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REVIEW ARTICLE

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The range of uses of virtual reality for intensive care unit staff training: A narrative synthesis scoping review

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Abstract

Background: The use of virtual reality (VR) in medical education allows learners to make mistakes safely without risk to patients and to refine a range of clinical skills by repetition. However, there is still wide variability both between, and within countries regarding the amount of training delivered using VR, particularly in relation to intensive care medicine

Objectives: To identify the range of uses, phase of development and effectiveness of VR for intensive care unit (ICU) staff training.

Methods: The review followed the scoping review framework set out by Levac et al. (2010). A multi-database search was undertaken. All study types were included if they explored the use of VR for intensive care staff (ICU) staff training. Full paper screening, data extraction and assessment of bias was carried out by a single reviewer with verification by a second reviewer. A narrative synthesis was chosen to summarize the data.

Results: The search strategy identified 647 records. Following the removal of duplicates, screening of titles, abstracts and full texts, five studies were included. VR for ICU training has primarily focused on skill acquisition for surgical procedures. The majority of studies in this area were classified to be at an early stage of assessing acceptability, tolerability and efficacy. There was very low-quality evidence that VR for ICU training is effective.

Conclusions: Studies have explored the use of VR for a small number of surgical procedures and emergency patient scenarios. VR for ICU training demonstrates some potential, however further development and high-quality research is required. Research relating to virtual reality for ICU staff training is currently of weak methodological quality and as such, no recommendations to clinical practise can be made. Wherever possible when using VR for ICU staff training it should be utilized as part of a high-quality study.

KEYWORDS
effectiveness, evidence synthesis, intensive care medicine, medical education, technology-assisted learning, virtual reality

1 | INTRODUCTION

The term virtual reality (VR) refers to a three-dimensional computer-simulated environment that synchronously stimulates human senses, closely resembling the reality of the physical world (Appel et al., 2020). People using VR typically wear a head-mounted device whereby their field of vision is completely occupied by the device lenses, constructing a fully immersive environment (Specht et al., 2021). There is a growing body of evidence to support VR simulation in all industries, particularly healthcare (Pottle, 2019). In medical practice, VR has been used to effectively train clinicians on how to treat a range of disorders (e.g., anxiety, post-traumatic stress disorder, etc.), employing ideologies from both exposure and cognitive-behavioural therapy techniques (Bohil et al., 2011).

2 | BACKGROUND

With the outbreak of coronavirus-19, medical education has seen an increased focus on VR simulation to supplement traditional in-hospital training for students and healthcare professionals due to the need for distance learning (Papapanou et al., 2021). In response to this, studies have explored the effectiveness of VR based training and established that the method facilitates knowledge acquisition, improves operative performance, enhances skill coordination, improves decision making, and refines psychomotor skills (Chen et al., 2020; Zhao et al., 2020).

Computer assisted learning as a pedagogical method is not a new phenomenon, however the development of head mounted-display based VR has altered the experience, largely removing human interaction (Ellinger & Frankland, 1976; Hamilton et al., 2021). Developments in virtual reality-based training have been useful in allowing learners to make mistakes safely without risk to patients, and learn through deliberate repeatable practice to improve performance (Alaker et al., 2016; Pottle, 2019). VR has also allowed for medical students to acquire cognitive skills (within simulated environments) that may have been challenging to gain in clinical practise due to environmental risks (e.g., infection transmission) (Çaliskan, 2011; Vlake et al., 2021). Additionally, for students such as surgical trainees, learning to perform challenging procedures (e.g., laparoscopic surgery) through VR has promoted psychological safety and enjoyment without exposure to increased stress (Pottle, 2019; Vlake et al., 2021). Despite these benefits, several studies have suggested that VR as a pedagogical method may not be more effective than other education (mannequin arm model for surgical practice) methods in areas of student confidence (Hwang & Kim, 2014), and satisfaction (Khan et al., 2018).

To date, multiple reviews have been undertaken exploring the effectiveness of VR in medical training (Barsom et al., 2016). These reviews have shown that VR training is effective in improving procedural times for surgery (Mao et al., 2021), skills in laparoscopic surgery (Larsen et al., 2012), cognitive outcomes (Shorey & Ng, 2021), orthopaedic practice (Clarke, 2021), and knowledge acquisition (Woon et al., 2021). Although the benefits for medical practitioners (i.e., surgeons) and medical students are well documented, there is still wide variability both between and within countries regarding the amount of training delivered using VR (Bion & Rothen, 2014). This is particularly relevant in relation to intensive care medicine (Smith et al., 2007). Intensive care unit (ICU) specific VR training may be particularly beneficial because it allows staff to visualize a complex environment whereby the condition of patients are often unstable, risk factors relating to ill health are often greater, and there is a range of complex emergency scenarios (Reader & Cuthbertson, 2011).

A focus on training for ICU staff is important given that VR has the potential to improve staff decision-making in emergency scenarios, without the risk of harm for critical care patients (Puel et al., 2021). Training methods for ICU staff have historically included simulation training using patient manikins, blended learning, and face-to-face lectures (Duffy & Vergara, 2021; Lautrette et al., 2011; Seam et al., 2019). However, it is currently unclear to what extent VR has been used for ICU staff, and how effective this may be as a mode of training (Reader & Cuthbertson, 2011). Therefore, a synthesis of existing evidence is needed to identify what is currently known about the degree of adoption of VR for ICU staff training, and its current phase of development. This is important because it could provide a foundation for evidence-based decision making and policy development for medical education. To the best of the authors knowledge no review has been undertaken exploring the use of VR for ICU staff training.

