Developing a Patient-Centered Virtual Reality Healthcare System To Prevent the Onset of Delirium in ICU Patients

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***Abstract*—The purpose of the DREAMS project (DREAMS = Digital Rehabilitation Environment-Augmenting Medical System) is to research the feasibility and clinical potential of a virtual reality (VR) system for reducing the occurrence of delirium among patients in the intensive care unit (ICU). Preliminary results of this ongoing study show VR produces minimal clinical effects but are strongly enjoyed by patients and easy to administer. We discuss important lessons learned from applying VR in the ICU.**

Keywords—VR, Serious games, Health, VR therapy, ICU

I. Introduction

Delirium is a common complication that affects 50-80% of patients in the intensive care unit (ICU) [1, 2]. Delirium is characterized by sudden and severe changes in cognition, activity levels, consciousness, and alertness. A delirium diagnosis correlates with increases in resource use, costs to finances and quality of life, higher rates of mortality, long-term physical and cognitive impairments, and increased risk of dementia. The annual impacts of delirium are estimated to cost $38-$152 billion in the United States [3]. Patients experiencing delirium have been shown to take a longer time to wean from mechanical ventilation, are more likely to be readmitted to the hospital, and face an increasing risk of death with each additional day of delirious symptoms [4]. All of these effects are difficult to monitor in real-time and further contribute to worsening of patient's mental abilities, thereby preventing a smooth recovery and rehabilitation process.

Use of virtual reality (VR) is a promising application for patient care and rehabilitation. Interventions using VR have produced feasible and effective therapies for pain perception in sufferers of traumatic injury [5], treatment compliance in burn victims [6], stroke rehabilitation [7], and cognitive deterioration in the elderly [8]. Applications for VR continue to expand towards improving patient care and comfort for serious medical conditions. There is good reason to believe VR applications can help treat pain perception [9], stress [10], quality of sleep [11], and cognitive deterioration [12]—all major risk factors of delirium in the ICU.

VR may be an ideal candidate for intervention upon the common risk factors for delirium. VR technologies can provide users with an immersive visual and auditory experience that can evoke states of presence in which the users respond to artificial sights and sounds as if they are real [13]. Medical applications of VR are a growing topic; not only for training and simulation for healthcare professionals [14, 15] but also for clinical treatment and therapy [16]. Rehabilitation and therapy in these spaces is a result of action and reflection in a consequential and purpose-driven context. Based on studies conducted to date [17], there seems to be a consensus that the highly interactive virtual environments indeed can improve the patient recovery process.

In summary, delirium is a common and serious complication that develops in many ICU patients. Previous research using VR for medicine has shown effectiveness in reducing pain and anxiety, which are prime candidates of modifiable risk for delirium in the ICU. The purpose of this study was to evaluate the feasibility of VR-based meditation for preventing delirium in ICU patients. In this paper we present preliminary results in an ongoing study [18] of a VR system to prevent delirium by improving quality of sleep, reducing pain, lowering the usage of sedatives, and stimulating cognition in ICU patients.

II. Method

A. Participants and Setting

The study was conducted in the general ICU of a university-affiliated hospital in the southeast United States. Data from the first 10 completed patients are presented here. At recruitment, patients were of adult age (+18 years), tested negative for delirium, were not in isolation (e.g., high risk of infection), were likely to stay in the ICU for several days, were not intubated, and did not have conditions which might limit face, head, or neck movement. All procedures were approved by the university institutional review board and were supervised by members of the ICU healthcare team.

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B. Materials

We used two Google Daydream VR systems in this study (vr.google.com/daydream). The VR systems consisted of the Google Daydream headset, a hand-held controller, and a smartphone to insert into the headset (Figure 1). Each VR system required its own smartphone to display the VR and run the VR apps. We used one Google Pixel and one Samsung Galaxy S8. We selected VR apps with various amounts of interactivity for patients to sample: *Google Spotlight Stories, Relax VR,* and *Bait!.*

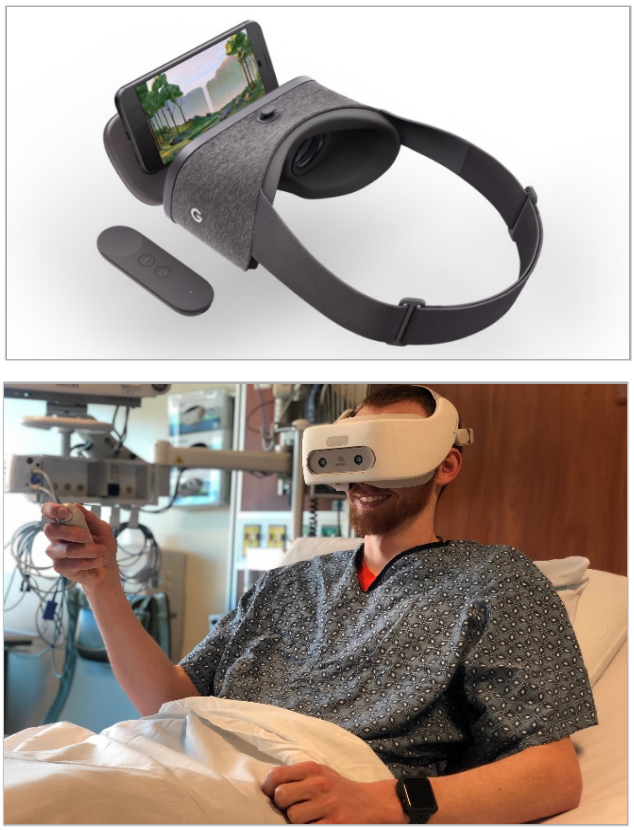

Figure 1. The Google Daydream headset and controller (top) and a depiction of in-hospital patient using VR (bottom) for future studies.

