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Operational feasibility of prehospital neuromonitoring in traumatic brain injury: a simulation study

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Abstract

Background

Traumatic brain injury (TBI) is a leading cause of death and disability worldwide, with secondary brain injury significantly contributing to poor outcomes. Early identification of patients at risk remains challenging in the prehospital environment due to limited diagnostic capability. Portable neuromonitoring technologies may enhance early assessment, however, their feasibility and impact on prehospital workflow are not well established. This study aimed to evaluate the integration of novel neuromonitoring devices into standard Helicopter Emergency Medical Service (HEMS) TBI care within a simulated environment.

Methods

A high-fidelity simulation study was conducted between August 2024 and May 2025 at a UK HEMS base. Twenty-four clinician pairs (critical care paramedics and doctors) participated in simulated TBI scenarios. Six portable neuromonitoring devices were introduced across 16 simulations, with 8 control simulations conducted without devices. The primary outcomes extracted from video recordings were phase of care for device deployment, time to data acquisition, and interruptions encountered. Secondary outcomes included the temporal impact on prehospital phases of care and standard clinical interventions.

Results

Neuromonitoring devices were successfully deployed in all 16 simulations and used almost exclusively during consecutive prehospital activity. Devices were predominantly used either prior to prehospital emergency anaesthesia or during transport. Data acquisition was achieved in all but three instances of device use, and time to data acquisition varied by device between 1.4–5.3 minutes. Interruptions occurred across all devices, most commonly due to user-related factors. There were no significant differences observed in the duration of prehospital phases of care between device and control groups including elapsed scene time until anaesthesia (device: 25.7mins [IQR 22.0-29.6], control: 25.4mins [IQR 22.8–28.1], $p > 0.99$).

Conclusion

Portable neuromonitoring devices can be integrated into simulated prehospital TBI care without delaying critical interventions or prolonging scene time. While deployment is generally successful, variability in duration of device use and associated interruptions highlight the importance of targeted training for optimisation of user–device integration. These findings support further investigation into real-world application and the potential of neuromonitoring to improve early TBI assessment and management.

Background

Globally, 69 million individuals are estimated to suffer traumatic brain injury (TBI) each year (1), and severe TBI has the highest burden of mortality and longer term cognitive-behavioural and functional morbidity (2,3). Secondary brain injury is associated with severe TBI, arising from increasing brain oedema, raised intracranial pressure (ICP), and decreased cerebral perfusion pressure, and increases the risk of poor outcome (4–6). Prehospital and early in-hospital TBI management aims to minimise secondary brain injury, and therefore timely detection of those most at risk is important (7). However early detection of TBI in prehospital care is currently challenged by limited diagnostic and therapeutic resources (8,9)

Early assessment of TBI and the associated severity and prognosis is currently measured using the Glasgow Coma Scale (GCS) and pupil reactivity (10–13). GCS has a prominent role in the prehospital assessment of TBI, but the prognostic validity of this tool is insufficient for predicting outcome in individual patients (14). GCS also lacks discrimination in older patients where intracranial injury may go undetected because of a discordantly high GCS or in those with clinical features that may mimic TBI without intracranial pathology (15–18). Furthermore, interobserver variability is inherent in measuring GCS and pupil size(19–22). A new strategy is needed for characterising TBI more accurately (23), where ICP monitoring, blood biomarkers, brain tissue pO2 measurements, and electroencephalogram (EEG) may have a role (24). This may be particularly beneficial in settings where expensive, bulky, and non-portable clinical neuroimaging is not feasible (25). Some Helicopter Emergency Medical Service (HEMS) and land ambulance teams are beginning to explore the use of portable neuromonitoring devices to aid early TBI assessment. Transorbital ultrasound to detect raised ICP (26), EEG acquisition in trauma patients (27), and near-infrared spectroscopy (NIRS) (28) have been reported in prehospital settings. Whilst these have potential for monitoring individual cerebral physiological parameters, given the complexity of TBI pathophysiology it may be that combining several neuromonitoring devices brings greater benefit (29).

Implementation of neuroinformatics to support clinical decision-making in this field is needed (30). To introduce new technology safely into clinical practice it is appropriate to evaluate utility and function preclinically. Simulation-based translational research helps to move results from the laboratory to patient management in a safe environment (31). Therefore, the overall aim of this simulated-based study was to evaluate the impact of introducing novel neuromonitoring devices to standard HEMS TBI management. The primary objective was to explore the feasibility of deployment of neuromonitoring devices in the prehospital phase, including the time taken to deploy and capture data. Secondly, we aimed to identify any interruptions in data capture. Finally, we examined the devices' impact on the phases of care and standard prehospital interventions.

