfitted with the OctaMon to collect fNIRS signals from the prefrontal cortex. Signals reported changes in oxygenated and deoxygenated hemoglobin concentrations, which were used to determine moments of increased cognitive activity. Increased cognitive activity was determined by significant increases in oxygenated hemoglobin and decreases in deoxygenated hemoglobin. Significant changes in fNIRS signals were associated with specific concurrent clinical tasks recorded by two independent researchers using video review.

Results: We recorded cognitive activity of EMS providers in 18 POHCA simulations. We found that a proportion of PIC's experienced relatively high cognitive load during medication administration, defibrillation, and rhythm checks compared to other events.

Conclusion: EMS providers commonly experienced increased cognitive activity during key resuscitation tasks that were related to safely coordinating team members around calculating and administering medications, defibrillation, and rhythm and pulse checks. Understanding more about activities that require high cognitive demand can inform future interventions that reduce cognitive load.

Keywords: Prehospital emergency care, Out-of-hospital cardiac arrest, Simulation, Pediatrics, Cognitive load, Functional near-infrared spectroscopy

Introduction

Background

Pediatric out-of-hospital cardiac arrest (POHCA) is a rare event, and outcomes are poorer than those of adults[1]. Unique challenges in POHCA resuscitation include age and size considerations regarding medications, equipment, and treatment algorithms.[2,3] Recently, studies have identified POHCA resuscitation as high risk for care-related patient safety events.[4,5] Some authors have postulated a link between errors in care and high cognitive load.[6]

Cognitive load theory posits that humans have a limited amount of working memory available and when the demand of a task supersedes this availability, decrements in performance may occur.[7] Traditionally, cognitive load has been measured using instruments that are subjective and summative, such as the NASA-TLX. Investigators have also attempted to measure physiologic markers of cognitive load, using techniques such as pupillometry, galvanic skin response,

Abbreviations: AIDE, Automatic Identification of Functional Events, fNIRS, Functional near-infrared spectroscopy, POHCA, Pediatric out-of-hospital cardiac arrest, PFC, Prefrontal cortex, PIC, Person in charge, HbO, Oxygenated hemoglobin concentration, HbR, Deoxygenated hemoglobin concentration, HRF, Hemodynamic response function

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fMRI, and EEG.[8] Many of these techniques measure cognitive activity indirectly or use equipment that restrict mobility.

Functional near-infrared spectroscopy (fNIRS) is a tool for directly measuring cognitive activity that could potentially be used in naturalistic environments. fNIRS utilizes near-infrared light to determine concentrations of oxygenated (HbO) and deoxygenated hemoglobin (HbR), which is reflective of the overall metabolic activity of a tissue of interest.[9] When assessing cognitive load, the fNIRS device is applied to the prefrontal cortex (PFC), which is the region of the brain utilized when tasks involving working memory are performed.[10] fNIRS is similar to fMRI as a direct measure of cognitive activity, but provides the added benefit of being low cost, lightweight, portable, and resistant to motion artifacts making it attractive for use in dynamic environments including clinical care. The objective of this study was to utilize fNIRS to identify specific events during simulated POHCA resuscitation associated with physiologically measured increases in cognitive load.

Methods

We recruited teams of EMS responders from fire departments located throughout the Portland, OR metropolitan area between June and August 2022 to voluntarily participate in POHCA simulations. Each team consisted of both emergency medical technicians (EMTs) and paramedics. Teams self-selected one member to serve as the person in charge (PIC) who would be outfitted with the fNIRS device during the simulations. The only criterion for selection was that the PIC must be a paramedic.

Simulations were conducted at local fire department training centers. Each session began with an orientation where teams became acquainted with the manikins (SimJunior, Laerdal Medical, Norway) and patient monitor simulator (iSimulate, Albany, NY). Teams utilized their own equipment to ensure that their response was as similar to real-life as possible.

Following the orientation period, teams were dispatched to a call involving a 6 year-old boy who had two syncopal episodes while playing outside within the past week, and today parents witnessed him passing out while running around the house. 911 was called and CPR was initiated by the parent. Upon EMS arrival, ineffective compression-only CPR was being performed. The patient was in ventricular tachycardia and teams were expected to provide treatment using the Pediatric Advanced Life Support[11] algorithm which included high quality CPR, rhythm checks within 1 minute, defibrillation, basic and/or advanced airway techniques, vascular access (IV or IO), and administration of appropriate doses of medications when indicated. In the scenario, ROSC was achieved after the third defibrillation. All simulations were concluded at approximately 10 minutes.