3 | AIMS

The aim of this review is to identify the range of uses of VR for ICU staff training and classify their current phase of development. The secondary aim of this review is to evaluate the effectiveness of VR for ICU staff training using the Kirkpatrick model (Kirkpatrick, 1998).

3.1 | Design and methods

This review followed the scoping review framework set out by Levac et al. (2010), which recommends a five-stage review process and has been reported in accordance to the preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews guidelines (PRISMA-ScR) and Guidance for Reporting Involvement of Patients and the Public 2 (GRIPP2) (Levac et al., 2010; Page et al., 2021; Staniszewska et al., 2017). This scoping review protocol was registered on Prospero (register number removed for blind review).

The review has been undertaken with patient and public involvement (PPI). The aim of this involvement was to ensure readability of the final manuscript and, also support scoping and the interpretation of findings. The patients attended all meetings regarding scoping of the review and proofread both protocol and the final manuscript.

3.2 | Search strategy

A multi-database search was undertaken on six databases: Medline, Embase, Cumulative Index to Nursing & Allied Health, PsycINFO, Cochrane Library, and Web of Science from date of inception to March 2021 with no language or additional restrictions. Additional studies were identified through screening of all included studies and relevant systematic reviews' reference lists. Duplicate removal was undertaken using EndNote.

The search strategy conducted in each database consisted of three domains relating to VR, ICU and training. Within the domains, search terms were combined using the Boolean Operator "OR" and the operator "AND" was used to combine across domains. Keywords for each database search were informed by existing literature relevant to the areas of interest. Thesaurus searches within each database provided additional terms that were used for keyword searches. See supplementary electronic File 1 for full Medline search.

3.3 | Study selection

We included any type of study, which explored the use of VR for ICU staff training, irrespective of duration, follow-up, session frequency, mode, type of equipment, or publication year. Any review or systematic review which met the inclusion criteria were screened for individual eligible studies, but the reviews themselves were not included in this scoping review.

We included any type of healthcare staff who was described by the studies as working on an ICU (e.g., ICU nurses, ICU consultants, ICU fellows, ICU paediatricians). We included studies whereby the purpose of employing VR was designated as training of ICU staff (e.g., intensive care nurses, doctors, physiotherapist and speech and language therapist). We did not outline a specific definition for 'training' given the wide range of possible descriptions but included all studies whereby VR was utilized for 'training' purposes (defined by the authors). Training could include descriptions of the steps involved, visual demonstrations, practise opportunities, skill development or education (Agasthya et al., 2020).

We defined VR as an artificial environment which is experienced through sensory stimuli (such as sights and sounds) and in which one's actions partially determine what happens in the environment (Marshall et al., 2017), delivered through a head-mounted headset display.

We classified an ICU as a unit, which provides a spectrum of monitoring and life support technologies and serves as a regional resource for the care of critically ill patients (Marshall et al., 2017). An ICU provides intensive, specialized medical and nursing care and is typically based in a defined geographic area of a hospital (Marshall et al., 2017).

No specific outcomes were set as an inclusion criterion.

Title and abstract screening were undertaken by one reviewer using EndNote software (JH). Full paper screening a was carried out by a single reviewer (JF) and verified by a second reviewer (JH). Any discrepancies were resolved by discussion with a third reviewer (JW). The researchers undertaking study selection had extensive experience and expertise in conducting and publishing reviews.

3.4 | Data extraction

Data extractions were carried out by two reviewers using a prepiloted form, which included columns and rows (with headings) for all the vital data (JF or HB). Data extraction was checked and verified by a second reviewer (OH or JH). The piloting process included data extraction of a single paper independently with comparison of accuracy and comprehension after completion. The data items extracted were date of publication, study type, country of study, department (if applicable), number of staff receiving training, age, intervention description, duration of training, technical description, comparator (if applicable), outcomes, results and level of development.

The phases of development were coded using a three-tiered approach:

1. VR1 studies focus on content development by working with patient and provider end-users through principles of human-centred design.
2. VR2 trials conduct early testing with focus on feasibility, acceptability, tolerability, and initial clinical efficacy.
3. VR3 trials are randomized controlled trails that compare clinically important outcomes between intervention and control condition.

This coding system was used to identify at what level of development VR was used in the included studies (Birckhead et al., 2019).

3.5 | Evaluation model for the process of data synthesis

This study employed the Kirkpatrick model to evaluate the evidence presented in support of the training conducted within each study (Kirkpatrick, 1998). The Kirkpatrick model has been widely used in research for evaluating training and education programs (Heydari et al., 2019; Smidt et al., 2009). The model has a diverse range of uses which accounts for any style of training (both formal and informal), to determine ability based on four levels of criteria (Smidt et al., 2009).

