Healthcare Provider Stress and Virtual Reality Simulation: A Scoping Review

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Summary Statement: Despite the significant role that stress plays in clinical care and education and the potential benefit of virtual reality (VR) as a simulation modality, there is a dearth of literature on stress and VR. The results of this scoping review have shown the positive effect that VR simulation can have on mitigating the negative aspects of stress during simulation and clinical training as well as improving provider performance and affect. Virtual reality technology, and immersive VR specifically, has the potential to powerfully transform how simulation education is being conducted. Because of this, the authors encourage researchers to put more focus into this topic and in determining how VR can be used to provide simulations with excellent training and a strong sense of presence for the purpose of addressing how stress can impact learners' clinical training and performance.
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Key Words: Virtual reality, simulation, scoping review, immersive virtual reality, VR, stress, provider stress.

Many industries that deal with high-risk environments make extensive use of simulation to provide a safe environment for repetition of exposure and practice of decision making under stress.[1,2] However, in healthcare, simulation experiences often focus on specific technical tasks or team communication goals and the efforts to induce a stressful scenario are largely implicit. Stress, in the clinical setting, can be defined as the sum of external effects that can weigh down the clinician. In simulation studies, both stress and cognitive load are measured using subjective assessments and objective physiologic responses.[3] These physiological markers that signify either stress or cognitive load include heart rate (HR), HR variability (HRV), or cortisol levels.[4,5] Both excessive cognitive load and high emotional stress have been associated with poor performance.[6] Fraser et al[6] propose that emotions brought on from a high-fidelity stressful simulation can serve as its own cognitive load, both as intrinsic or extrinsic load. Emotional states from stress can be either negative or positive, and high-fidelity team simulations can cause swings from one polar end to the other.[7] Bong et al[4,8] found higher cortisol levels among participants of simulation compared with observers, suggesting that the experiential nature of simulation can induce a higher level of cognitive load, emotional stress, or both. Although stress can diminish available working memory and negatively impact performance, repeated stress using simulation can consolidate long-term memory with potential to improve future performance. This phenomenon is due to how moderate intrinsic stress directly related to the task to be learned can enhance memory consolidation, but that extraneous stress or very high levels of intrinsic stress can reduce learning.[6]

Repeated simulations of any modality also require an immense amount of time and resources to perform consistently. High-fidelity simulations capable of inducing stress through either mannequins or standardized patients require substantial facility space, setup and preparation, trained facilitators, confederates, and technicians. It further requires standard, identical courses for groups over time and geographical space; the resources required can limit the opportunities for simulation-based practice. This level of simulation is even less accessible outside the locus of a tertiary care university setting in community centers and rural areas.

Screen-based and digital simulation is a burgeoning modality of simulation that addresses these limitations.[9] Screen-based and digital simulations include serious games, virtual/computerized worlds, and virtual reality (VR).[10] Although this medium offers multiple benefits for healthcare training, this simulation modality, like traditional simulation, rarely addresses the substantial negative impact of healthcare provider stress during intense clinical situations.[11–15] Furthermore, VR technologies in 2015 to 2020 have experienced several technological improvements and advances toward a commercially friendly product. The term "virtual reality" is transitioning to refer to a fully immersive VR environment using a 3-dimensional (3D) head-mounted display, environmental audio, haptics, and spatial tracking, rather than virtual avatars on a screen-based simulation, such as in Second Life. This new "immersive VR" is defined as a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to 1 or more senses, giving the feeling of being mentally immersed or present in the simulation.[16] Having a strong sense of "presence" is important in that it is the degree to which someone feels like they exist on a personal, social, and environmental level as an entity inside of a virtual world.[17] Immersive VR gives users a higher sense of presence and thus

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a richer user experience, than screen-based simulations and traditional VR.[18] Figure 1 depicts the 3D head-mounted version of VR technology.

This methodology of using VR for training in stressful immersive environments has already been shown to improve allostasis (the process by which the body responds to stressors to regain homeostasis) and decision making under stress in other high-risk industries such as mining and spaceflight.[19,20] In addition, there is evidence that VR can be used in managing posttraumatic stress disorder by carefully curating a stressful experience to process the emotional and cognitive reactions of patients.[21,22] Because of the degree of audio/visual/proprioceptive stimulus experienced with VR simulation, the stressors experienced by learners can be precise and titrated. This enables VR to be used as a stress management tool for simulation-based training in healthcare. However, there is currently a substantial gap between the evidence of VR use for stress mitigation between nonhealthcare providers (high-risk workers, soldiers, or patients with anxiety or posttraumatic stress disorder) and healthcare providers in their own work. Therefore, this scoping review was performed to answer the question: "How is VR in the healthcare literature addressing stress experienced by healthcare providers delivering patient care?"

