Title: Enhancing High-Fidelity Simulation Flight-Based Training for Critical Care Paramedics in EMS Aviation: A Systematic Review

Short title: Simulation for aviation paramedics: systematic review

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Summary conflict of interest statement:

The authors declare that there are no conflicts of interest.

Funding information:

No funding outside of University of Sunderland.

Notation of prior abstract publication/presentation:

None to declare.

Acknowledgement of all authors' contribution(s) to the research and manuscript:

All authors declare that the CrediT statement below is correct. Publication is approved by all authors.

CRediT author statement

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Acknowledgements
The first author wishes to dedicate this article to his father, Gordon McCormick (Gordy), who passed in October 2024 after a long illness. Gordy was his best friend, mentor, and an exceptional paramedic and educator. Gordy known for his integrity, kindness, and dedication, Gordy left a lasting impact on the ambulance service and wider healthcare community. Admired by all who worked with him, his calm presence and wisdom touched many lives. He served with compassion and selflessness and is missed by all who knew him.

Abstract

Objective: High-fidelity simulation (HFS) is used with critical care paramedics (CCP) to enhance preparedness in high-stakes scenarios. This systematic review aims to assess the evidence on the role and effectiveness of HFS flight-based training, evaluating its application in education for CCPs operating within emergency medical services (EMS) aviation settings.

Methods: A systematic literature search was performed using a set of inclusion and exclusion criteria, resulting in eight articles which were appraised using the Critical Appraisal Skills Programme (CASP) tool.

Results: HFS training equips learners with skills relevant to their practice. CCPs register improved expertise, engagement and motivation, responsiveness, and general mood. There was insufficient evidence on whether this modality enhances self-awareness.

Conclusions: HFS learning is feasible in training CCPs in EMS aviation. However, there is limited evidence on the performance of CCPs trained utilising HFS learning in the prehospital setting. The findings suggest that standardising training and assessment methods is recommended to optimise skill acquisition, improve team performance, and enhance patient safety in high-acuity emergencies.

Introduction

Within air medicine, critical care paramedics (CCP) are a unique member of the Helicopter Emergency Medical Service (HEMS). They operate in high-risk environments, with an extended scope of practice and autonomy, this makes them an integral member of the HEMS team. Simulation is an integral part of the learning and updating of staff. This can help in assisting learners to acquire and master skills in an environment that does not expose them or patients to undue risks.[1]SBL facilitates learners to develop new skills through repetition and reflection. It also allows them to engage with clinical processes and follow them through to their natural conclusion.[2] Another advantage of SBL is that it exposes learners to the relevant situations for their practice therefore gaining the relevant experience and fostering deliberate practice when conducted in their own teams.[3]

Simulation-based learning (SBL) has therefore become an important teaching method across all healthcare professionals, but if particularly important in those situations that are highly time/skill intensive and infrequent. This is particularly important for air medical helicopters where the reason for its use is less the severity of the injury but more the geographical location that necessitates its use.[4]

High-fidelity simulation-based training (HFS) refers to an education approach that combines realistic aviation environments with advanced simulation technology to prepare the CCPs for emergency aviation.[2] HFS flight-based training is necessary to ensure EMS aviation CCPs are well-trained to deliver enhanced clinical practice in critical care, working at a high level of expertise to manage complex patient needs. Patient safety through enhanced communication and timely decision-making are critical in any healthcare environment. Experiential learning using approaches such as HFS education has proven particularly effective in enhancing aspiring healthcare providers' decision-making and clinical skills.[5] More specifically, CCPs programmes rely heavily on such experiential learning modalities to build the healthcare providers' technical proficiency and adaptive judgment for the unpredictable pre-hospital environments.[6]

SBL involves structured activities replicating clinical or operational scenarios that mirror authentic challenges encountered in professional practice.[7] By exposing learners to lifelike emergencies, SBL encourages the development of cognitive, psychomotor, and affective competencies in a controlled setting. For CCPs, SBL education provides invaluable experience in managing complex scenarios, integrating teamwork, communication, and situational awareness, skills central to competent prehospital care.[7] Notably, simulation technology has evolved from low fidelity simulation (LFS) classroom exercises to sophisticated, HFS with the help of computer-based systems, advanced manikins, and virtual or augmented reality environments.[8]

