Immersive Virtual Reality Use Medical Intensive Care: A Single-Center Feasibility Study

Brian W Locke, Te-yi Tsai, C. Mahoney Reategui-Rivera, Aileen Gabriel, Aref Smiley, Joseph Finkelstein

Submitted to: JMIR Serious Games
on: June 02, 2024

Table of Contents

Immersive Virtual Reality Use Medical Intensive Care: A Single-Center Feasibility Study

Brian W Locke[1, 2] MD, MSc; Te-yi Tsai[3]; C. Mahoney Reategui-Rivera[3] MD; Aileen Gabriel[3]; Aref Smiley[3] PhD; Joseph Finkelstein[3] MD, PhD

[1]University of Utah Division of Pulmonary, Critical Care, and Occupational Pulmonary Medicine Salt Lake City US
[2]Intermountain Health Department of Pulmonary and Critical Care Murray US
[3]University of Utah Department of Biomedical Informatics Salt Lake City US

Corresponding Author:
Brian W Locke MD, MSc
University of Utah
Division of Pulmonary, Critical Care, and Occupational Pulmonary Medicine
30 N Mario Capecchi Dr
Salt Lake City
US

Abstract

Background: Immersive virtual reality (VR) is a promising therapy to improve the experience of patients with critical illness and may help avoid post-discharge functional impairments. However, determinants of interest and usability may vary locally and reports of uptake in the literature are variable.

Objective: This mixed-methods, feasibility study aimed to assess the acceptability and potential utility of immersive VR in critically ill patients at a single institution.

Methods: Non-delirious adults admitted to one of two intensive care units were offered the opportunity to participate in 5-15 minutes of immersive virtual reality delivered by VR headset. Patients' vital signs, mood, and pain were assessed before and after the experience. A semi-structured interview was then administered to elicit patient descriptions of the experience, issues, and potential uses.

Results: Of 35 patients who were offered the chance to participate, 20 (57%) agreed to partake in the immersive VR experience, with no difference in participation rate by age. Improvements in overall mood (mean 1.8 points, [95% confidence interval 0.6-3.0], P=.002), anxiety (1.7 points [0.8-2.7], P=.001), and pain (1.3 points [0.5-2.1], P = .003) on 1-10 scales were observed. Mean heart rate changed by -1.1 (-0.3 to -1.9; P = .008) beats/minute (bpm) from a baseline of 86.1 (SD 11.8) bpm, and heart rate variability changed by -5.0 (-1.5 to -8.5; P = .004) sec-2 from a baseline stress index of 40.0 (SD 23) sec-2. Patients commented on the potential for the therapy to address pain, lessen anxiety, and facilitate calmness. Technical challenges were minimal and there were no adverse effects observed.

Conclusions: Patient acceptance of immersive was high in a mostly medical intensive care population with little prior virtual reality experience. Patients commented on its potential to ameliorate cognitive and emotional symptoms. Heart rate and heart rate variability were consistent with increased relaxation. Clinical Trial: N/A

(JMIR Preprints 02/06/2024:62842)
DOI: https://doi.org/10.2196/preprints.62842

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

✓ **Please make my preprint PDF available to anyone at any time (recommended).**
Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.
Only make the preprint title and abstract visible.
No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**
Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain v
Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <a href="http

Original Manuscript

Original Paper

Immersive Virtual Reality Use Medical Intensive Care: A Single-Center Feasibility Study

Brian W Locke, MD MSc[1,2] (ORCID 0000-0002-3588-5238)
Te-yi Tsai[3] (ORCID 0000-0002-9118-3978)
C. Mahoney Reategui-Rivera MD[3] (ORCID 0000-0002-4030-8777)
Aileen Gabriel[3] (ORCID *0000-0002-5872-9078)*
Aref Smiley PhD[3] (ORCID 0000-0002-1077-2229)
Joseph Finkelstein. MD PhD[3] (ORCID 0000-0002-8084-7441)

1. University of Utah, Division of Pulmonary, Critical Care, and Occupational Medicine
2. Intermountain Health, Department of Pulmonary and Critical Care
3. University of Utah, Division of Biomedical Informatics

Abstract

Background: Immersive virtual reality (VR) is a promising therapy to improve the experience of patients with critical illness and may help avoid post-discharge functional impairments. However, determinants of interest and usability may vary locally and reports of uptake in the literature are variable.

Objective:
This mixed-methods, feasibility study aimed to assess the acceptability and potential utility of immersive VR in critically ill patients at a single institution.

Methods: Non-delirious adults admitted to one of two intensive care units were offered the opportunity to participate in 5-15 minutes of immersive virtual reality, delivered by VR headset. Patient vital signs, mood, and pain were assessed before and after the experience. A semi-structured interview was then administered to elicit patient descriptions of the experience, issues, and potential uses.