METHODS

This was a scoping review conducted in the fall of 2019, focusing on original research articles. This study was guided by the Joanna Briggs Institute methodology for scoping reviews as well as the PRISMA extension for scoping reviews.[23,24] An a priori review protocol and eligibility criteria were developed and iteratively edited by the 3 authors, based on the population, concept, and context elements (Table 1).[25] In short, we included literature on VR and stress, but only applicable to the stress experienced by clinical providers in their own clinical setting. This excluded VR for therapeutic uses for patient care, such as in clinical psychology treatments or for distraction therapy for painful procedures. In addition, the inclusion criteria were strict about the definition of VR; we only included VR when it referenced hardware that was of the 3D head-mounted variety. Given the relative novelty of the commercial hardware, we did not include any publication date parameters.

FIGURE 1. Three-dimensional head-mounted version of VR technology.

Relevant studies were identified through collaboration with a healthcare librarian who developed a comprehensive search strategy to identify articles on the topic of VR simulation in healthcare provider stress. The search was conducted in July 2019 using the databases PubMed, Embase, EBSCO CINAHL, and ProQuest PsycINFO. Medical Subject Headings, Emtree, and other database-specific controlled vocabulary were used in combination with key words to capture the concepts of healthcare personnel, psychological stress, and VR. All titles and abstracts were independently reviewed for inclusion by 2 researchers with VR and clinical experience, and full text was obtained and reviewed when either reviewer selected a reference.

The flowchart in Figure 2 details the identification, screening, and inclusion of articles for this review. The primary search strategy identified 910 nonduplicate records (see document, Supplemental Digital Content 1, http://links.lww.com/SIH/A547, search strategies). After title and abstract screening, 26 articles were retrieved and subjected to full text review. A total of 10 articles were included for review (see document, Supplemental Digital Content 2, http://links.lww.com/SIH/A548, articles included for review).

RESULTS

The subsequent subsections provide a synopsis of the study characteristics, VR systems, interventions, assessment methods, and major outcomes identified in the review.

Studies Characteristics

Six of the studies were randomized controlled trials (RCT),[26–31] 3 were cohort studies,[32–34] and 1 of the designs was a cross-over study.[35] The studies are derived from a North American and European–based group of authors with 4 of the studies being conducted in the United States,[30,33–35] 2 in the United Kingdom,[26,33] 1 in Canada,[32] 1 in France,[27] 1 in Italy,[28] and 1 in Denmark.[29] Although all of the studies involved healthcare personnel, there was some variability in the level of training and discipline of the participants. Four of the studies involved only residents,[26,27,29,30] one study was a mix of residents and staff physicians,[33] one study was a mix of residents, medical students, and staff physicians,[32] one study only included staff physicians and fellows,[34] one study included medical residents and fellows,[35] one study looked at nurses and teachers,[28] and the final study used combat medics.[31]

Virtual Reality Systems

Three studies used the same system of a LAP Mentor VR [3D Systems (formerly Simbionix), Littleton, CO],[26,33,35] but every other study implemented a different VR system. The other systems used: an Oculus Rift Touch (Oculus from FaceBook, San Jose, CA),[34] HTC Vive (HTC Corporation,

TABLE 1. A Priori Review Protocol and Eligibility Criteria

Population	Concept	Context
Inclusion ▪ Healthcare providers	Inclusion ▪ IVR technology exclusively (eg, use of fully immersive 360-degree IVR, ie, HMD) products or CAVE systems, eg, HTC Vive, Samsung, Oculus Rift, or similar with or without haptics ▪ Healthcare providers	Inclusion ▪ Tertiary teaching learning and education, ie, undergraduate university/college, postgraduate university/college, and vocational education and training programs ▪ Studies published or translated in English ▪ Published quantitative (ie, RCT's, cohort, case control, cross sectional, proof of concept, case study papers), Qualitative and mixed-method papers
Exclusion ▪ Nonhealthcare providers	Exclusion ▪ NIVR technology, eg, virtual worlds (ie, Second Life and similar); AR technology alone or in combination with VR use; low- and high-fidelity simulation technology, ie, mannequin; Smartphone applications; screen-based programs; web/computer based education and training programs; hybrid virtual simulation models ▪ All other nonstress-based evaluations/interventions (eg, solely task/procedural trainers, studies only focus on validity/design, patient interaction education, anatomy education, etc)	Exclusion ▪ All other education, teaching, and learning programs (ie, high school) ▪ Studies not published or translated in English ▪ All other literature, ie, Opinion/discussion pieces, editorials, gray literature, thesis documents, conference proceedings, books, or book chapters.