Outcomes for the effectiveness of the intervention were classified into the four levels of the Kirkpatrick model: (1) 'reaction' (2) 'learning' (3) 'behaviour' and (4) 'results' (Heydari et al., 2019; Kirkpatrick, 1998). The first level (reaction) evaluates how the learner perceives the educational intervention, specifically related to clarity, conciseness, and any potential improvements. The second level (learning) measures the participant's acquired knowledge which may have been achieved from the intervention (Heydari et al., 2019). This level may employ a test, which evaluates skills or knowledge pre and post training, however the application of this knowledge is not measured at this stage. Level three (behaviour) is concerned with evaluating how the learner has implemented changes to their behaviour because of the intervention (Nelson, 1999). Measurement at level three typically includes a control group and a larger sample with repeated follow up evaluation. Level four (results) describes the evaluation at organization level, for example, what impact has the changes had on an institution. Level four is challenging to measure but is typically concerned with institutional level outcomes, performance, and achievements in goals (Kirkpatrick, 1998).

3.6 | Quality assessment

Critical appraisal of included studies was undertaken by a single reviewer (OH) using the corresponding Joanna Briggs Institute (JBI) critical appraisal tool based on study type (Tufanaru, 2017).

3.7 | Data synthesis

Due to the wide scope of the review and the expected heterogeneity of the included studies, a narrative synthesis approach was used to classify and describe the VR phase of development and the effectiveness of the VR training methods (Girard et al., 2008). This approach has been used in other health related scoping reviews whereby there was substantial heterogeneity in the characteristic under study (Hamer et al., 2021). The structure of the narrative synthesis was grouped on the current phase of development (i.e., VR1, VR2 or VR3) and on the four levels of training outcomes of the Kirkpatrick's model (Level 1; Reaction, level 2; Learning, level 3; Behaviour, and level 4; Results).

4 | RESULTS

The search strategy identified 647 records. Following the removal of duplicates, 432 records were screened. Screening of titles and abstracts identified 40 records for full text review. No additional papers were identified through screening of citations. 35 studies were excluded during full text screening, largely because the population did not include ICU participants (see Figure 1 for PRISMA flow diagram). In total, five studies were included in this scoping review.

The included studies were published between 2004 and 2021, with the majority published after 2016 ($n = 4$). The studies were set in four countries including Spain ($n = 1$), United Kingdom ($n = 1$), India ($n = 1$), and in the United States of America ($n = 2$). Only one study reported the age of participants of 26 to 47 years (Viciana-Abad et al., 2004). The remaining studies did not indicate the age of participants (Agasthya et al., 2020; Dhanasree et al., 2018; McLean et al., 2016; Ralston et al., 2021). Number of participants within the included studies ranged from six to 45 (Agasthya et al., 2020;McLean et al., 2016; Ralston et al., 2021; Viciana-Abad et al., 2004). See Table 1 for full study characteristics and Table 2 for study findings relating to effectiveness.

4.1 | Assessment of quality for included studies

All five studies were judged to be of weak quality due to a wide range of methodological issues. The most common issues being the lack comparators, control groups, poor reporting of study methods, and follow up (Agasthya et al., 2020; Dhanasree et al., 2018;McLean et al., 2016; Ralston et al., 2021; Viciana-Abad et al., 2004). The quasi-experimental studies had the greatest concerns of bias because they did not include a follow up or control group (McLean et al., 2016; Ralston et al., 2021; Viciana-Abad et al., 2004). See Table 3 for full assessment of quality for the included studies. In summary, most studies were of weak methodological design, with only one randomized trial identified.

4.2 | Characteristics of studies: Stages of development (VR1 to VR3)

The application of VR for ICU staff training has been used to develop clinical skills and decision-making using simulation training of a clinical scenario (Agasthya et al., 2020; McLean et al., 2016; Ralston et al., 2021; Viciana-Abad et al., 2004), with the main focus being on new skill acquisition for surgical procedures (Agasthya et al., 2020; McLean et al., 2016; Ralston et al., 2021). See Table 3 for full classification of studies. Notably, most studies were at the VR2 stage of development of feasibility, acceptability, tolerability, and initial clinical efficacy assessment.

4.2.1 | Stage of development: VR1 studies

Of the five studies, only the study by Dhanasree et al. (2018) was classified to be at the VR1 phase of development. The paper proposed a system to help medical students learn new skills required in medical ICU. The proposals included three main components to develop and facilitate training with VR: (1) Environment creation; (2) Integrate gear VR with hand controller; and (3) Applying leap motion capabilities (leap motion allows for a spatial tracking of a user's hands in VR). The study suggested that combining VR and leap motion technology may reduce the complexity of training and offer a safe learning resource for medical students in ICU (Dhanasree et al., 2018).

4.2.2 | Stage of development: VR2 studies

Three quasi-experimental studies were classified at the VR2 phase of development (McLean et al., 2016; Ralston et al., 2021; Viciana-Abad