Results: Of 35 patients who were offered the chance to participate, 20 (57%) agreed to partake in the immersive VR experience, with no difference in participation rate by age. Improvements in overall mood (mean 1.8 points, [95% confidence interval 0.6-3.0], *P*=.002), anxiety (1.7 points [0.8-2.7], *P*=.001), and pain (1.3 points [0.5-2.1], *P* = .003) on 1-10 scales were observed. Mean heart rate changed by -1.1 (-0.3 to -1.9; *P* = .008) beats/minute (bpm) from a baseline of 86.1 (SD 11.8) bpm, and heart rate variability changed by -5.0 (-1.5 to -8.5; *P* = .004) sec^{-2} from a baseline stress index of 40.0 (SD 23) sec^{-2}. Patients commented on the potential for the therapy to address pain, lessen anxiety, and facilitate calmness. Technical challenges were minimal and there were no adverse effects observed.

Conclusions: Patient acceptance of immersive was high in a mostly medical intensive care population with little prior virtual reality experience. Patients commented on its potential to ameliorate cognitive and emotional symptoms. Heart rate and heart rate variability were consistent with increased relaxation.

Trial Registration: N/A

Keywords: Immersive Virtual Reality; Intensive Care Unit; Distraction therapy.

Introduction

Critically ill patients experience many noxious sensations, stress, and restricted mobility while being treated in intensive care units (ICUs). There is a burgeoning evidence base demonstrating a loss in mental, emotional, and physical functioning after critical illness. Approaches to improve the experience of critical illness and functional outcomes after hospitalization are needed.

Immersive virtual reality (VR) has been proposed as a promising tool to address these issues [1,2]. Immersive VR often involves the use a headset to project the viewer into an interactive artificial environment that elicits the feeling of embodiment in the artificial environment [3]. Preliminary work assessing the efficacy of immersive VR for physical and cognitive mobilization [4–8], sleep [9], distraction from pain [10,11], and mood [12,13] have been performed, with many further trials ongoing.

A major challenge to applying the results from prior studies of VR is that there are numerous permutations of how, when, and for whom immersive VR might be used. For example, the equipment [14], the particular VR experience [14,15], and clinical purpose may all vary [3]. Potential barriers that might influence whether VR is accepted may be specific to the setting, providers, and patients for which the VR is being used [16]. Accordingly, widely variable uptake has been reported in prior studies [6,17,18]. Thus, it is difficult to infer, from the current literature, how acceptable VR might be in a particular situation.

We evaluated the feasibility of an immersive virtual reality experience for patients admitted to one of two ICUs at a single institution. Our aim was to better understand the acceptability, barriers to use, and potential effectiveness of immersive VR in a medical ICU context.

Methods

We conducted a prospective, mixed methods, non-randomized feasibility study of critically ill patients using immersive VR headsets. The study was conducted in two ICUs (a 25-bed medical ICU and a 16-bed cancer-specialty ICU that cares for both medical and surgical critically ill patients with cancer) at a single institution in Salt Lake City, Utah. The study was approved by the University of Utah Institutional Review Board (#00170975).

Recruitment

Patients who were potentially eligible for study inclusion were identified by attending physicians after daily rounds. To be included, patients needed to be age 18 or older, admitted to the intensive care unit, free from delirium [19] (as assessed by their providers, nurses, and able to pass an additional attention screen), and able to consent on their own behalf. Exclusion criteria included severe visual or auditory impairments (e.g. legal blindness of deafness), isolation precautions for infection, recent condition potentially exacerbated by VR (seizure, uncontrolled nausea, traumatic brain injury, history of psychosis, or admission for a mental health crisis), or other craniofacial injury prohibiting headset use. Additionally, current use of an orofacial mask to deliver positive airway pressure ventilation precluded headset use and so these patients were excluded, but intubated patients, patients receiving high flow nasal cannula, and patients receiving oxygen via a regular face mask were eligible to participate.

After patients were identified as potential candidates, nursing staff were approached to identify any conflicting patient care-tasks (e.g. physical therapy, travel for diagnostic testing or procedures). Patients were then approached about whether they were interested in trying an experimental immersive virtual reality therapy. Patient demographics, reasons for admission, and comorbidities

were assessed by chart review of clinical notes.

Experimental Protocol

Participating patients were presented with three visual analog scales (1-10) asking them to rate their current overall wellbeing, their current level of anxiety, and their current level of pain. Pre-intervention heart rate signals were recorded using a BIOPAC MP160 (BIOPAC Systems Inc, Goleta, California) for 5 minutes prior to VR initiation. (Figure 2)

Figure 2: Experimental Setup, as demonstrated by study personnel. The two laptops were used to ensure the adequacy of monitoring, project the real-time VR experience of the patient to troubleshoot any technical issues or adverse effects, and to transcribe interview responses after the experience. Meta Quest headset use was chosen out of several possibilities due the lack of fabric components to facilitate cleaning after use.