AQ, augmented reality; HMD, head-mounted devices; IVR, immersive virtual reality; NIVR, nonimmersive virtual reality.

Taipei, Taiwan ROC),[27] Vuzix Wrap (Vuzix Corporation, West Henrietta, NY),[28] Oculus Rift paired to LapSim,[29] Z800 3D Visor (eMagin Corporation, Hopewell Junction, NY),[31] da Vinci (Intuitive Surgical, Sunnyvale, CA) simulator (3D Systems, Rockwell, SC),[30] and NeuroTouch (CAE Healthcare, Sarasota, FL).[31]

Interventions

The VR interventions fell within 4 different categories: 5 of the studies had participants performing a surgical task or procedure,[27,28,30,32,33] 2 studies dealt with a experiencing a stress inducing event and subsequent coping exercises,[28,31] 2 dealt with mental warm-up exercises before a surgical procedure,[26,35] and 1 study focused on clinical decision making in an emergency.[34]

Assessment Methods

Although there was some similarity in the assessment tools used between studies, most of the studies used a wide variety of evaluation metrics. Five studies used physiologic monitoring

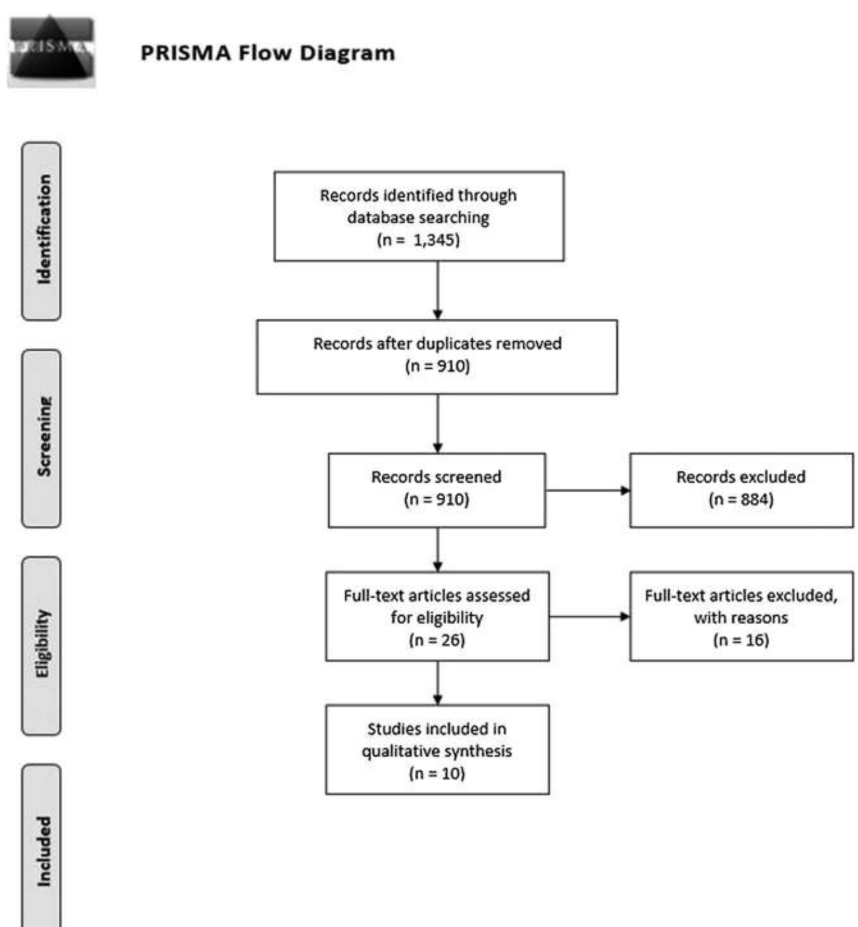

FIGURE 2. PRISMA diagram.