Methods

This was a simulation study, used to test the feasibility of portable neuromonitoring devices in a prehospital TBI scenario between August 2024 and May 2025.

Site

Essex and Herts Air Ambulance (EHAAT) is a HEMS unit providing prehospital critical care in Essex, Hertfordshire, and the surrounding counties in the UK. The simulations took place in a dedicated simulation suite at an EHAAT Airbase. Each high-fidelity simulation involved a clinical scenario using a SIMBODIES manikin by Safeguard Medical with two non-clinical staff members acting as patient and bystander and two non-HEMS clinical staff acting as an ambulance crew.

Participants

The study included a convenience sample of 24 pairs of EHAAT HEMS Critical Care Paramedics (CCP) and Prehospital Care Doctors.

Eligibility criteria

EHAAT clinicians that had completed their training portfolios and were working autonomously in their roles were invited to participate. The CCPs have at least four years' post paramedic registration experience before working at EHAAT. Doctors are from an anaesthetic or emergency medicine background with a minimum of five-years post graduate experience and at least six-months' experience in anaesthesia and Emergency Medicine.

EHAAT clinicians who met eligibility criteria and expressed an interest in participating were provided with a participant information sheet and a consent form via email. Involvement in this study was entirely voluntary, and there was no obligation to participate. Those providing consent to take part were invited by return email to attend a simulation study session.

Ethics

Ethical approval for this project was provided by the Queen Mary University of London Devolved School Research Ethics Committee (DSRECPG_02_v1).

Device selection

Following an evidence review, portable technologies proposed as classifiers of head injury or previously evaluated by prehospital services, supported by UK Conformity Assessed (UKCA) certification were included. Vscan Air by GE Healthcare was already in use by EHAAT for cardiac and vascular ultrasound but not for optic nerve sheath ultrasonography (ONSUS). A further five devices were purchased or loaned from UK distributors and a total of 24 simulations were undertaken. One clinician had previous clinical experience with the Nonin CO-Pilot and two clinicians had previous clinical experience with the NeuroOptics NPi-300 Pupillometer. Quantitative pupillometry was shortlisted for feasibility review due to the importance of pupil examination in neurological assessment and cognisant that standard pen torch light reflex is subject to interobserver variability. Sixteen initial simulations included the introduction of six devices: three in each simulation (Table 1). At 12 weeks after the initial simulations, eight control simulations without devices were carried out.

Table 1. Devices utilised in the simulation study

	Device	Manufacturer	Technology Utilised	Detects
Simulations 1-8	Epoc X - 14 Channel Wireless EEG Headset	Emotiv	Electroencephalography (EEG)	Neurophysiological dysfunction
	iSTAT Alinity with TBI cartridges	Abbott	Point-of-care device for measuring blood biomarkers ubiquitin C-terminal hydrolase-L1 (UCH-L1) and glial fibrillary acidic protein (GFAP).	Structural brain damage
	Vscan Air Handheld Ultrasound	GE HealthCare	Optic nerve sheath ultrasonography (ONSUS)	Increased intracranial pressure
Simulations 9-16	CO-Pilot Wireless Handheld Multi-Parameter System	Nonin	Cerebral oximetry via near-infrared spectroscopy (NIRS)	Cerebral hypoxia
	NPi-300 Pupillometer with SmartGuard	NeuroOptics	Objective measurement of pupil size and reactivity	Neurological dysfunction
	Infrascanner Model 2000	InfraScan Brain Diagnostics	NIRS	Intracranial haematomas
Simulations 17-24 (controls)	No device			

Protocol

Prior to the simulations, each CCP and Doctor pair were allocated ten-minutes ‘hands-on’ familiarisation time per neuromonitoring device. Participants had access to a ‘quick user guide’ and a healthy volunteer for testing the device. The clinical aspect of each simulation was underpinned by the EHAAT TBI standard operating procedure (SOP). The neuromonitoring tools were not a feature of the SOP but were to be included within the scenario at a point that the clinicians felt appropriate. At the start of the simulation the scenario detail was read from a script by the researcher (Additional file 1.docx, Information given to participants before entering the scenario).