Patients were offered one of three commercially available virtual reality experiences delivered by Meta Quest Pro headset (Meta, Menlo Park, California): an urban travel experience (YoutubeVR; Google LLC, Menlo Park, California), a nature experience (NatureTreksVR; GreenerGames, Telford, Shropshire, United Kingdom), or a synthetic landscape experience (TRIPP, TRIPP Inc. Los Angeles, California). In all 3 scenarios, the experiences involved passive exploration of the environment and did not involve use of the hand controllers. Patients planned to use the virtual reality headset for at least 5 minutes, with an option to continue for up to 15 minutes if desired. Physiologic recording was continued for 5 minutes after VR use finished.

After completing the VR experience, 5-minutes of post-intervention vital signs and visual-analog scale assessments of wellbeing, anxiety, and pain were administered. Lastly, a semi-structured qualitative interview was then administered by a trained research assistant using a moderator guide. Conversations were transcribed verbatim and finished with time for open-ended feedback. Representative quotes were selected to summarize patient perceptions of the VR experience.

Statistical Analysis

A sample size of 20 participating patients was targeted in accordance with rule-of-thumb guidance for a pilot study emphasizing qualitative assessment and protocol feasibility [20]. Descriptive statistics of participants and non-participants in VR were used to describe the population of interest. For physiologic signals, the first two minutes of pre-VR recording was compared to the first two-minutes after the VR experience. Kubios (Kuopio, Finland) automatic beat detection software was used to preprocess HR data [21]. Heart rate variability (HRV) is summarized using the square root of Baevsky's stress index[22]. Pre-post comparisons of vital sign data and mood assessments were performed using paired, two-sided *t*-tests. Statistical analyses were performed using Stata version 18 (StataCorp, College Station, Texas) and are available[23].

Results

Patients were enrolled between November 8, 2023, to February 6, 2024. A total of 35 patients were identified as potential candidates and approached. Twenty of 35 (57%) agreed to participate in the virtual reality experience (Figure 1). Comorbidities and reasons for ICU admission mirrored the general ICU population (Table 1). Characteristics of participants and non-participants are listed in Table 2. The age of participants did not differ significantly from nonparticipants (61 [SD 17] years and 54 [SD 22] years, respectively; $P = .33$), but nonparticipants were significantly more likely to have previously used VR (4 of 15 vs. 1 of 20, $P = .005$).