(such as HR, respiratory rate, salivary cortisol, etc),[26,31,32,34,35] 4 studies used the National Aeronautics and Space Administration Task Load index (NASA-TLX),[27,30,33,34] 3 used simulator metrics (eg, total time, path length, total movements, simulated tissue damage, total errors),[29,30,33] 2 studies used the State Trait Anxiety Inventory,[28,32] 2 used the Simulator Sickness Questionnaire,[27,30] and 2 used the Presence Questionnaire.[27,31] A complete listing of the used assessment tools can be seen in Table 2. Besides the use of simulator metrics, the only nonexternally validated assessment method used was the author created Fidelity Questionnaire in Bharathan et al.[33]

Major Outcomes and Conclusions

Immersive VR is capable of producing a significant stress response in participants and repeat exposure to the simulation significantly reduces the stress response and cognitive load both in subsequent sessions and in clinical care (Table 3). Bajunaid et al,[32] Chang et al, Frederiksen et al,[29] and Stetz

TABLE 2. Assessment Tools

Assessment Tool	What It Assess	Structure
Imperial Stress Assessment Tool	Built on the premise that stress is both an objective physiological response of the organism and also a subjective experience of the person who feels stressed.	An objective measurement of cortisol levels (typically via saliva samples) and a continuous assessment of HR. A subjective self-report based on the 6-item form of the State Trait Anxiety Inventory.
State Trait Anxiety Inventory	Commonly used measure of trait and state anxiety. It can be used in clinical settings to diagnose anxiety and to distinguish it from depressive syndromes.	It has 20 items for assessing trait anxiety and 20 for state anxiety. All items are rated on a 4-point scale.
Mental Imagery Questionnaire	Designed to capture surgeons' private experience of their mental imagery.	Contains 8 items that measure visual and kinesthetic imagery as well as confidence.
NeuroTouch safety, quality, and efficiency metrics	User efficiency and quality of motion during use of the simulation.	Software generated report of 16 different measures of safety, quality, and efficiency metrics.
Physiological responses	Physiologic responses to stress.	Varied based on study but entails the continuous measurement of: HR, HRV, respiratory rate, electro dermal activity, and/or cortisol levels.
National Aeronautics and Space Administration Task Load index	A tool for measuring and conducting a subjective MWL assessment. It allows you to determine the MWL of a participant while they are performing a task.	It rates performance across 6 dimensions: (1) mental demand, (2) physical demand, (3) temporal demand, (4) effort, (5) performance, and (6) frustration level.
Borg Scale of Perceived Exertion	A subjective way of measuring physical activity intensity level. Perceived exertion is how hard you feel like your body is working.	A rating scale that ranges from 6 to 20, where 6 means "no exertion at all" and 20 means "maximal exertion."
Manikin Discomfort Scale	Expression of physical discomfort during a task.	Scale of 0 (no complaints) to 10 points (extreme amount of complaints) coupled with identification of pain on a manikin drawing.
Simulator Sickness Questionnaire	Provides an index of overall simulator sickness severity as distinguished from motion sickness. Provide scores that are more diagnostic of the locus of simulator sickness in a particular simulator.	Scores 16 symptoms on a 4-point scale (0–3). These symptoms can be placed into 3 general categories: oculomotor, disorientation, and nausea.
Presence Questionnaire	Measures the degree to which individuals experience presence in a VR environment and the intensity of the experience.	32 items on an 8-point scale.
System Usability Scale Questionnaire	Measures subjective usability.	10 items on a 5-point scale.
Subjective Mental Effort Questionnaire	Measures the mental effort that people feel was involved in a certain task.	1 item that is a scale from 0 to 150.
Coping Orientation to the Problems Experienced Inventory	Assesses an individual's coping strategies.	15 items on a 4-point scale.
The Perceived Stress Scale	Measure of the degree to which situations in one's life are appraised as stressful.	10 items on a 5-point scale.
The Psychological Stress Measure	Measures an individual's perceptions of their cognitive, physiological, and behavioral state.	49 questions.
Visual Analogue Scale for Anxiety	Measures anxiety across a continuum.	It is a horizontal line, anchored by word descriptors at each end (no anxiety to very severe anxiety). Individuals mark on the line the point that they feel represents their perception of their own current state.
Secondary-task Reaction Time	Measurement of cognitive load.	A reaction timer measures participants' response time (in hundredth seconds) to an auditory stimulus (a beep).
The Satisfaction with Life Scale	Measure of life satisfaction (subjective well-being) that is designed to measure global cognitive judgments of satisfaction with one's own life	5 items on a 7-point scale.
Motion Sickness Questionnaire	Assesses motion sickness as a multidimensional rather than unidimensional construct.	16 items on a 9-point scale.
Multiple Resources Questionnaire	Subjective workload assessment.	17 items on a 5-point scale.
Short Stress State Questionnaire	Measures subjective state response in stressful environments.	24 items on a 4-point scale.
Multiple Affect Adjective Check List-Revised	Measures both positive and negative affect and can be used in the diagnosis and treatment of mood disorders.	66 item check list that measures domains of: anxiety, depression, hostility, positive affect, and sensation seeking

MWL, mental workload.