The simulated activities were recorded using the Scotia Medical Observation and Training System (SMOTS) hardware and software installation via two wall-mounted cameras, one mobile trolley-mounted

camera and two body-worn cameras worn by the HEMS clinicians. The Immersive Interactive installation was used to project a skate park environment for the ‘scene’, and the internal walls of a land ambulance in two adjacent simulation rooms. Sounds accompanying these environments (e.g. sirens, road noise) were made audible at the appropriate volume. The scenario ended when the simulated patient departed the scene and for those simulations involving neuromonitoring devices, an attempt had been made to use all three.

Data collection

Standard care, neuromonitoring device use and timings were collected from video footage. Interruptions where challenges with the devices inhibited data collection were captured using a stopwatch and categorised into ‘user’, ‘device’, ‘user-device interface’ or ‘extraneous’ factors. The cumulative delay was recorded for each neuromonitoring device during each simulation.

Data analysis

Start and end points of phases of care, standard interventions and neuromonitoring were categorised and the favoured window for device application recorded (Table 2). The time spent using each neurological device and the interruptions encountered were analysed. The iSTAT Alinity by Abbott requires a 15-minute blood analysis period to process the blood sample and as this interval did not require any clinician input it was not included in the temporal data analysis. The duration of phases of care and standard clinical interventions were compared between device and no device (control) simulations. Continuous data were non-parametric according to Shapiro Wilk test, compared with Mann Whitney U tests and are displayed as medians with interquartile ranges (IQR). A p value of <0.05 was considered statistically significant.

Table 2. Phases of care and start and end points of interventions

		Starting Point	End Point
Phase of Care	Primary survey	Clinician speaks to the patient	Clinician shares their primary survey findings with the other clinician
	Before Prehospital Emergency Anaesthesia (PHEA)	Completion of the primary survey	Anaesthetic drugs are administered
	After PHEA but before loading the patient into the ambulance	Endotracheal tube tied into place	Patient crosses the threshold of the simulated ambulance
	After loading the patient into the ambulance but before transport to hospital	Patient crosses the threshold of the ambulance	EHAAT crew request that the land ambulance crew depart for the hospital
	During transport to hospital (phase not a feature of the control simulation)	Ambulance departs for the hospital	All three neuromonitoring devices have been used
Standard Intervention	Arterial line	Clinician places a hand on the arterial line pouch	Transducer connected to the monitor
	PHEA	CCP steps away to perform PHEA kit preparation	Endotracheal tube tied into place
Neuromonitoring	iSTAT Alinity	Clinician places their hand on the device	Analysis period completed and results returned
	Vscan	Clinician places their hand on the device	Optic nerve sheath diameter obtained from one eye
	EEG	Clinician places their hand on the device	30 seconds of EEG data obtained
	CO-Pilot	Clinician places their hand on the device	30 seconds of oxygen saturations observed over both frontal hemispheres
	Pupillometer	Clinician places their hand on the device	Pupil size and NPi obtained for both eyes
	Infrascanner	Clinician places their hand on the device	Data obtained for 6 out of 8 zones (occiput not measured due to patient's supine position)

Results

Devices were successfully applied in all 16 simulations and each type of neuromonitoring modality was used almost exclusively during consecutive prehospital activity. The predominant phases of care in which the devices were deployed had a bimodal distribution, generally either before prehospital emergency anaesthesia (PHEA) or during transport (Figure 1). The median time from leaving scene until all neuromonitoring devices had been used in transport was 8.3mins [IQR 4.4-17.6].

Insert Figure 1

Figure 1. Phase of care neuromonitoring device was used during simulation.

The clinical objectives of each device were met, and data was successfully acquired in all of the simulations using Emotiv Epoc X - 14 Channel Wireless EEG Headset, Vscan for ONSUS and Pupillometer. During one simulation each for iSTAT, CO-Pilot and Infrascanner Model 2000 by Infrascan Brain Diagnostics, deployment did not provide data, with user factors responsible in two cases and device factors in the third (Table 3).

Table 3. Number of successful uses of the neuromonitoring device.

Simulation	Device	Objective	No. of sims objective successful	% success	Reason for failure
1-8	EEG	Record 30secs of EEG data	8	100	n/a
	iSTAT Alinity	Measure the GFAP and UCH-L1 from a sample of control agent	7	88	Error message ‘insufficient sample’ (U)
	Vscan for ONSUS	Measure the optic nerve sheath diameter in one eye	8	100	n/a
9-16	CO-Pilot	Record the highest and lowest saturations in 30secs of data from the left and the right hemispheres	7	88	Device stopped working (D)
	Pupillometer	Measure pupil size and NPi for both eyes	8	100	n/a
	Infrascanner	Record a positive or negative result for haematoma over 6 areas (3 regions) of the brain	7	88	Consumable incorrectly fitted (U)

U, user; D, device

Time to capture data for each device varied, with shortest observed in the Pupillometer (1.4mins) and longest in the Infrascanner (5.3mins) (Figure 2a). Interruptions occurred during the use of each device, but total delay varied (Figure 2b) with the longest experienced with the Infrascanner (median 3.0mins).