Optical measurements were recorded using a functional near-infrared spectrometer (OctaMon, Artinis Medical Systems, The Netherlands). The OctaMon is a wireless, headband-like device with embedded optodes that allow for the noninvasive detection of changes in concentration of HbO and HbR of the PFC. The detection of changes in concentration can be related to cognitive load through neurovascular coupling which states that as mental workload increases, so will cerebral blood flow, thus resulting in a simultaneous increase in HbO and decrease in HbR.[12]

Data analysis

We used the signal quality index (SQI) to exclude low quality signals from analysis.[13] After screening for signal quality, wavelet and recursive least-squares (RLS) filters were applied to remove artifacts caused by motion and physiological noise related to heart rate and blood pressure fluctuations.[14,15].

Cleaned signals were passed through the Automatic Identification of functional Events (AIDE) algorithm which identified cognitive events by comparing the signals on a second-by-second basis to a model of functional activity.[16] The Benjamini-Hochburg procedure was used to correct the false discoveries rate in signal spikes, wherein we presumed 5% of our detected peaks are false discoveries and set the p-value threshold to exclude them.[17] This method is less conservative but useful considering the space being explored. The output from the AIDE algorithm provided time points where spikes in cognitive demand occurred (Fig. 1).

Two reviewers independently reviewed video recordings of each simulation and coded the clinical actions being performed at each time point. The standard steps of resuscitation were used to code activities performed by the PIC. Any discrepancies were resolved through consensus and validated by a clinical expert.

Ethics approval

This study was approved by Oregon Health & Science University's Institutional Review Board (IRB# 00018494). Informed consent was given by all participants.

Results

A total of 18 simulation sessions, each with a different team and PIC, were conducted. Teams had a mean (SD) size of 7 (1) members, including the PIC. Table 1 details PIC characteristics.

PICs appeared to have elevated cognitive load during similar clinical tasks: 15 (83%) of the PICs had cognitive events during medication administration, 14 (78%) during defibrillation, and 13 (72%) during rhythm checks (Fig. 2). Medication administration included looking up, calculating, and giving drugs to the patient. Events coded as defibrillation referred to moments where the PIC cleared team members from the patient and administered an electrical shock. Lastly, rhythm was coded when the PIC paused team activity to analyze the patient's rhythm, presence of a pulse, and determined the next course of action.

Discussion

In this study we utilized fNIRS as a physiologic measure of cognitive load in order to identify moments in which EMS providers experienced an increase in cognitive demand during POHCA simulations. Our findings suggest that while there were numerous event types where EMS providers experienced increased cognitive load, the most common event types were surrounding the calculation and administration of drugs, defibrillation, and rhythm and pulse checks.

Prior works exploring cognitive load during resuscitation simulation have commonly relied on self-assessment measures such as the NASA-TLX, or physiologic measures such as changes in heart rate or cortisol levels to determine levels of workload.[18] In addition, much of the work has centered on the variation of cognitive load between team members, showing that team leads often have the