TABLE 3. Major Outcomes

Major Outcomes	Supporting Papers
VR is able to produce a significant stress response during study engagement	▪ Bajunaid et al[32] ▪ Chang et al ▪ Frederiksen et al[29] ▪ Stetz et al[31]
VR presurgical warm-up reduced participant stress response during clinical surgery as well as showing improvements in cognitive and psychomotor performance	▪ Arora et al[26] ▪ Lee et al[35] (2012)
In comparison with control, the VR group had reduced mental load, physical workload and stress during actual clinical surgery postintervention	▪ Barre et al[27]
Practice in VR improved novice surgeon performance while reducing cognitive load	▪ Bharathan et al[33] ▪ Lee et al[30] (2018)
VR can be used to reduce acute and chronic anxiety experienced by providers delivering care during stressful clinical encounters	▪ Eyesenbach et al
Demonstrated that VR can be used to produce an "inoculation" effect to the stress response in combat medical providers.	▪ Stetz et al[31]

et al[31] were able to produce a detectable stress response during immersive VR scenario engagement. Both Arora et al[26] and Lee et al[30] (2012) demonstrated that an immersive VR presurgical warm-up reduced participant stress response during clinical surgery as well as showing improvements in cognitive and psychomotor performance. Barre et al[27] found that in comparison with control, the immersive VR group had reduced mental load, physical workload, and stress during actual clinical surgery postintervention. Bharathan et al[33] and Lee et al[30] (2018) demonstrated that practice in immersive VR improved novice surgeon performance while reducing cognitive load. Eyesenbach et al. showed that immersive VR can be used to reduce acute and chronic anxiety experienced by providers delivering care during stressful clinical encounters. Results by Stetz et al[31] indicated that immersive VR can be used to produce an "inoculation" effect to the stress response in combat healthcare providers.

DISCUSSION

This is the first scoping review looking at how VR simulation is being used to address the impact of stress on healthcare providers. Answering this question is significant because, despite commercial implementation of this modality, there is a paucity of evidence for its use. Although there is some evidence in the literature on how VR can be used for stress mitigation in patients, there is a dearth of research for clinicians specifically. It is also important to understand how VR, and its many advantages as a simulation modality, is being used to address the effect stress has on clinical providers during training and clinical performance. This issue is even more pronounced because of the increasingly alarming issue of clinician burnout.

Although most studies were conducted as a RCT, 40% of the studies were done with an observational or quasi-experimental design. It is possible that the analytic observation format was chosen because of the challenge involved in acquiring participants at the graduate healthcare and healthcare professional level. In addition, observational and quasi-experimental analytical studies both allow for reduced logistical burden and quasi-experimental analytical studies can reduce ethical concerns when treatment and educational effects are still mostly unknown.

The fact that the studies had broad representation among European and North American countries speaks to the importance of this topic among international healthcare providers and also shows the power of VR to educate in a variety of healthcare systems. That being said, our review was limited to English-language studies, which likely affected our continental palette. It may be possible that the wide variety of VR systems used in the different studies was due in part to the differing preference of hardware in each of the studies' country of origin. However, this could also be explained by the nascent state of the field, and thus, no clear de facto industry standard hardware has been defined.

Study interventions were organized in 4 major categories. They dealt with either (1) experiencing and coping with a stress event, (2) using mental practice before a surgical procedure, (3) optimizing cognitive load and performance, or (4) clinical decision making during an emergency. Most interventions dealt with a surgical procedure and how the intervention and stress effected performance and affect. However, 3 of the studies did address nonsurgical situations and how providers made decisions under stress and were affected by that stress. It is likely that surgical and procedural interventions, such as laparoscopy and endoscopy, are the current mainstay of VR research because they are amenable to a defined technical approach and the programming for a staged technical procedure is often fairly straight forward as compared with a multibranching decision tree. It is also easier to measure and study the many technical steps that are performed during a procedure. However, surgical simulations, by nature of their haptic requirements, are more difficult and costlier to perform in comparison with nonprocedural healthcare situations.[36] Virtual reality represents a relative cost savings compared with specific mannequin-based simulations that require expensive internal anatomical fidelity and replaceable parts. The cost of a high-fidelity mannequin can be anywhere from tens to over a hundred thousand dollars, whereas purchasing even a top of the line VR system along with a VR capable computer is only a little more than US $2000.[37] Although procedural training is important, it is the authors' hope that this research will continue to expand to other clinical arenas such as healthcare decision making, crisis management, and patient interaction, as these nonhaptic skills also induce stress.[38]