Insert Figure 2a and 2b

Figure 2.**a:** Median duration of EEG use: 4.5mins [IQR 3.6 – 7.7], Median duration of iSTAT use: 5.1mins [IQR 3.2 – 10.0], Median duration of Vscan for ONSUS use: 3.2mins [IQR 3.0 – 4.1], Median duration of CO-Pilot use: 3.4mins [IQR 2.9 – 3.8], Median duration of pupillometer use: 1.4mins [IQR 1.3 – 2.1], Median duration of Infrascanner use: 5.3mins [IQR 4.0 – 5.8]. **b:** EEG interruptions: 1.3mins [IQR 0.3-2.0], iSTAT interruptions: 1.0mins [IQR 0.3 -3.4], Vscan for ONSUS interruptions: 0.3mins [IQR 0.1 – 0.7], CO-Pilot interruptions: 0.1mins [IQR 0.4 – 1.2], pupillometer interruptions: 0.3mins [IQR 0 – 0.7], Infrascanner interruptions: 3.0mins [IQR 1.3 – 3.3].

Cause of interruption varied according to device, but the most prevalent were user-related factors. (Table 4). The commonest interruption was observed with the Infrascanner where multiple rescans of the same region were required to achieve a result.

Table 4. Classification and frequency of challenges that caused interruptions in device deployment.

Device	Causes of interruption	Most common	No of sims this error occurred in
Emotiv EEG	U – 6 UDI – 2 E – 3 **Total = 11**	Multiple attempts needed to improve electrode contact quality (UDI).	6
iSTAT Alinity	U – 10 D – 2 UDI – 1 **Total = 13**	Multiple attempts required to successfully scan a cartridge barcode (U).	5
Vscan for ONSUS	U – 6 D – 1 UDI – 1 **Total = 8**	Multiple attempts were required to adjust the measuring callipers to find the nerve sheath edges (U).	2
CO-Pilot	U – 9 D - 1 UDI – 1 **Total = 11**	Display not connecting with the signal processor (D).	4
Pupillometer	U – 6 UDI – 1 E – 1 **Total = 8**	Failed scan (UDI)	3
Infrascanner	U – 9 UDI – 4 E – 3 **Total = 16**	Device requesting repeated scan of the same region (UDI).	7

U, user; D, device; UDI, user-device interface; E, extraneous

The effect of device use on standard prehospital clinical interventions and simulation times was analysed (Figure 3). Critical phases of care including elapsed scene time until PHEA was performed did not differ between groups (device: 25.7mins [IQR 22.0-29.6], control: 25.4mins [IQR 22.8-28.1], p>0.99,

Figure 3b). Overall, there was no significant difference in the duration of intervals between neuromonitoring device simulations and controls (Figure 3a-e).

Insert Figure 3a-e

Figure 3 – (a) Duration of arterial line placement device:7.5 mins [IQR 5.4-11.0], control: 7.8mins, [IQR 6.8-12.0], p=0.44. (b) – Elapsed scenario time until anaesthetic drugs administered device: 25.7mins [IQR 22.0-29.6], control: 25.4mins [IQR 22.8-28.1], p=>0.99. (c) - Duration of PHEA preparation and delivery device: 18.3mins [IQR 17.3-20.8], control: 19.8mins, [IQR 15.5-22.5], p=0.93. (d) – Elapsed scenario time until patient loaded into the simulated ambulance device: 32.3mins [IQR 28.1-36.0], control: 31.5mins [IQR 28.5-34.4], p=0.93. (e) - Elapsed scenario time until ambulance left scene device: 35.8mins [IQR 32.7-40.3], control: 35.8mins [CI 32.8-39.4], p=0.98.