Figure 1: Enrollment flow diagram

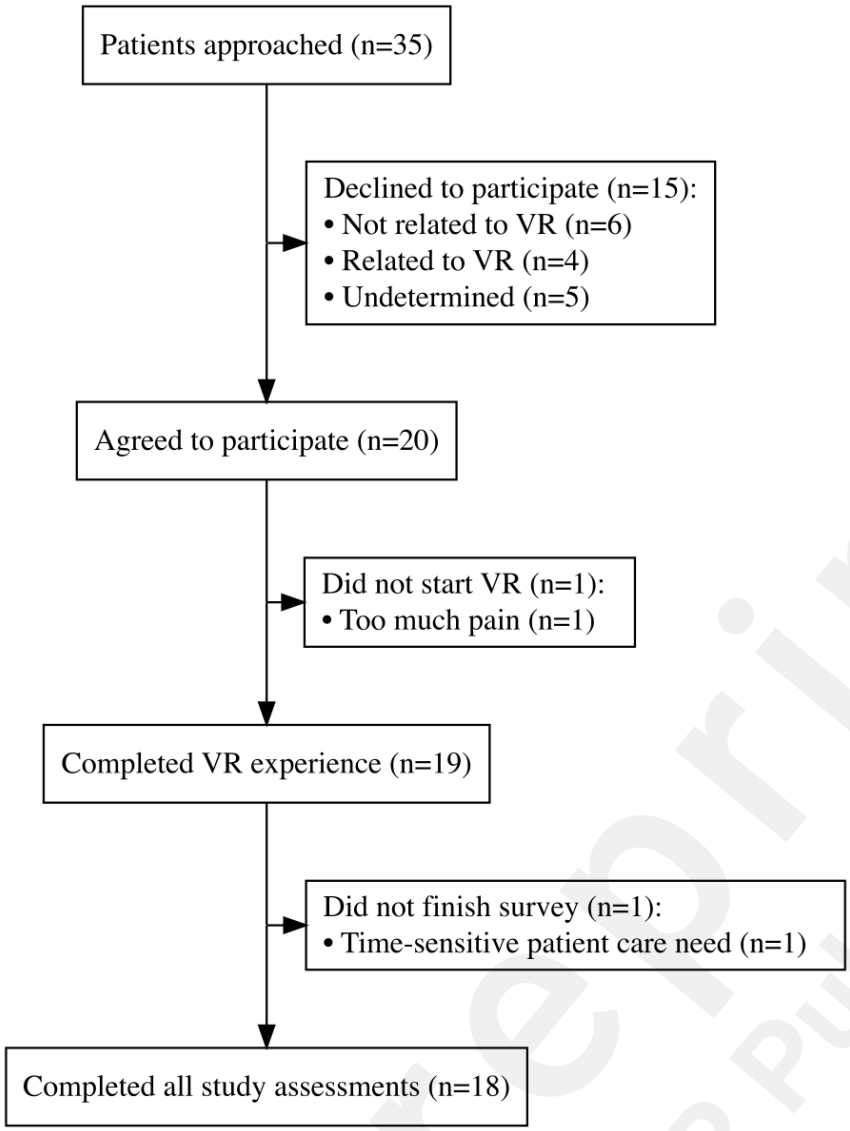


Table 1: Characteristics of patients approached.

	Total (N=35)
Age	58 (±19)
Female	31% (11)
Comorbidities	
Type 2 Diabetes	34% (12)
Atrial Fibrillation	17% (6)
Chronic Obstructive Pulmonary Disease	9% (3)
Congestive Heart Failure	20% (7)
Obstructive Sleep Apnea	6% (2)
Chronic Kidney Disease	9% (3)
Deep Vein Thrombosis	6% (2)
Cirrhosis	14% (5)
Cancer (any)	14% (5)
Common Reasons for ICU Admission	
Respiratory Failure (n=10), Glucose/Electrolytes (n=4), Thromboembolism (n=3), GI Bleed (n=3), Heart Failure (n=2), Sepsis (n=2)	

Table 2: Characteristics of patients who declined or agreed to participate in the VR experience

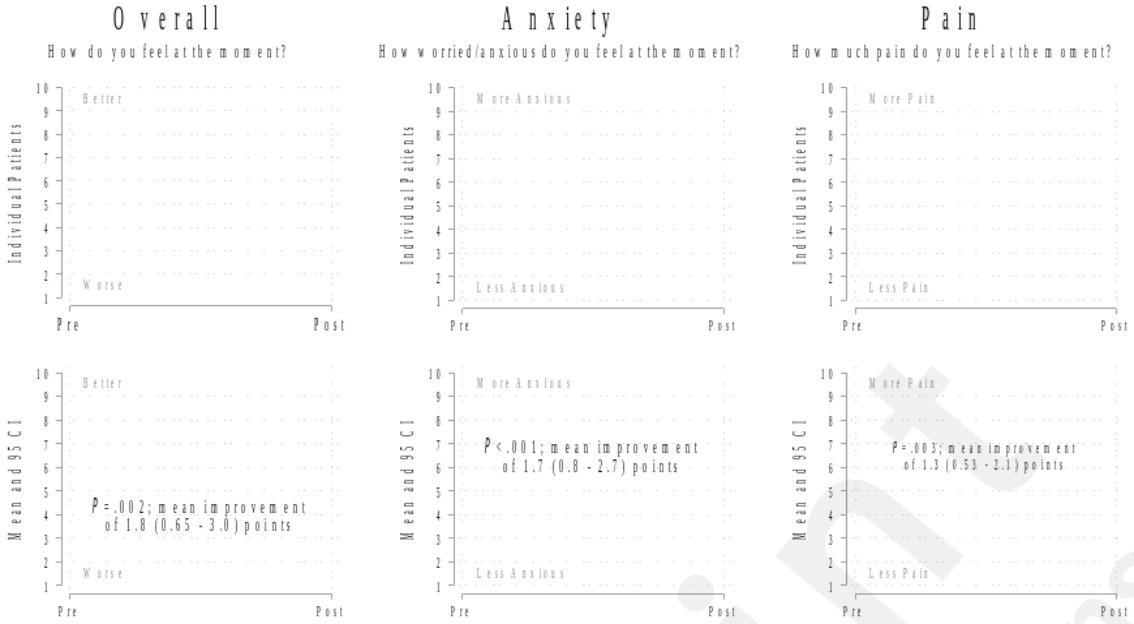
	Declined (N=15)	Agreed (N=20)	*P* value
Age	54 (SD 22)	61 (SD 17)	.33
Female	40% (6)	25% (5)	.34
Race			.40
Asian	0% (0)	5% (1)	
Black	0% (0)	5% (1)	
Native Hawaiian / Pacific Islander	9% (1)	0% (0)	
White	91% (10)	90% (18)	
Hispanic Ethnicity	27% (3)	15% (3)	.41
Any Hearing Impairment?	11% (1)	0% (0)	.13
Eyeglasses?	44% (4)	45% (9)	.98
Respiratory Support			.32
Face Mask or variant	9% (1)	0% (0)	
High Flow Nasal Cannula	9% (1)	30% (6)	
Nasal Cannula	45% (5)	45% (9)	
None	36% (4)	25% (5)	
Prior VR Use?	57% (4)	6% (1)	.005