In recent years, HFS flight-based training has emerged as an extension of this pedagogy, replicating the unique challenges of aviation-based EMS. For example, simulation scenarios may place CCPs in a mock helicopter cabin with active rotor noise, vibration, and limited lighting while managing a deteriorating trauma patient during a simulated in-flight emergency or weather diversion. These simulations incorporate realistic aircraft environments, sound, vibration, and operational stressors, preparing CCPs for critical decision-making in confined and dynamic in-flight conditions. Although HFS flight-based training can be used to teach CCPs at any stage, it is most vital at the intermediate and advanced stages of CCPs education.[9] As such, CCPs stand to benefit the most from HFS flight-based training when they are exposed to this learning modality before clinical placement and high-acuity practice to enhance their independent decision-making responsibilities. While there are a number of primary studies on this topic, there has been no systematic review of this literature. This systematic review seeks to fill the critical literature gap while synthesising diverse evidence that could inform future practice.

Methods

Aim

This systematic review aims to assess and synthesise evidence on the role and effectiveness of HFS flight-based training, evaluating its application in education for CCPs operating within EMS aviation settings.

Objectives

The review seeks to achieve the following objectives:

- To assess the impact of High-fidelity Simulation (HFS) flight-based training on critical care paramedics (CCP).
- To assess the self-perceived changes to learning from CCP engaging in HFS flight-based training.
- To establish the impact of HFS flight-based training on the CCP's technical skill proficiency.

A Population, Intervention, Comparison, and Outcome (PICO) framework[10] was used to formulate the literature search strategy outlined in Table 1. This systematic literature search was conducted using the appropriate keywords within the following databases; MEDLINE, CINAHL, PUBMED, EMBASE, Cochrane Library, and Web of Science platforms. Google Scholar and snowball searching were used to retrieve more articles from other open-access databases. Inclusion and exclusion criteria are identified in Table 2 and were applied at each stage of the process. Search strings and combinations that were used for each database are outlined in Table 3.

Following best practice for evidence-based research snowballing technique was applied to identify further studies from the reference lists of relevant papers.[11]The first author independently screened titles and abstracts, followed by a full-text review according to predefined and agreed eligibility criteria, which was verified by the additional authors. The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement of 2020 was used to guide reporting in this systematic review.[12] Figure 1 summarises the selection process and application of criteria following PRISMA guidelines. This review has been registered with PROSPERO (No. 1176262).

Screening and Quality Appraisal Checks

The included studies were assessed for methodological quality using the Critical Appraisal Skills Programme (CASP). The tools assess the methodological choices in journal articles to ascertain their effectiveness in addressing the research question.[13] Disagreements were resolved by consensus between authors. The checklists enable the interrogation of the methodological choices in journal articles and ascertain their effectiveness in addressing the research question.[14] The completed CASP tables are attached in Appendix B.

Data Extraction and Synthesis

A data extraction table was used to help summarise the research articles by highlighting key information such as the author, year, setting, participants, design, intervention, and outcomes[15] (Table 4). Data synthesis was used to answer the research question. Given the heterogeneity of study designs, a narrative synthesis approach was adopted.[16] Themes were organised around: applicability to practice of HFS in CCP education; factors affecting implementation; and future recommendations for research.

Table 4 below shows a data extraction table with study characteristics and key findings from the selected articles.

Findings

The findings below have been organised into groups relating to the overall methodologies employed within the studies found and the application of their findings to the population under consideration (i.e, CCPs).

All papers included met the predefined inclusion criteria; however, when appraised critically, they did not collectively provide a clear or robust answer to the research question concerning the effectiveness of HFS flight-based training within EMS aviation. The majority of the studies included were evaluations of high-fidelity simulation-based education (n = 5; see table 4). The stated aims of the included studies aligned broadly with SBL education, with only two not explicitly evaluating training.[17,18]

Study Designs

The appropriateness of study design varied considerably. The majority of studies identified were evaluations of educational interventions. For example, some employed pre-/post-test designs[19,20] however, all study designs[19, 20, 17, 21, 18, 22, 23] had some element of self-report questionnaires which related to either their (the participants) perceptions of the course and their own perceptions of what they had learned during the programme (see table 5). Different scales were employed in which to do this with a focus on self-assessment of their (i.e., education participants) competence and evaluation of training, normally focused on satisfaction with the programme.