Discussion

This simulation study examined the feasibility and utility of multiple prehospital neuromonitoring devices in patients with suspected TBI. Devices were applied almost exclusively during consecutive prehospital activity, predominantly prior to PHEA or during transport. Data were successfully captured with the devices in all but one attempt each with the iSTAT, CO-Pilot and Infrascanner. Duration of device use was highly variable, as was the time spent dealing with challenges that resulted in device deployment interruptions. Device interruptions were predominantly related to user factors, however the prehospital period and durations of standard TBI clinical interventions were unaffected by the introduction of neuromonitoring devices.

Timing of device use

Although some neuromonitoring devices were applied before PHEA, the preferred phase was during transport, and this may have been to limit their impact on on-scene times. Expediting on-scene times has been a principle of prehospital care for many years with an on-scene goal of less than 10 minutes and better patient outcomes anticipated if definitive care is reached within the ‘Golden Hour’ (32–34). More recently however, TBI patients arriving at hospital within the 60-minute threshold have not shown a survival benefit (35). There are very few TBI patients that require immediate transport for in-hospital neurosurgical intervention. A search of the US National Trauma Data Bank yielded 731,823 trauma patients of which 213,357 had a head injury reported and only 1% required craniotomy: Of all craniotomies, only 6.5% were performed within one-hour of hospital admission (36). An increased odds of survival with longer on-scene times has been detected in this patient group, possibly related to the impact of targeted prehospital care and tailored triage destination decisions (37).

Deployment

Despite a brief familiarisation before the simulations, clinicians were in all but three instances, able to successfully deploy the neuromonitoring devices. There was a high degree of variability in duration of

device use, and in the interruptions associated with device challenges. Medical equipment design flaws, mishandling, user error, and malfunction are common causes of errors and are inevitable (38). User factors, including mishandling or user error, were responsible for the greatest number of interruptions across all devices. Errors specifically identified in medical simulation, can highlight knowledge and skill gap to reduce future error and support skill-retention in the clinical setting (39). The device challenges identified from the simulations, especially those that occurred across multiple simulations, should be explored and mitigations such as additional written materials and video instruction, and additional targeted training, put in place to reduce interruptions and variability for real-world clinical use.

Effects on standard prehospital TBI management

Regardless of the additional time and cognitive burden of introducing neuromonitoring devices, this did not adversely influence the duration of standard prehospital interventions, phases of care, or total on-scene time. Our findings may be of particular interest to prehospital organisations who are considering the introduction of new healthcare technology and their longitudinal impact. This study may reflect prehospital clinicians' ability to multi-task and introduce new assessments without a linear extension of scene times.

Limitations

There are a number of limitations to be acknowledged. Although efforts were made to ensure a high-fidelity scenario, results derived from simulation must be interpreted with caution. Simulation cannot fully replicate the cognitive load, stress, environmental complexity, and dynamic prioritisation inherent to real prehospital trauma care. Scenarios inevitably simplify logistical constraints, interruptions, and competing clinical demands, and therefore may underestimate the true time required to deploy or repeat interventions in operational settings. The eight CCPs who participated in the control simulations following a 12-week washout period had a repeat exposure to the scenario which may have reduced measured times. Consequently, simulation-based timing data should be regarded as estimates of feasibility rather than definitive reflections of real-world integration.

The simulated ambulance was unable to mimic the motion of a vehicle and any subsequent artefact that could impact device data acquisition. Vehicle motion may, for example, have a significant impact on the ability to obtain quality readings from the EEG device. Although the prosthetic arm was cannulated during the scenario, and the drawing of a sample of blood mimicked, a control solution was used for blood biomarker analysis. This step may have had an influence on time to data acquisition.

Conclusion

This simulation study demonstrates that neuromonitoring devices can be integrated into prehospital TBI assessment and management without prolonging scene time or delaying critical interventions. Across all simulations, devices were successfully deployed and achieved high rates of data acquisition. Deployment interruptions were largely attributable to user factors and highlight the importance of

targeted training. Further research should focus on device reliability and data interpretation in the field, and the extent to which prehospital neuromonitoring can meaningfully inform triage, treatment decisions, and early neuroprotective strategies.