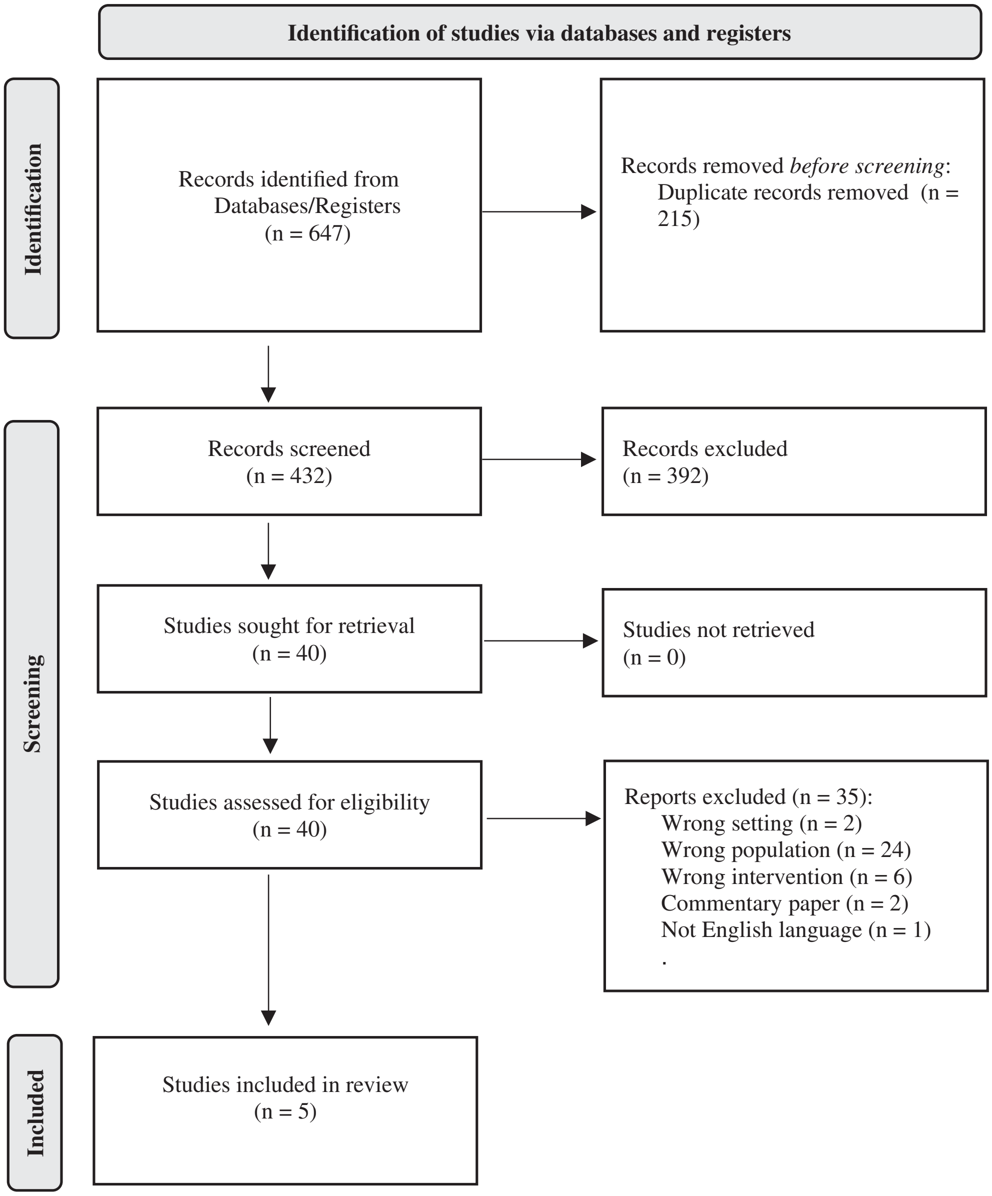

FIGURE 1 PRISMA 2020 flow diagram for systematic reviews.

et al., 2004). Each study focused on establishing the feasibility, acceptability, tolerability, or clinical efficacy of VR for ICU training.

Early work in this area by Viciana-Abad et al. (2004) explored the realism of VR in emergency medical training (Viciana-Abad et al., 2004). Although the research was conducted in the early 2000's, the study is somewhat comparable to later studies as it used V8 Head Mounting Display as the device (both fill the field of view with an image and track small movements). Six critical care specialists (ICU) and six people with similar academic degrees (in other fields of science) were exposed to three different VR tasks: (1) a simple ordering game; (2) a clinical scenario of a complex myocardial infarct in a relatively quiet environment; and (3) a task which replicated task two but in a noisy environment. The study measured outcomes stress index, galvanic skin response and postural movements to evaluate if the VR environments could provoke a similar physiological response to a real-life scenario.

McLean et al. (2016) explored the use of VR simulation as a supplement method for training with more traditional lectures and physical simulation to improve skills and decision making when undertaking a bronchoscopy in ICU (McLean et al., 2016). 45 trainees (71%), consultants (9%), clinical fellows/ associate specialists (20%) in intensive care medicine attended this national training course for intensive care medicine for bronchoscopy. The study assessed participants' confidence to perform a bronchoscopy pre and post intervention (McLean et al., 2016).

A recent study by Ralston et al. (2021), assessed the acceptability of VR training for cardiac intensive care units (CICUs) scenarios relating to infectious disease and recovery from surgery (Ralston et al., 2021). Six critical care fellows working in paediatric critical care participated in the intervention (Ralston et al., 2021). Clinicians were blinded to the clinical scenarios until the beginning of each simulation. Following a short briefing, participants were asked to individually

TABLE 1 Study characteristics.