While such designs are suitable for exploring the trainee's experiences and perceived gains during the training they are inherently limited in their ability to determine effectiveness of said training or causality, as their focus is on perceptions. This is particularly important in terms of identify the effect of an educational intervention as previous research has shown that self-reports in competence are not accurate.[24] The predominance of non-experimental designs therefore constrains conclusions regarding whether HFS flight-based training produces meaningful improvements in HEMS performance, limiting the strength of evidence available to support practice change. This is also true of the follow-up periods identified within the papers. This limits the evidence to the immediate self-reported benefits of simulation.

A major limitation across the studies was heterogeneity of study populations. Although all participants were emergency personnel, recruitment strategies resulted in samples that included single-discipline clinicians, interdisciplinary teams, and mixed ground and air EMS staff. HEMS flight teams, however, typically consist of experienced clinicians from multiple professional backgrounds, such as CCPs, whose effectiveness depends on advanced team integration rather than individual competence alone. Several studies assessed individual skills or isolated NTS competencies, which does not reflect the operational realities of HEMS practice. From a CASP standpoint, this heterogeneity substantially limits external validity and reduces confidence in the transferability of findings to real-world flight-based EMS teams.

Several studies lacked fundamental methodological safeguards, including control groups, randomisation, and blinding, increasing susceptibility to selection, performance, and reporting bias; this is not usually as the majority of studies were evaluations of training. Therefore, the sample sizes were frequently small, further reducing statistical power and increasing the likelihood of Type I (false positive) and Type II (false negative) errors. Taken together, these factors reduce internal validity and severely limit causal inference.

There was marked inconsistency in how HFS was defined and implemented across studies. Interventions ranged from in situ simulations to structured training programmes delivered in mock or purpose-built environments, with wide variation in frequency, duration, and fidelity. Few studies provided justification for simulation design choices or demonstrated that selected outcome measures were sensitive to performance changes relevant to HEMS contexts. Whilst this heterogeneity limits comparability across studies and weakens synthesis of findings, reducing the overall coherence of the evidence base, it should also be noted that there should be an element of specificity within the simulation training. There is evidence in other acute areas to suggest that scenarios should be tailored to the workforce undertaking the simulation[25, 26]; which is reflected within current professional guidance.[27]

Applicability to Practice

Team performance and crew integration key determinants of safety and effectiveness in HEMS, were insufficiently addressed, mainly due to overall study designs. Only a minority of studies attempted to evaluate higher order team functioning, including communication, leadership, shared situational awareness, and decision-making under flight specific constraints, encompassing non-technical skills (NTS) and team trauma non-technical training (TNTS); however, this was again via self-report questionnaires than by assessment. This is a critical omission, as contemporary simulation practice in other high-risk domains, such as Advanced Life Support (ALS) training, has shifted decisively toward team-based effectiveness rather than individual performance. The failure to evaluate the “whole team” significantly limits the applicability of findings to HEMS operations and weakens the evidence base from a CASP contextual relevance perspective. Furthermore, as discussed previously, these were self-reported evaluations rather than objective measures of individual ability.

This fidelity and linking to deliberate practice therefore links explicitly with applicability. While several studies reported perceived benefits of SBL, including improvements in technical skills, communication, and confidence, these findings must be interpreted cautiously. Those studies from Pietsch et al.[23] and Langdalen et al.[18] demonstrate positive self-reported outcomes in realistic or *in situ* environments; however, these outcomes cannot be assumed to directly translate into objectively measured operational or patient-centred improvements. The absence of clinically meaningful endpoints prevents firm conclusions regarding the effectiveness of HFS flight-based training in routine HEMS practice.