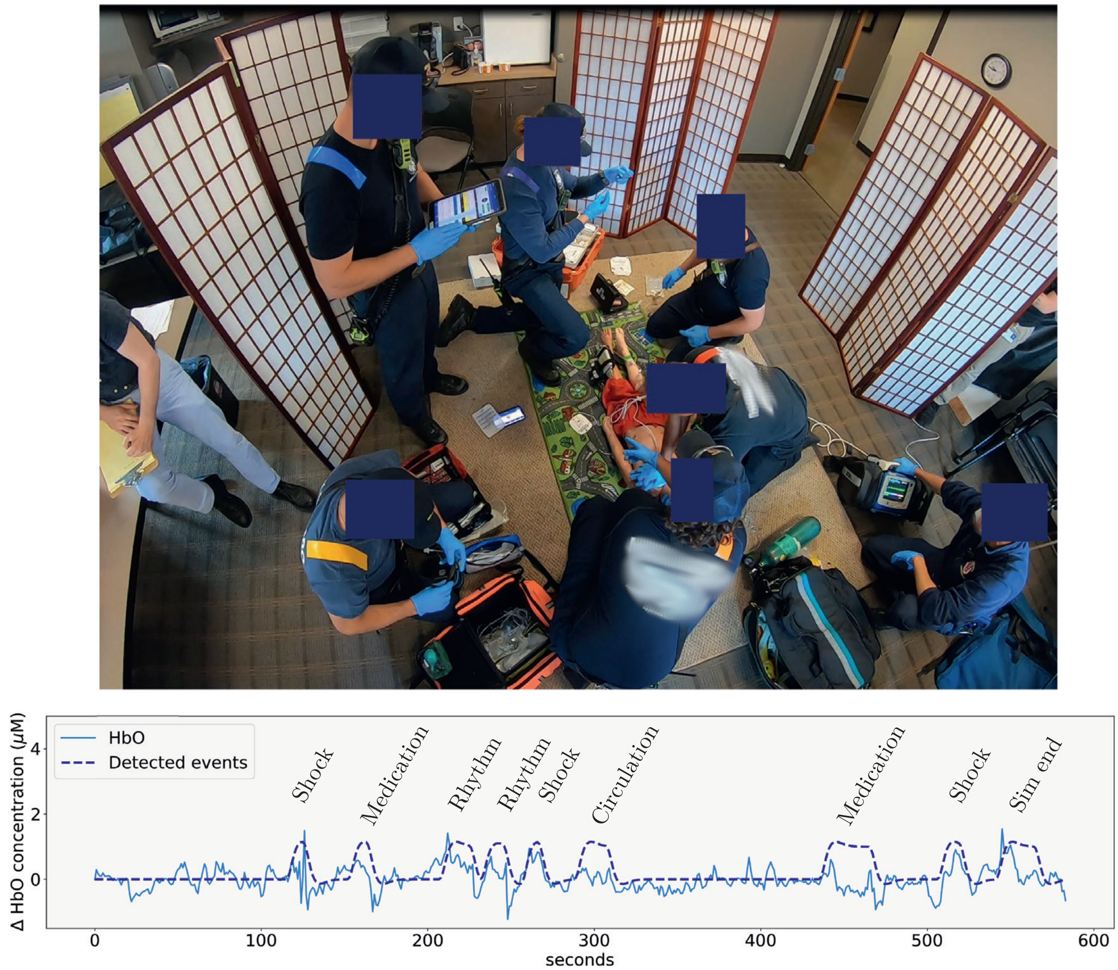

Fig. 1 – Output in one of six fNIRS channels from the AIDE algorithm providing time points of interest.

Table 1 – PIC characteristics, data represented as mean (SD).

PIC Characteristics, n = 18	
Gender (Male, Female)	17.1
Age	32 (7)
Years of Experience	7.9 (6.7)
Pediatric cardiac arrests treated in past year	1.3 (0.5)
Simulated pediatric cardiac arrests treated in past year	1.8 (0.6)

highest level of workload and that cases involving pediatric patients result in increased cognitive load.[19–21] This study builds upon the work of others, exploring the use of fNIRS as a physiologic measure that can be used in ecologically valid environments, and focusing on the specific care events that may lead to increases in cognitive load among team leaders during resuscitation.

Defibrillation is a critical step that improves a patient's chances of long-term survival following OHCA.[22] We identified high cognitive load around defibrillation. This could be related to concern for team safety (clearing the patient); calculating age-appropriate energy dose; and anticipating that defibrillation may lead to ROSC and a consequent change in management. We separately identified a physiologic spike in cognitive load at the time of the rhythm check. We theorize this may be related to interpretation of pediatric rhythms and the determination of shockable vs non-shockable algorithm. Int erestingly, this cognitive challenge is the basis for the development of AEDs, however, EMS crews generally did not use the AED mode of their defibrillator during the simulated resuscitation.

Finally, medication dosing presents a unique challenge in the resuscitation of POHCA due to weight-based dosing requirements. A robust literature has described medication dosing errors in the pre-hospital setting and some have speculated that high cognitive load may be a factor contributing to error.[5,6] Our observation of a physiologic spike in cognitive load may support this theory. Specific cognitive tasks related to medication delivery in pediatric resuscitation include navigating cognitive aids, identifying the correct medication