Among the 20 patients consenting to participate, 19 completed at least 5 minutes of the VR experience (1 did not begin VR due to uncontrolled pain, but completed pre-VR baseline data collection), and 18 completed all study assessments (1 had competing care needs prior to interview). Participants used VR for 10 (SD 3) minutes. Ten (of 19, 53%) chose the travel experience, five (of 19, 26%) chose the nature experience, and four (of 19, 21%) chose the synthetic experience. No cyber-sickness or other adverse events occurred.

Among the 17 patients with valid heart rate data (n=1 patient had excess artifact), the mean heart rate prior to initiation the VR experience was 86.1 (SD 11.8) beats per minute (bpm) which decreased by 1.1 (95% confidence interval [95% CI] 0.3 to 1.9, P=.008) bpm by the end of the experience. Heart rate variability was 40 (SD 23) sec^{-2} at baseline and decreased by 5.0 (95% CI 1.5 to 8.5, *P*=.008) sec^{-2},

At baseline, participating patients reported moderate overall wellbeing (6.5 SD 2.1 on a 1-10 visual analog scale with 10 being best, n=20), anxiety (4.0 SD 2.8 with 1 being no anxiety, n=20), and pain (3.9 SD 2.8 with 1 being no pain, n=20). Overall mood improved by a mean of 1.8 points (95% CI 0.65 to 3.0; *P* = .002; n=19) from baseline, anxiety decreased by 1.7 points (95% CI 0.8 to 2.7; *P* = .001; n=19), and pain decreased by 1.3 (95% CI 0.53 to 2.1; *P* = .003; n=19) after use of immersive VR.

Figure 3. Overall mood, anxiety, and pain scores before and after use of immersive virtual reality. All scores were assessed using visual analog scales (Supplemental material) on a 1-10 scale, with 10 being best for overall mood, and 1 being best for anxiety and pain. Paired *t*-test used for comparisons. 95% confidence intervals of the mean change presented in parentheses.



Five themes were commonly mentioned in the post-VR interviews (Table 3). The use of the VR headset to view relaxing scenery content was met with approval by all patients. Patients had a variety of positive responses when the use of the VR headset, which was described as good, easy, enjoyable, comfortable, and pleasant. These responses indicate overall acceptance and satisfaction.

Patients also identified potential benefits of VR in alleviating symptoms of anxiety and depression. Many reported a reduction in feelings of anxiety, nervousness, and isolation, suggesting a positive impact on mental well-being. Several patients highlighted that the VR intervention helped distract them from their current pain symptoms. The immersive nature and engaging VR content enabled patients to briefly "forget" about their pain and discomfort. The VR environment was described by patients as calming, relaxing, and meditative. The opportunity to escape the ICU environment and immerse themselves in nature or travel scenery was highly valued, contributing to a sense of relaxation and calm.

Lastly, most patients reported having no problems using the VR headset. A few patients reported experiencing slight discomfort with the headset weight, and difficulty seeing the side visuals. No patients reported motion sickness or claustrophobia.

Table 3. Themes and representative quotes from interviews after immersive VR use in ICU patients.

Theme	Representative Quote
Acceptance of the VR system	“It was comforting, it was easy, from start to finish it’s so calm, it felt so fast. I don’t mind wearing it longer. it was my first time using it, I was amazed” [P18]
Improvement in mental health symptoms	“I think will help someone like me, facing what I face, sitting here for all days, waiting for my surgery, being anxious, not having anything to do, and not being allowed to eat or drink. I really appreciate you guys showing up. It really helps me.” [P20]
Distraction from pain symptoms	“I forgot about the pain, some of it is there. I feel relaxed and comfortable, it took me out of my mind and I’m able to focus on the virtual world, I like what I see, it’s so beautiful.” [P09]

Feelings of relaxation, calmness	"Mostly the calmness, being calm helps you deal with your physical issues better, and the visual experience has a lot of benefits, it helped me forget that I have clog in my lung." [P16]
Problems using the VR headset	"No, don't have any problem with it, it could be lighter with the headset. The side part it's a bit blurry, but the other it's good. It will be good to wear my glasses." [P12]

Discussion

In this feasibility study of commercially available immersive VR use among critically ill patients, we found that most patients did not have prior experience with VR technology but had high levels of interest and acceptance of the technology. Participants commented on VR's potential to alleviate cognitive and emotional symptoms. Changes in heart rate variability were consistent with increased relaxation. Only minor technical challenges, and no severe adverse effects, were noted.