Abbreviations

CCP – Critical Care Paramedic

ECG – Electrocardiogram

EEG – Electroencephalogram

EHAAT – Essex and Herts Air Ambulance

GCS – Glasgow Coma Scale

HEMS – Helicopter Emergency Medical Service

ICP – Intracranial pressure

NIRS – Near-Infrared Spectroscopy

ONSUS – Optic Nerve Sheath Ultrasonography

PHEA – Prehospital Emergency Anaesthesia

SMOTS – Scotia Medical Observation and Training System

SOP – Standard Operating Procedure

TBI – Traumatic Brain Injury

UKCA – UK Conformity Assessed

Declarations

Ethics approval and consent to participate

Ethical approval for this project was provided by the Queen Mary University of London Devolved School Research Ethics Committee (DSRECPG_02_v1). EHAAT clinicians who met eligibility criteria and expressed an interest in participating were provided with a participant information sheet and a consent form via email. Involvement in the study was entirely voluntary, and there was no obligation to participate. Those providing consent to take part were invited by return email to attend a simulation study session.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

CU is Chief Medical Officer for Crainio, a portable, non-invasive neuromonitoring device that this was not included in this study. The authors declare that they have no known conflicts of interest.

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Authors' contributions

Conceptualisation: L.P., C.U., E.C.; Methodology: L.P., EC.; Investigation: L.P.; Data curation: L.P.; Formal analysis: L.P., E.C.; Writing – original draft: L.P., E.C.; Writing review & editing: L.P., G.G., E.C.; Supervision: C.U., G.G., E.C.; Project administration: L.P.; Resources: L.P., G.G.; Funding acquisition: L.P., G.G. All authors reviewed and approved the final manuscript.

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Figures

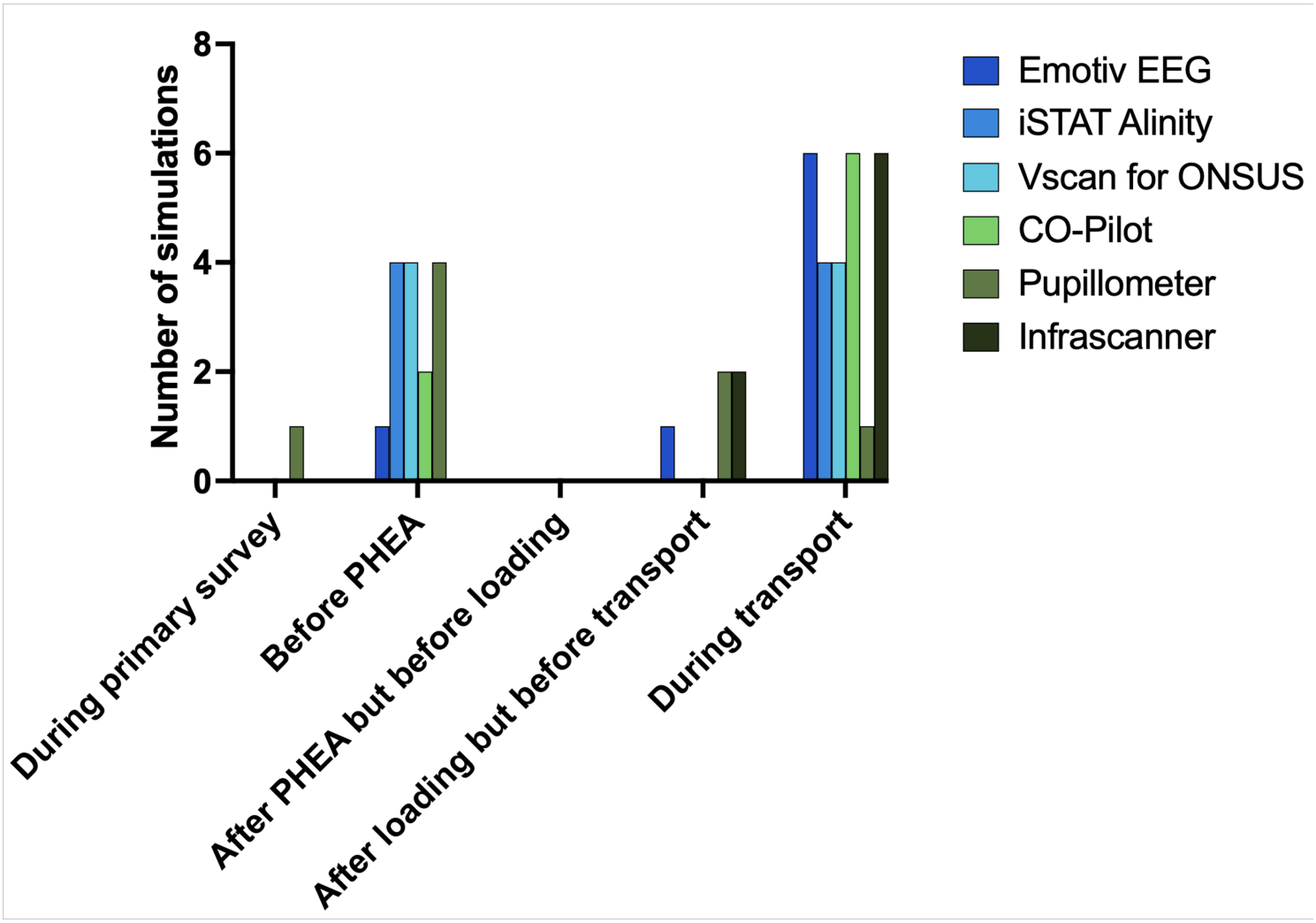


Figure 1

Phase of care neuromonitoring device was used during simulation.