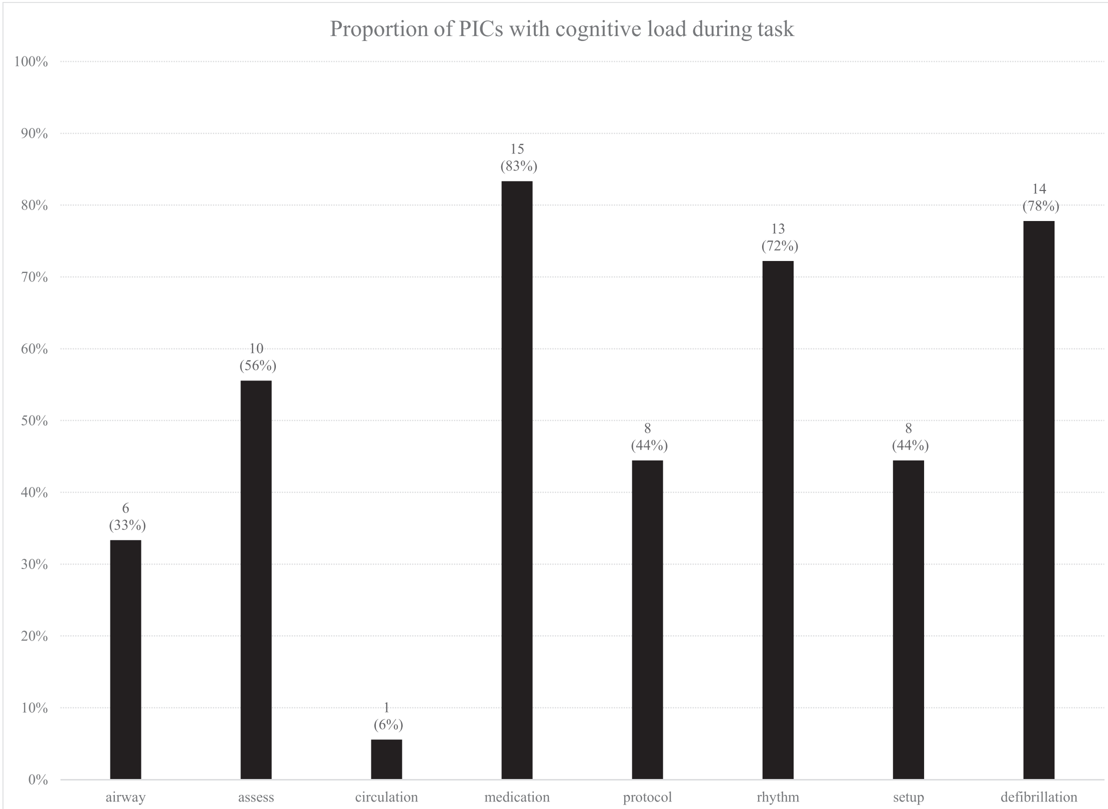

Fig. 2 – The proportion of PICs who experienced cognitive load while performing specific tasks during a simulated resuscitation.

and syringe size, drawing up the dose, double checking the dose, and administering the medication.

While we have proposed a number of potential explanations for events associated with high cognitive load, it is possible that the low-frequency, high-stakes nature of pediatric resuscitation is inherently stressful and may contribute to cognitive load even among events well practiced by paramedics caring for adult cardiac arrest. Studies have previously described reasons for high levels of EMS provider stress inherently related to pediatric patients, including perceived vulnerability, sympathy for the patient, and insufficient exposure.[23] We acknowledge the exploratory nature of this work which provides fertile ground for future confirmatory studies with the ultimate goal of identifying potential experimental interventions to mitigate cognitive load during POHCA resuscitation.

Limitations

This study contains limitations. The biggest limitation is that we used simulated events and cognitive load in patient resuscitations may differ. We tried to mitigate this limitation through the use of high-fidelity manikins and professional actors. Additionally, in each simulation session fNIRS data was only collected from one participant, the PIC. Although the PIC on each team was responsible for the same general duties, specific tasks might have differed on a case-to-case basis given the unconstrained simulation environment. It is also plausible that the PIC and other team members experienced load differently because of the variation in the responsibilities while delivering care. Additional studies would be needed to further explore the impact that provider role has on cognitive load and how load is distributed among teams. Lastly, given the observational approach to this study, we were unable to determine the exact stimuli that caused each event. Because of this, there is a possibility for false negatives and positives in our coded events.

Conclusion

During POHCA simulations, EMS providers commonly experienced increased cognitive load surrounding the performance of tasks related to medication administration, defibrillation, and rhythm analysis. The findings from this exploratory study may guide future studies exploring cognitive load during pediatric resuscitation and the development of new interventions to improve care.

CRediT authorship contribution statement

Jonathan Ivankovic: Conceptualization, Investigation, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Nathan Bahr:** Conceptualization, Investigation, Methodology, Data curation, Formal analysis, Software, Visualization, Writing – review & editing. **Garth D Meckler:** Conceptualization, Writing – review & editing. **Matthew Hansen:** Conceptualization, Writing – review & editing. **Carl Eriksson:** Conceptualization, Writing – review & editing. **Jeanne-Marie Guise:** Conceptualization, Investigation, Funding acquisition, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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