Prior work has explored the potential for immersive virtual reality for several ICU use cases [1,24]. However, this work has reported widely variable rates of uptake, and has hinted at a 'digital divide' where older patients may be less interested in new technology [25]. In contrast, we found high levels of participation among patients of all ages. Thus, VR might be considered for study even in settings that frequently care for older adults. We found that patients who had previously used VR were less likely to participate in our study. However, this might indicate that the novelty of the experience drove participation in this feasibility study. Interest may improve in prior users if VR were offered as a validated treatment. Only a minority of patients who did not participate gave reasons related to the VR itself.

After use, several subjects commented on the potential of the therapy to address anxiety and foster relaxation or calmness. This was corroborated by the improvement in vital sign correlates of relaxation, such as improved heart rate variability. Some[6], but not all[18], prior studies of VR have shown consistent changes in vital signs.

Participants also highlighted the potential of VR to distract from pain, which is consistent with current guidance from the Society of Critical Care Medicine that recommends consideration of 'cybertherapy [VR]' for this purpose [26]. The high usability scores and low rate of technical challenges with 'off-the-shelf' commercially available options suggests that extensive customization is not a pre-requisite for use. Furthermore, we did not observe claustrophobia, nausea or 'cybersickness' in any patients. Cybersickness may be less common with more modern VR headset technology that minimizes latency [27] and discordance between virtual and actual head positioning [28], which could explain why this was not encountered in our study. In contrast to prior work suggesting nature scenes may maximize relaxation [15], travel was the most frequent VR experience choice among participants. The potential for VR to enable "escape" from the ICU was also frequently mentioned in qualitative interviews.

This work has several important implications for the study of VR in the ICU. First, we used commercially available technology and found that the sessions were acceptable to patients. This suggests that customization of either software or hardware are not necessarily required for some use cases. Furthermore, we found broad interest among critically ill patients. Lastly, we encountered minimal disruptions to patient care or study protocols, with 95% of patients completing the experience and 90% completing all study assessments. This suggests that protocols to study the

impact of VR can be integrated into usual ICU care with little impingement on clinical workflows.

Limitations:

Several limitations deserve mention. We cannot fully describe what characteristics may have influenced which patients were judged to be potential candidates for study by attending physicians. There was no control group, thus time-trends and the influence of conversing with study staff may also contribute to changes in symptoms and vital signs. Prior work has suggested that VR's effectiveness correlates with the degree of immersion [29], which we did not directly assess. We also did not attempt to eliminate distractions, which might limit the immersion or effectiveness of the intervention. However, it may better reflect the conditions that would be encounter in actual use. Lastly, the uptake of VR may differ when it is offered as a treatment for specific conditions as opposed to offering the opportunity to help assess feasibility, particularly among patients who have previously used the technology.

Conclusions

We find that a relatively short session of off-the-shelf immersive virtual reality is acceptable to critically ill patients; resulted in improved pain, anxiety, and overall mood scores; and did not result in side effects or present major technical challenges. This work suggests that studies on the effect of VR on patient important outcomes in critically ill patients is feasible and may be accomplished without substantial customization of the technology or large changes to patient care workflow.

Acknowledgements

This research was supported by the National Institutes of Health under Ruth L. Kirschstein National Research Service Award 5T32HL105321 (BWL).

Author Contributions:
Brian W Locke Conceptualization, Formal Analysis, Investigation, Writing – Original Draft, Preparation, Visualization. **Te-yi Tsai:** Methodology, Software, Investigation, Data Curation **C. Mahoney Reategui Rivera:** Methodology, Software, Investigation, Data Curation. **Aileen Gabriel:** Formal Analysis. **Aref Smiley**: Data Curation, Formal Analysis. **Joseph Finkelstein:** Conceptualization, Methodology, Resources, Writing – Review & Editing, Supervision, Project administration

Conflicts of Interest

Financial Disclosures
BWL holds financial stake in Mountain Biometrics, Inc (which focuses on the application of machine learning methods to physiologic sensor data unrelated to the current paper)

Abbreviations

HRV: Heart rate variability
ICU: Intensive care unit
VR: Virtual reality

Multimedia Appendix 1

Visual Analog Scales.pdf includes the instrument used to assess mood before and after the VR

experience.