Study	Study type	Country of study	Number of participants (n)	Population (clinical staff type)	Intervention/ training program	Focus of training	Mean age	Number and duration of training sessions	Control group	Outcomes	Level of research
Agasthya et al. (2020)	RCT	United States of America	15	Residents versus paediatric critical care fellows	19-min immersive tutorial	Education for skill development (steps required to prepare for a paediatric airway intubation).	Not reported	1 (19-min duration)	Inexperienced trainees without VR training	The 24-point testing checklist, timing of procedures, request for procedures/ medication which were not demonstrated in the VR training.	VR3
Dhanasree et al. (2018)	Text/ opinion paper	India	N/A	Medical intensive care students	Leap motion user interface	Skills required in medical Intensive care unit	Not reported	N/A	N/A	N/A	VR1
McLean et al. (2016)	Quasi-Experimental Studies	United Kingdom	45	Consultants, clinical fellows & associate specialists with backgrounds in intensive care medicine	Course consisting of lectures, and both physical and VR simulation	Skills required for Bronchoscopy procedure in intensive care medicine	Not reported	Not reported	N/A	Pre- and post-intervention (course) feedback. Primary outcome is the perceived confidence of course participants reported from 0 (not at all confident) to 10 (extremely confident).	VR2
Ralston et al. (2021)	Quasi-Experimental Studies	United States of America	6	Paediatric cardiology and critical care fellows as well as advanced practice providers and bedside nursing staff participate	Periodic mannequin-based in situ simulations in the CICU	Teach specialized skills required for practice in paediatric cardiac intensive care unit	Not reported	Not reported	N/A	Not reported	VR2
Viciana-Abad	Mixed method design	Spain	12	Critical care specialists and	Control exposure: game ‘Simon’.	Decision making in stressful	Age range 26–47 years		Two comparator groups: Group A	Questionnaires to estimate stress	VR2

TABLE 1 (Continued)

Study	Study type	Country of study	Number of participants (n)	Population (clinical staff type)	Intervention/ training program	Focus of training	Mean age	Number and duration of training sessions	Control group	Outcomes	Level of research
et al. (2004)				people with academic degrees in other fields of science	virtual experience in quiet environment, virtual experience in noisy	emergency situation (Noisy environment treating specific clinical problem)		Two (60-min duration per session)	– critical care specialists, Group B: people with similar academic degrees in other fields of science	and achieved presence, (Galvanic Skin Response). Questionnaire by Slater adapted – 5 items with a 7-point scale, one further item relating to virtual patient. The Stress Arousal Checklist.	

Note: RCT – random controlled trial, CICU – Cardiac Intensive Care Unit, N/A – not applicable, VR – virtual reality, VR1 – studies focus on content development by working with patient and provider end-users through principles of human-centred design, VR2 – trials conduct early testing with focus on feasibility, acceptability, tolerability, and initial clinical efficacy, VR3 – trials are randomized controlled trails that compare clinically important outcomes between intervention and control condition.

manage two clinical scenarios: (1) recognize and treat junctional ectopic tachycardia and low cardiac output syndrome (JET/LCOS) following congenital heart surgery; and (2) follow correct infection control procedures of a patient with suspected coronavirus-19. The study measured correct diagnosis of medical condition and time taken to perform a clinical procedure (overdriving pacing in a patient), to evaluate the effectiveness of the intervention.

4.2.3 | Stage of development: VR3 studies

Of the five, only the study by Agasthya et al. (2020) was considered to be at the VR3 phase of development (Agasthya et al., 2020). This was a prospective randomized comparison study including a VR group and control group. Paediatric residents and first-year fellows were included in the VR group and upper-year fellows and emergency medicine residents were included in the non-VR group. The VR group completed a 19-min immersive tutorial that outlined the steps involved in preparation for paediatric airway intubation, and the control group did not receive the VR training. The VR group was asked to demonstrate the learned steps on a traditional manikin, verbally declaring each procedural step. The non-VR group listed the steps in the airway preparation process from memory without demonstrating the steps on the manikin. The study measured correct procedural steps and time to completion of airway intubation, to evaluate the effectiveness of the intervention (Agasthya et al., 2020).

4.3 | Phases of Kirkpatrick's model (Level 1; reaction, level 2; learning, level 3; behaviour, and level 4; results)

Evaluation based on the Kirkpatrick model established that more than half the studies included in this review assessed learning at level II (Agasthya et al., 2020; McLean et al., 2016; Ralston et al., 2021). No study included in this review measured the impact of learning on clinical practise or evaluated high-level institutional data (e.g., performance of non-simulated procedures or examinations), at level three or level four of the Kirkpatrick model (Kirkpatrick, 1998) (see Table 1 and stages of VR development for full studies description).

4.3.1 | Kirkpatrick's model: Level 1 outcome

One study included in this review was judged to evaluate how the learner perceived the educational intervention (Ralston et al., 2021). Ralston et al. (2021) found that most clinicians "agree" or "strongly agree" that the VR was realistic, representative of real-life situations, did not distract from medical decision-making, enhanced the simulation experience and was useful for education in the paediatric ICU. This study also evaluated learning at level two of the Kirkpatrick framework (Kirkpatrick, 1998).

TABLE 2 Effectiveness for VR for ICU training.