Besides the use of physiological monitoring, and possibly the NASA-TLX, there seems to be little cohesion as to the agreed upon or even de facto assessment measures for determining the degree and/or effects of the stress response upon performance and psychological affect in immersive VR. We believe that this has to do with the nascent state of the research into stress and immersive VR. This nascent state is even further highlighted by the parallel use of using validity and usability assessments alongside the stress assessment tools. It should be noted that the assessments range in their constructs measured, such as cognitive load, workload, and stress. These are separate, but related, concepts.[39]

Ultimately, the theories and paradigms that inform this construct come from a variety of disciplines, each with their own set of assessments—entertainment, clinical psychology, healthcare education, and simulation. Thus, while assessment measures such as HRV and the NASA-TLX are being incorporated from other disciplines, many of these assessment measures have been extensively validated in other fields of study and likely are applicable for use with stress and immersive VR.[40]

Principal outcomes of these studies demonstrated that VR not only is able produce a predicted stress response but also that repeat exposure reduces both the stress response and cognitive load in participants. Repeated exposure seems to improve germane cognitive load, per cognitive load theory.[6,41] That is, performance can be hindered both by the intrinsic cognitive load of the emotionally charged scenario within the real-world context or by extrinsic load imposed by the simulation. Resuscitations, disaster management, or emergency surgeries are not simple tasks, and there is inherent cognitive load within the real-world context of managing a decompensating patient. The VR simulation software can add or subtract extrinsic cognitive load by controlling environmental distractions or game mechanics of the simulation. Intrinsic, extrinsic, and germane load all add up to high cognitive load, overwhelm working memory, and could provide a sense of higher stress. However, future performance may be improved with *repeated* exposure as resilience develops and long-term memory schemas develop.[6] This contributes directly to stronger germane load, improved working memory, and the capacity to "handle" the intrinsic and extrinsic cognitive load. This concept is in line with cognitive psychology and education literature for deliberate practice models.[42] These findings provide proof of concept on how simulation could be used to mitigate the stress response in participants and ultimately improve both clinical performance and reduce the negative ramifications of being exposed to the chronic and acute spikes of stress that many healthcare providers experience. Ghazali et al[43] have shown that repeated mannequin-based simulations lead to reductions in learners' sympathetic activity as measured by HRV compared with learners with limited simulation exposure. The role of repeated stress exposure may be key in clinical performance improvement, as low-stress procedural training does not always lead to clinical procedural success, when stress was markedly higher.[44] Given the positive literature on stress training using mannequin-based simulation, there is likely a role for VR and other digital simulations capable of inducing similar stress levels.

The combination of stress exposure with VR simulation training may allow for simulation that better approximates the psychological fidelity of actual clinical care environments.[45] Most participants also rated the experience with high user enjoyment scores, which could increase user desire to frequently participate in simulation training.

Specific Limitations

Limitations in this review are largely because the use of VR simulation is an emerging field and thus has a low quantity of available publications. This limitation is even more evident when evaluating VR and stress. Much of the research done in VR simulation also has been focused on purely technical procedural performance and thus applicability to other aspects of clinical care may be nontransferable. Study populations are also small in most studies, likely because of the recruitment challenges of enrolling graduate healthcare education learners. Finally, only studies in the English language were included, and thus, research published in predominantly non-English–speaking countries was not considered.

CONCLUSIONS

Despite the significant role that stress plays in clinical care and education and the potential advantage of VR as a simulation modality, there is a dearth of literature on stress and VR. However, the results of this scoping review have shown the positive effect that VR simulation can have on mitigating the negative aspects of stress during simulation and clinical training as well as improving provider performance and affect. Virtual reality technology, and immersive VR specifically, has the potential to powerfully transform how simulation education is being conducted. Literature in many different disciplines clearly demonstrates that stress can produce a strong detrimental effect on performance and personal affect. Because of this, the authors encourage researchers to put more focus into this topic and in determining how VR can be used to provide simulations with excellent training and a strong sense of presence for the purpose of addressing how stress can impact learners' clinical training and performance.

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