References

1. Hill JE, Twamley J, Breed H, Roger Kenyon, Rob Casey, Jennifer Zhang, Clegg A. Scoping review of the use of virtual reality in intensive care units. Nurs Crit Care 2021 Nov 15; doi: 10.1111/nicc.12732

2. Vlake JH, van Bommel J, Wils E-J, Korevaar TIM, Bienvenu OJ, Klijn E, Gommers D, van Genderen ME. Virtual Reality to Improve Sequelae of the Postintensive Care Syndrome: A Multicenter, Randomized Controlled Feasibility Study. 2021 Sep 1;3(9). doi: 10.1097/cce.0000000000000538

3. Bruno RR, Wolff G, Wernly B, Masyuk M, Piayda K, Leaver S, Erkens R, Oehler D, Afzal S, Heidari H, Kelm M, Jung C. Virtual and augmented reality in critical care medicine: the patient's, clinician's, and researcher's perspective. Crit Care 2022 Oct 25;26(1):326. doi: 10.1186/s13054-022-04202-x

4. Navarra-Ventura G, Gomà G, de Haro C, Jodar M, Sarlabous L, Hernando D, Bailón R, Ochagavía A, Blanch L, López-Aguilar J, Fernández-Gonzalo S. Virtual Reality-Based Early Neurocognitive Stimulation in Critically Ill Patients: A Pilot Randomized Clinical Trial. J Pers Med 2021;11(12). doi: 10.3390/jpm11121260

5. Gerber SM, Jeitziner M-M, Knobel SEJ, Mosimann UP, Müri RM, Jakob SM, Nef T. Perception and Performance on a Virtual Reality Cognitive Stimulation for Use in the Intensive Care Unit: A Non-randomized Trial in Critically Ill Patients. Front Med 2019 Dec 10;6:287. doi: 10.3389/fmed.2019.00287

6. Turon M, Fernandez-Gonzalo S, Jodar M, Gomà G, Montanya J, Hernando D, Bailon R, de Haro C, Gómez-Simón V, López-Aguilar J, Magrans R, Martinez-Perez M, Oliva JC, Blanch L. Feasibility and safety of virtual-reality-based early neurocognitive stimulation in critically ill patients. Ann Intensive Care 2017 Aug 2;7(1):81–81. doi: 10.1186/s13613-017-0303-4

7. Suvajdzic M, Bihorac A, Rashidi P, Rashidi P, Ruppert MM, Williams S, Ozrazgat-Baslanti T, Ong T, Appelbaum J. Developing a Patient-Centered Virtual Reality Healthcare System To Prevent the Onset of Delirium in ICU Patients. Int Conf Serious Games Appl Health 2019 Aug 1;1–7. doi: 10.1109/segah.2019.8882442

8. Kho ME, Damluji AA, Zanni JM, Needham DM. Feasibility and observed safety of interactive video games for physical rehabilitation in the intensive care unit: a case series. J Crit Care 2012 Apr 1;27(2):2–9. doi: 10.1016/j.jcrc.2011.08.017

9. Lee SY, Kang J. Effect of virtual reality meditation on sleep quality of intensive care unit patients: A randomised controlled trial. Intensive Crit Care Nurs 2020 Aug 1;59:102849. doi: 10.1016/j.iccn.2020.102849

10. Faber AW, David R. Patterson, Patterson DR, Bremer M. Repeated use of immersive virtual reality therapy to control pain during wound dressing changes in pediatric and adult burn patients. J Burn Care Res 2013 Sep 1;34(5):563–568. doi: 10.1097/bcr.0b013e3182777904

11. Spiegel B, Fuller G, Lopez M, Dupuy T, Noah B, Howard A, Albert M, Tashjian V, Lam R, Ahn J, Dailey F, Rosen BT, Vrahas M, Little M, Garlich J, Dzubur E, IsHak W, Danovitch I. Virtual reality for management of pain in hospitalized patients: A randomized comparative effectiveness trial. PLOS ONE Public Library of Science; 2019 Aug 14;14(8):e0219115. doi: 10.1371/journal.pone.0219115

12. Haley AC, Wacker DA. Cinematic virtual reality for anxiety management in mechanically ventilated patients: a feasibility and pilot study. Acute Crit Care Korean Society of Critical Care Medicine; 2022;37(2):230–236.

13. Rodrigues IM, Lima AG, Santos AE dos, Santos ACA, Nascimento LS do, Serra MVCL, Pereira T de JS, Barbosa FDS, Seixas VM, Monte-Silva K, Scipioni KRD da S, Cruz DMC da, Piscitelli D, Goffredo M, Gois-Junior MB, Zanona A de F. A Single Session of Virtual Reality Improved Tiredness, Shortness of Breath, Anxiety, Depression and Well-Being in Hospitalized Individuals with COVID-19: A Randomized Clinical Trial. J Pers Med 2022 May 19;12(5):829–829. doi: 10.3390/jpm12050829

14. Merliot-Gailhoustet L, Raimbert C, Garnier O, Carr J, Jong AD, Molinari N, Jaber S, Chanques G. Discomfort improvement for critically ill patients using electronic relaxation devices: results of the cross-over randomized controlled trial E-CHOISIR (Electronic-CHOIce of a System for Intensive care Relaxation). Crit Care 2022 Sep 3;26(1). doi: 10.1186/s13054-022-04136-4