Study	Study type	Intervention	Outcomes	Results
Agasthya et al. (2020)	Randomized Control Trial	A 19-min immersive VR tutorial that outlined the steps involved in preparation for paediatric airway intubation	Correct steps for the placement of nasopharyngeal airway, laryngoscopy, and endotracheal tube insertion (KF2)	No significant difference was observed in correct procedural steps within the non-VR group compared to the VR group (50.5% vs. 50.8%, P = 1.000). Steps missed most frequently by the VR group included failing to request an end-tidal carbon dioxide detector (42%), choosing a variety of nasopharyngeal airways (57%), failure to request a nasogastric tube (100%), failure to request set-up of repetitive cyclic blood pressure measurements during subsequent intubation (42%), and failure to request nursing confirmation of functioning peripheral intravenous access (57%).
			Time to complete the set-up steps (KF2)	Significant differences were observed in time to complete set-up steps in the VR group compared to the non-VR group (6 vs. 3.5 min, P = 0.005).
McLean et al. (2016)	Quasi -experimental study	National training course in ICM bronchoscopy, involving lectures, both physical and VR simulation	Confidence (KF2)	Significant increases in confidence, with pre- and post-course medians of 5 and 8, were observed in participants of the VR training (p < 0.01). The effect was more pronounced amongst junior than senior participants, reporting confidence score increases of 4 compared with 3 (p = 0.03).
Ralston et al. (2021)	Quasi-experimental study	Periodic mannequin-based in situ simulations in a ICU of a junctional ectopic tachycardia and low cardiac output syndrome (JET/LCOS scenario) and intubating a patient with suspected coronavirus disease 2019 (Coronavirus-19)	Correct recognition of diagnosis and treatment (JET/LCOS scenario) (KF2)	All participants correctly recognized the diagnosis in the JET/LCOS scenario and completed the critical objective of overdriving pacing the patient within an acceptable range of 4–8 min. Of the five checklist objectives, most participants met all five (range 3–5), with the most frequently missed item being 'cooling the patient'.
			Correct procedural steps/ objectives (Coronavirus-19 scenario) (KF2)	All five objectives were met by five participants. One participant conducted a time-out before entering the patient room.
			Post-participation intervention evaluation surveys (KF1)	Four out of six reported they "agree" or "strongly agree" that the VR environment felt realistic. All six participants "agreed" or "strongly agreed" that the clinical scenarios were realistic and representative of real-life situations. Five out of six "agreed" or "strongly agreed" that VR enhanced the simulation experience. Four out of six felt that the VR medium did not

TABLE 2 (Continued)

Study	Study type	Intervention	Outcomes	Results
				distract from medical decision-making. All but one participant “agreed” or “strongly agreed” that VR can be useful for education in the paediatric CICU.
Viciana-Abad et al. (2004)	Quasi-experimental study	The virtual patient was presenting an acute myocardial infarction, with a clinical history of ischemic cardiac myopathy and diabetes. Initial baseline data was collected during VR game ‘Simon’. Two groups of clinicians group A experience ICU clinicians and group B non-experienced clinicians were exposed to treating patient in two different scenarios: a quiet living room, and a noisy street.	Stress index (SI) (N/E)	All trials produce a positive increment of stress. The control trial increased stress index by 10% for specialists and 4% for non-specialists compared to approximately 30% in specialists and 20% in non-specialists for the stressful environment.
			Galvanic skin response (GSR) (N/E)	GSR, as an arousal indicator, increased when each trial begins. GSR Baseline (GSR -GSR Baseline) GSR = 10. In group B, a slight decrease of GSR tonic level can be seen in trials 2 and 3, while not in the control trial. Group A presents the opposite effect. In this case, tonic level of GSR can only be used as a generic arousal index.
			Postural movement (N/E)	Postural movement was measured with the assumption it indicates presence within the VR training. Group A subjects made more significant movements than group B, while being exposed to the simulator. Group B subjects, however, were much more static during the experience, especially during the second trial.

Note: KF1 – Kirkpatrick's model level I, KF2 – Kirkpatrick model level II, N/E – non educational outcomes, CICU – cardiac intensive care units, ICM – Intensive Care medicine, JET/LCOS – clinical scenarios, GSR – Galvanic skin response, CICU – Cardiac intensive care unit., SI – Stress index, VR – Virtual reality.

4.3.2 | Kirkpatrick's model: Level 2 outcome

Of the five studies, three studies met the criteria for a level two study by measuring learning or skill development following VR training (Agasthya et al., 2020; McLean et al., 2016; Ralston et al., 2021). The study by Ralston et al. (2021) which assessed clinicians' ability to undertake two clinical paediatric intensive care scenarios found that five or more out of the six clinicians correctly diagnosed both clinical scenarios and completed the objectives of the procedure. Most clinicians achieved the five-objective checklist for both clinical scenarios (Ralston et al., 2021).

Agasthya et al. (2020) assessed knowledge acquisition of a 19-min VR training program using a 24-point timed checklist (Agasthya et al., 2020). The findings suggested that there was no significant difference in correct steps of a medical procedure of those trained with VR, compared to those who were not trained with VR ($P = 1.000$). However, significant differences were observed in time to complete set-up steps in the VR group compared to the non-VR group (6 vs. 3.5 min, respectively; $P = 0.005$).

McLean et al. (2016) evaluated confidence of intensive care medicine doctors to determine if a VR training intervention could improve confidence of undertaking a surgical procedure (bronchoscopy) (McLean et al., 2016). The study found a statistically significant increase in confidence comparing pre- and post-perceptions of confidence for all clinicians for performing the clinical procedure (5/10 vs. 8/10, $p < 0.01$). This improvement in confidence was notably higher in more junior clinicians than senior ones (McLean et al., 2016).

4.3.3 | Kirkpatrick's model: Level 3 and 4 outcomes

No study identified by this review evaluated how participants had implemented the knowledge acquired from the VR training within non-virtual clinical practise (e.g., performance of non-simulated

TABLE 3 Assessment of quality for included studies using JBI's critical appraisal tools.