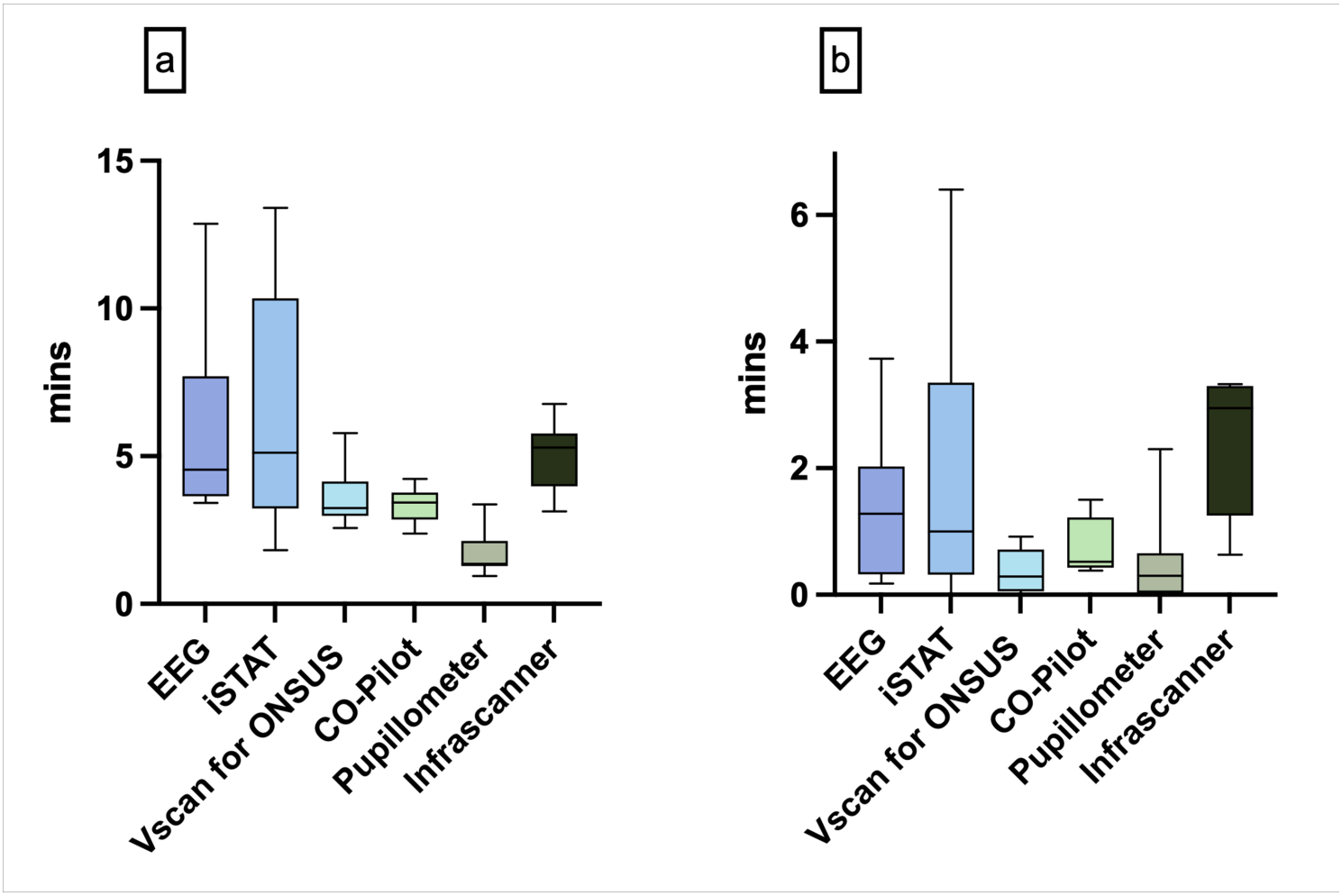


Figure 2

a: Median duration of EEG use: 4.5mins [IQR 3.6 – 7.7], Median duration of iSTAT use: 5.1mins [IQR 3.2 – 10.0], Median duration of Vscan for ONSUS use: 3.2mins [IQR 3.0 – 4.1], Median duration of CO-Pilot use: 3.4mins [IQR 2.9 – 3.8], Median duration of pupillometer use: 1.4mins [IQR 1.3 – 2.1], Median duration of Infrascanner use: 5.3mins [IQR 4.0 – 5.8]. **b:** EEG interruptions: 1.3mins [IQR 0.3-2.0], iSTAT interruptions: 1.0mins [IQR 0.3 -3.4], Vscan for ONSUS interruptions: 0.3mins [IQR 0.1 – 0.7], CO-Pilot interruptions: 0.1mins [IQR 0.4 – 1.2], pupillometer interruptions: 0.3mins [IQR 0 – 0.7], Infrascanner interruptions: 3.0mins [IQR 1.3 – 3.3].

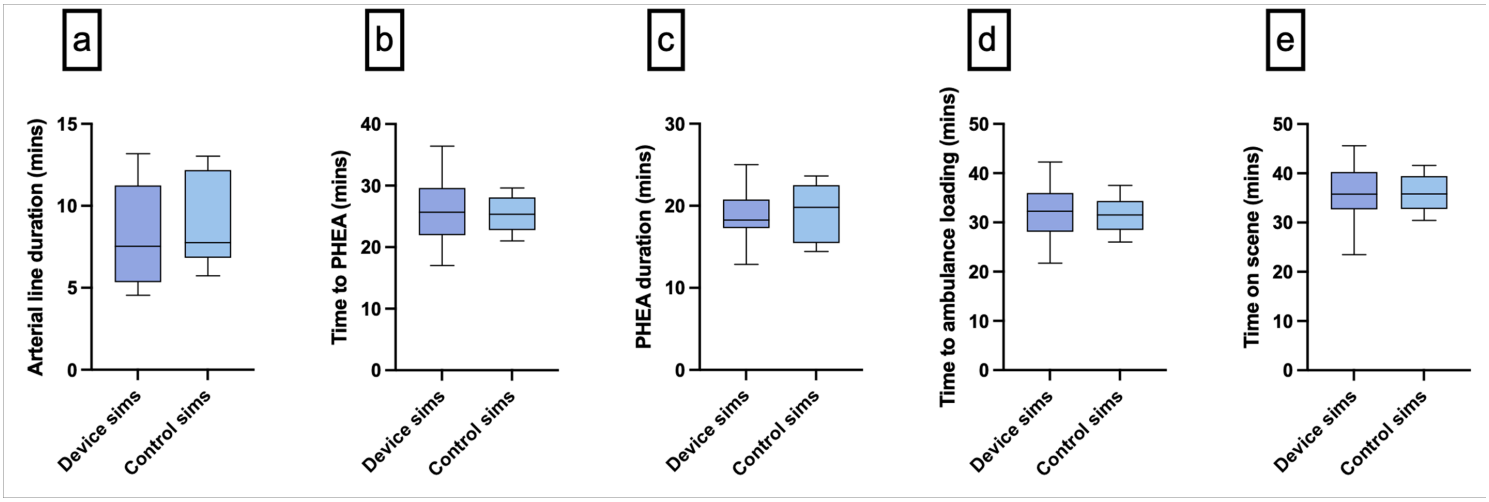


Figure 3

(a) Duration of arterial line placement device:7.5 mins [IQR 5.4-11.0], control: 7.8mins, [IQR 6.8-12.0], p=0.44. (b) – Elapsed scenario time until anaesthetic drugs administered device: 25.7mins [IQR 22.0-29.6], control: 25.4mins [IQR 22.8-28.1], p=>0.99. (c) - Duration of PHEA preparation and delivery device: 18.3mins [IQR 17.3-20.8], control: 19.8mins, [IQR 15.5-22.5], p=0.93. (d) – Elapsed scenario time until patient loaded into the simulated ambulance device: 32.3mins [IQR 28.1-36.0], control: 31.5mins [IQR 28.5-34.4], p=0.93. (e) - Elapsed scenario time until ambulance left scene device: 35.8mins [IQR 32.7-40.3], control: 35.8mins [CI 32.8-39.4], p=0.98.

Supplementary Files

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