While the included studies suggest that HFS flight-based training is feasible and well accepted by EMS aviation personnel, critical appraisal using CASP highlights substantial methodological limitations. These include heterogeneous populations, insufficient focus on team-level performance, weak study designs, reliance on self-reported outcomes, and a lack of objective, educationally and clinically relevant effectiveness measures. Collectively, these issues prevent robust conclusions regarding the role and effectiveness of HFS in EMS aviation. The current evidence supports HFS as a promising educational modality, given the educational research within other areas, but as this review has shown this is not a *proven* intervention with definitive evidence for increasing operational performance or positive patient outcomes in HEMS. Future research must prioritise experimental studies that link HFS training to validated operational, safety, and patient-centred outcomes to address these critical gaps. It should be recognised that this is a similar finding across the simulation education literature and is comparable with Hegland et al[28] systematic review within pre-registration nursing education in terms of the wider patient impact of simulation.

Factors Affecting Implementation

Several studies highlighted resource and contextual barriers limiting the widespread adoption of SBL. HFS is more resource intensive version of SBL. Operating real aircraft for in situ SBL or full-scale mock-ups as demonstrated in Pietsch et al[23] require significant investment in maintenance, scheduling, and crew time. Despite these challenges, their educational value, particularly in enhancing teamwork and risk management, is often cited as justifying the expense for high-acuity EMS organisations[1721]; however, this is not necessarily as explicitly borne out in the empirical evidence within the papers.

The connection between the training and the improvement in patient-related outcomes is missing from the evidence base. There are of course significant challenges in linking any specific simulation training/scenario and patient outcomes from the field. Myes et al[29] for example, whilst not focused on HEMS undertook a retrospective evaluation of a simulation educational intervention for airway management and found no statistically significant link between training and success. Whilst there were shortcomings within the design (it was a feasibility study) it does demonstrate the importance of objective patient-related outcomes, rather than self-report questionnaires.

This review raises two major points within the evidence base for the implementation of high-fidelity simulations. The first is that the link between the use of high-fidelity simulation and the improvement of patient related outcomes. All of the studies included in this review focused primarily on learner experience or their perception of what they had learnt during the session. This can be -seen as being problematic, as simulation training is labour intensive and often expensive to run with some the evidence base often contested over whether the educational gains are superior. For example, Wu et al.[30] used a quasi-experimental study to investigate two educational interventions (high fidelity simulation and video-based discussion) showing that although skills-based scores were higher in the high-fidelity group, both groups saw significant improvements across skills and attitude-based measures (both of which were objective, rather than self-reported). None of the papers found that focused on HEMS teams used such objective measures of learning, relying on self-reported measures, usually, of satisfaction.

Future Initiatives and Recommendations

Based on the study outcomes, this review recommends that future initiatives should advance HFS education for EMS aviation CCPs through a coordinated, longitudinal, targeted training in tandem with effective measures for learning gain and patient outcomes. The health sciences education policy makers should focus on creating comprehensive frameworks that define learning objectives, scenario fidelity, and standardised assessment tools to ensure consistent skill acquisition and performance evaluation.

International registries linking simulation outcomes with operational mission data should enhance training relevance, identify performance gaps, and support collaborative research. Training programs should be optimised through systematic cost-effectiveness analyses, the strategic integration of virtual and augmented reality technologies, and structured refresher modules to mitigate skill decay in high-risk, low-frequency procedures. There is a need for the development and dissemination of evidence-based guidelines by professional associations to promote uniformity, quality, and continual improvement across aviation EMS.

Conclusion

This systematic review aimed to investigate the effectiveness of HFS training for CCPs in EMS aviation. The review has established that HFS education in EMS aviation allows CCPs to acquire both TNTS in a safe, controlled environment that does not expose themselves, staff, or patients to any risk. There was insufficient evidence on whether such a teaching modality enhances self-awareness among critical care paramedics.

Overall, the articles reviewed in this study have concluded that perceptions of training and self-perceived learning improve in the short-term following simulation-based interventions. However, there is a need to expand the body of literature to explore the evidence linking these improvements to operational performance and patient safety outcomes. Conducting more longitudinal research studies with the help of standardised frameworks and cross-institutional collaboration could help address these gaps.

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