Checklist for randomized controlled trials

Study	Study type	Randomisation	Allocation concealment	Treatment group similar at baseline	Blinding -assessor, treatment, and assignment	Treatment groups similar during trial	Follow up	Analysed in the groups to which they were randomized	outcomes measured consistently	outcomes measured reliably	Appropriate statistical analysis	Appropriate trial design
Agasthya et al. (2020)	RCT	Yes	Unclear	Unclear	No	Unclear	No	Yes	Yes	Yes	No	Yes

Checklist for Quasi-Experimental Studies

Study	Study type	Clarity of cause and effect	Similar comparisons	comparisons receiving similar treatment/care	Control group	Multiple measurements outcomes	Follow up	Outcome comparisons measured similarly	Outcomes reliably measured	Appropriate statistical analysis
McLean et al. (2016)	Quasi-Experimental Studies	Yes	N/A	N/A	No	Yes	No	Yes	No	Yes
Ralston et al. (2021)	Quasi-Experimental Studies	No	No	No	No	No	No	Unclear	Yes	No
Viciana-Abad et al. (2004)	Quasi-Experimental Studies	Unclear	Unclear	Yes	No	Yes	No	Yes	Unclear	No

Checklist for Text and Opinion papers

Study	Study type	Source of the opinion	Opinion have standing in the field of expertise	Relevant population	Analytical process guided opinion	Reference to literature	Incongruence with the literature justified
Dhanasree et al. (2018)	Text/ opinion	Yes	Yes	Yes	No	Yes	N/A

procedures or examination). Studies did not meet the criteria for evaluation at level three or level four of the Kirkpatrick model (Agasthya et al., 2020; Dhanasree et al., 2018; McLean et al., 2016; Ralston et al., 2021; Viciana-Abad et al., 2004).

4.3.4 | Other studies

Viciana-Abad et al. (2004), evaluated stress levels, postural movement, and galvanic skin response to determine if the intervention could replicate a stressful emergency scenario. Two groups of critical care clinicians and unexperienced people were exposed to three trials of a simple game, VR emergency scenario with loud noises and without. Galvanic skin response decreased for experienced clinicians but increased in the non-experienced group (Viciana-Abad et al., 2004). However, the stress index for the clinicians increased by 30% but only 20% for the non-experienced group. This may have been because clinical participants felt obliged to respond to the situation but were unable to cope with the situation's demands, whereas the non-experienced group may not have felt the urgency to respond. Clinicians also undertook more significant movements than the non-experienced group which was suggested to be an indication of presence within the VR environment.

5 | DISCUSSION

This review identified that existing studies have largely focused the use of VR for training specific clinical skills using scenarios for both adult and paediatric intensive care (Agasthya et al., 2020; McLean et al., 2016; Ralston et al., 2021; Viciana-Abad et al., 2004). There are several pilot trials that have evaluated the acceptability, feasibility, tolerability, and early assessment of effectiveness of VR training for surgical procedures (such as bronchoscopy or laryngoscopy) (Agasthya et al., 2020; McLean et al., 2016; Ralston et al., 2021; Viciana-Abad et al., 2004). However, the research in the use of VR for training in ICU is still in its infancy in terms of maturity and quality of evidence.

Studies in this area have yet to explore VR training for the acquisition of softer skills (e.g., compassion, communication and trust), which have a great importance in ICU settings given the fragility and critical needs of patients and their families (Laari & Dube, 2017). With soft (or non-technical) skills becoming a key component of medical education (because of a growing need for a holistic and integrated approach), VR interventions are now needed to establish effectiveness compared with other methods of education within clinical practise (Succi & Canovi, 2020).

In addition to soft skills, there are further opportunities for technological development in VR to improve the capabilities of ICU staff. The development of eye tracking and eye movement modelling in VR could have the potential to enhance training and research in this area (Clay et al., 2019). Combining these two technologies would help gather data about the time and duration at which an object was observed, as well as the distance of the observer to the object, and the exact point of observation (Clay et al., 2019). If precise, the data would serve to assist VR therapies (such as exposure therapy) to identify which objects provide the most stimulus during intervention. A further opportunity would be to develop tactile sensors and tactile feedback for ICU staff (Bhattacharjee et al., 2020). By using tactile feedback stimulus, it could enhance the realism of the ICU to allow the staff in training to touch rather than just visualize patients. This technology could be particularly beneficial when practitioners are assessing a patient (e.g., breathing, etc.) or needing to respond to a patients needs with a manual technique (e.g., manual hyperinflation or bagging) (Bhattacharjee et al., 2020).

Alongside the findings that VR is underutilized in ICU staff training, this review highlights that VR training has only been conducted with single provider simulations (one clinician within one simulation) (Xiao-Dan et al., 2014). This is problematic because ICU staff work within a collaborative team (rarely deciding on patient care alone), often consulting other clinicians before offering treatment. To better replicate the critical care experienced by patients in ICU, VR training may need to incorporate multiple-provider simulations which allow communication from two or more clinicians within one simulation (Xiao-Dan et al., 2014). Multi-provider simulations will likely have far-reaching benefits on teamwork, communication, treatment strategies and decision making for staff in ICU, similar to the benefits reported by research conducted within outpatient settings (Xiao-Dan et al., 2014).