15. Gerber SM, Jeitziner M-M, Sänger SD, Knobel SEJ, Marchal-Crespo L, Müri RM, Schefold JC, Jakob SM, Nef T. Comparing the Relaxing Effects of Different Virtual Reality Environments in the Intensive Care Unit: Observational Study. JMIR Perioper Med 2019 Nov 15;2(2). doi: 10.2196/15579

16. Twamley J, Hamer O, Hill J, Kenyon R, Twamley H, Casey R, Zhang J, Williams A, Clegg A. Exploring the perceptions of former ICU patients and clinical staff on barriers and facilitators to the implementation of virtual reality exposure therapy: A qualitative study. Nurs Crit Care John Wiley & Sons, Ltd; 2022 Dec 2;n/a(n/a). doi: 10.1111/nicc.12868

17. Jawed Y, Golovyan D, Lopez D, Khan SH, Wang S, Freund C, Imran S, Bin Hameed U, Smith J, Kok L, Khan BA. Feasibility of a virtual reality intervention in the intensive care unit. Heart Lung 2021 Jul 1;50(6):748–753. doi: 10.1016/j.hrtlng.2021.05.007

18. Ong T, Ruppert MM, Akbar M, Rashidi P, Rashidi P, Tezcan Ozrazgat-Baslanti, Ozrazgat-Baslanti T, Bihorac A, Suvajdzic M. Improving the Intensive Care Patient Experience With Virtual Reality-A Feasibility Study. 2020 Jun 8;2(6). doi: 10.1097/cce.0000000000000122

19. Kellmeyer P, Biller-Andorno N, Meynen G. Ethical tensions of virtual reality treatment in vulnerable patients. Nat Med 2019 Aug 1;25(8):1185–1188. doi: 10.1038/s41591-019-0543-y

20. Birkett MA, Day SJ. Internal pilot studies for estimating sample size. Stat Med Wiley Online Library; 1994;13(23-24):2455–2463.

21. Tarvainen MP, Niskanen J-P, Lipponen JA, Ranta-Aho PO, Karjalainen PA. Kubios HRV–heart rate variability analysis software. Comput Methods Programs Biomed Elsevier;

2014;113(1):210–220.

22. Baevsky RM, Chernikova AG. Heart rate variability analysis: physiological foundations and main methods. Cardiometry 2017;(10).

23. VR ICU statistical code. Available from: https://github.com/reblocke/vr_icu

24. Raphael R Bruno, Georg Wolff, Bernhard Wernly, Maryna Masyuk, Kerstin Piayda, Susannah Leaver, Ralf Erkens, Daniel Oehler, Shazia Afzal, Houtan Heidari, Malte Kelm, Christian Jung. Virtual and augmented reality in critical care medicine: the patient's, clinician's, and researcher's perspective. Crit Care 2022 Oct 25;26(1):326. doi: 10.1186/s13054-022-04202-x

25. Mosadeghi S, Reid MW, Mark W Reid, Reid MW, Martinez B, Rosen BT, Spiegel BMR, Brennan Mason Ross Spiegel. Feasibility of an Immersive Virtual Reality Intervention for Hospitalized Patients: An Observational Cohort Study. JMIR Ment Health 2016 Jun 27;3(2). doi: 10.2196/mental.5801

26. Devlin JW, Skrobik Y, Gélinas C, Needham DM, Slooter AJ, Pandharipande PP, Watson PL, Weinhouse GL, Nunnally ME, Rochwerg B. Clinical practice guidelines for the prevention and management of pain, agitation/sedation, delirium, immobility, and sleep disruption in adult patients in the ICU. Crit Care Med LWW; 2018;46(9):e825–e873.

27. Stauffert J-P, Niebling F, Latoschik ME. Latency and cybersickness: Impact, causes, and measures. A review. Front Virtual Real Frontiers Media SA; 2020;1:582204.

28. Palmisano S, Allison RS, Kim J. Cybersickness in head-mounted displays is caused by differences in the user's virtual and physical head pose. Front Virtual Real Frontiers Media SA; 2020;1:587698.

29. Phelan I, Furness PJ, Fehily O, Thompson AR, Babiker NT, Lamb MA, Lindley SA. A Mixed-Methods Investigation Into the Acceptability, Usability, and Perceived Effectiveness of Active and Passive Virtual Reality Scenarios in Managing Pain Under Experimental Conditions. J Burn Care Res 2019 Jan 1;40(1):85–90. doi: 10.1093/jbcr/iry052

Supplementary Files

Multimedia Appendixes

Visual Analog Scales used for the assessment of overall mood, anxiety, and pain. These analog scales were administered before and after the virtual reality experience by study staff.
URL: http://asset.jmir.pub/assets/7400a93383d7c93909e9ce9ae51ac296.docx