The findings of this review highlight that VR use in ICU staff training may be an effective mode of training, particularly for a small number of surgical procedures (and at level one and two of the Kirkpatrick model) (McLean et al., 2016; Qian et al., 2019). However, it is currently unclear whether acquired skills from VR training are retained long-term. In addition to this, existing research has yet to measure the impact of VR training on skill or knowledge that may be implemented into clinical practise. This finding highlights a gap in knowledge which provides a rationale to develop randomized control trials that compare clinically important outcomes between intervention (VR use in training for clinical skills in paediatric and adult intensive care) and control conditions. Further trials should aim to generate high quality VR3 tier evidence relating to routine practise and surgical procedures within ICU.

This scoping review has identified that VR has been used in a range of training for ICU staff, however there is a dearth of evidence related to its effectiveness. This is like other studies conducted with patients that have highlighted VR to show no evidence of effect on patient reported outcomes (Ong et al., 2020). As a result, no recommendations to clinical practise can be made. That said, initial data shows that VR may be a promising resource in training ICU clinicians how to correctly perform specific surgical procedures (i.e., bronchoscopy and laryngoscopy) (McLean et al., 2016). As such, VR use in ICU staff training should only be considered as part of an ethically approved study. However, there is a rationale to develop research in this area given that VR provides a resource for ICU staff to undertake challenging and complex tasks without risk to patients (Pottle, 2019).

This review highlighted substantial concern with the methodological quality of existing studies in this area of research. Based on this, future research should place an emphasis on methodological quality and follow the standard reporting guidelines (e.g., the CONSORT checklist) when publishing findings. It is encouraged that future research register a study protocol in a trials registry to enhance the transparency of the study methods and minimize publication bias (Odutayo et al., 2017). Additionally, there should be patients and public involvement at relevant stages of research (wherever possible) which should be reported using appropriate frameworks (e.g., Guidance for Reporting Involvement of Patients and the Public 2) (Blackwood et al., 2019; Staniszewska et al., 2017). Researchers conducting studies in this area should also consider the principles of 'open science', which encourage publishing in open access journals, disseminating more broadly and openly sharing information so that data is shared as early as possible in the process of digital technology development (Woelfle et al., 2011).

5.1 | Strengths and weaknesses

The key strengths of this scoping review were that it allowed for the synthesis of a broader range of evidence, whilst still maintaining systematic methods to undertake screening, study selection and data extraction. The study provides a broad insight into what is currently known about the range of VR use for ICU staff training, which may not have been possible under more stringent inclusion criteria of a systematic review (Ranganathan & Aggarwal, 2020). A further strength is that the review employed an evidence based theoretical framework to evaluate the current phases of development within existing research, using the methodology of VR clinical trials classification and the Kirkpatrick model (Kirkpatrick, 1998). A further strength is that PPI involvement facilitated both scoping of the review and the development of the final manuscript. This involvement helped to guide the particular focus and interpretation of the findings of the review. For future reviews, a glossary of key terms will be developed for service users as some of the terms used were difficult for them to understand and interpret.

The main limitations of this review are consistent with other research employing the scoping review methodology (Hamer et al., 2021; Sucharew & Macaluso, 2019). For example, the screening and risk of bias were undertaken by only one reviewer, which may have introduced error during the study selection process. It is also possible that there may be other studies that met the inclusion criteria which were not included because the search did not incorporate grey literature.

Aside from the scoping review limitations, the studies themselves were deemed to be of weak methodological quality due to poor reporting of study methods. A further limitation was that the included studies lacked data to determine the effectiveness of VR for ICU staff training, largely due to the exploratory study designs (Dhanasree et al., 2018; Ralston et al., 2021). Based on this, no firm conclusions could be made regarding effectiveness, highlighting a need for further research to confirm and quantify the effectiveness of VR use in ICU staff training. Unfortunately, we did not have the resources and capacity to translate any non-English papers. This may have led to one additional paper being excluded, which may have met the inclusion criteria. An additional limitation was that the literature search was conducted in January of 2021. A recommendation for future research would be that a systematic review be conducted with an up-to-date database search to ensure recency of the synthesis. Limitations aside, this review achieved its aim to identify the range of uses of VR for ICU staff training and classify their current phase of development.

6 | CONCLUSION

The findings of this review highlight that virtual reality for ICU staff training is still in the early stages of development. Notably, existing research is currently of weak methodological quality and as such, no recommendations to clinical practise can be made. In addition, the existing literature related to VR training in ICU has not yet evaluated how clinical behaviour has changed as a consequence of learning (VR3 studies) conducted at level one (reaction) and level two (learning) of the Kirkpatrick model. Similarly, there is a dearth of rigorous studies that have measured the impact of learning on clinical practise or evaluated high-level institutional data (level three or four criteria of the Kirkpatrick model) (Kirkpatrick, 1998). In addition, there is a notable lack of VR (for intensive care) training being developed for softer skills and for clinical scenarios with multiple users. Further high-quality research is needed to assess the effectiveness of VR use in ICU staff training, and for the development of VR training for softer skills.

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CONFLICT OF INTEREST STATEMENT

Robert Casey and Jennifer Zhang work at DancingMind Pte. Ltd., which develops virtual reality applications. Both authors were involved with the identification of scope of review and writing the manuscript. They did not directly contribute or undertake any of the following processes – search strategy, screening, assessment of bias and data extraction.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1111/jcal.12787.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from James Hill Email: Jehill1@uclan.ac.uk

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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