Google Spotlight Stories (atap.google.com/spotlight-stories) is a curated collection of ~5-min family-friendly VR films. We selected Stories as an immersive but minimally interactive VR experience in which patients could look around but not interact with the game world. *RelaxVR* (www.relaxvr.co) combines immersive video of real-world locations (e.g., beaches, forests, famous locations) with auditory guided meditation for breath control and relaxation. We selected *RelaxVR* as a VR environment that provided instructions but no programmed consequences for patient input. *Bait!* (www.resolutiongames.com/bait) is a VR fishing game in which the player must catch fish with a progressive story and difficulty level. We chose *Bait!* as a highly interactive game that involved cognitive coordination for tasks like aim, timing, and visual attention.

In addition to the VR headset, patients were provided with Bluetooth wireless earphones to receive the audio of the VR apps. Both the headset and the earphones were affixed with protective covers. The covers were discarded and the equipment was sanitized between each session. The headset, smartphone, controller, apps, earphones, and protective films were collectively referred to as the Digital Rehabilitation Environment Augmenting System (DREAMS).

C. Dependent Measures

The primary outcome measures of this study were patients' pain, sleep quality, affect, delirium status, and qualitative responses to using the DREAMS. Pain was measured with the Defense and Veteran's Pain Rating Scale (DVPRS) [19], a visual analog scale patients used to rate their pain from 0 (no pain) to 10 (as bad as it could be). Sleep was measured with the Richards-Campbell Sleep Questionnaire (RCSQ) [20], a 5-item survey administered to critically ill patients to estimate the quality of their sleep from 0 (worst sleep) to 100 (best sleep). Affect was measured with the Hospital Anxiety and Depression Scale (HADS) [21] and Impact of Events Scale (IES) [22]. The HADS is a 14-item survey with statements about fears and outlook that patients rated to estimate the likelihood clinical anxiety or depression, while the IES is a 22-item questionnaire to assess subjective stress caused by traumatic events. Delirium was measured with the CAM-ICU [23], a series of nurse-conducted evaluations to detect the presence of delirium. Qualitative responses to the DREAMS were measured with structured interviews which were recorded and thematically analyzed. We retrieved medical data for each patient's heart rate, breath rate, and medication log to track if VR had effects on vital signs and amount or frequency of sedatives and analgesics. Each of these measures have been extensively validated and are commonly used across ICU settings except for the DREAMS questionnaire, which was developed for the purposes of this study.

The CAM-ICU, DVPRS, heart rate, breath rate, and medication measures were regularly scored by nurses and entered into the hospital integrated data repository. Researchers retrieved these data for analysis after sessions were concluded. The RCSQ, HADS, IES, and DREAMS questionnaires were administered by the researchers during all sessions. Researchers would read the questions aloud to the participant and record responses into a REDCAP database. Researchers recorded responses on behalf of the patients to minimize the error and difficulty of input.

D. Session Procedures

Session 1. Session 1 began upon the patient's agreement to participate and signature of the informed consent. Researchers administered the RCSQ and HADS measures first to establish baseline measures. Then, patients were fitted with the DREAMS for comfort. Once the DREAMS was set up, researchers initiated the *Stories* video and instructed patients to enjoy the film by moving their head to look around. The DREAMS were removed when participants completed their viewing of *Stories* and researchers interviewed participants with open-ended questions about their experience (Appendix). Participants were then re-equipped with the DREAMS and proceeded through a 5-10-minute guided meditation for breath control in *Relax VR*. Afterwards, the DREAMS were again removed for researchers to go through the structured interview. At the end of the session, researchers asked participants to think about what the meditation in *Relax VR* had shown them and attempt to revisit the relaxation techniques whenever they felt the need to. The questionnaires, equipment setup, and VR exposure in Session 1 took approximately 1 hour to complete for each patient.

Session 2. Session 2 was initiated at least 24 hours after session 1. The procedures for session 2 were identical to session 1 except for the VR apps. Instead of *Stories* then *Relax VR*, participants were presented with the option to play *Relax VR* and *Bait!* in the sequence of their choice. The timing of questionnaires remained unchanged from session 1.

E. Data Analysis

Each participant's RCSQ and HADS were compared from before the first VR exposure (i.e., beginning of session 1) to at least 24 hours later before the second VR exposure (i.e., beginning of session 2). Participants' DVPRS, CAM-ICU, heart rate, breath rate, and medication logs were recorded at regular intervals by the healthcare staff. These more frequent background measures were analyzed in a chronological time-series to detect changes in the hours before VR exposure and the hours after.

III. *Results*

A. Participants

We enrolled 37 patients in the study. Of the total number of patients enrolled, a subset of 10 patients completed the full set of sessions. The 27 patients who did not complete sessions were either moved to other hospital wards before we could finish data collection or no longer wanted to participate due to changes in their medical status (e.g., change in medication, surgery). Participants' average age was 56.9 years (ranged 20-76) and consisted of 6 females and 4 males.

B. Pain

Patients' pain was measured using the DVPRS which ranges from 0 (no pain) to 10 (worst pain possible). Patient responses to the DVPRS in the two hours preceding the session were compared to the two hours after the session (Figure 2).

On average, patients' pain increased from 2 hours before the session (M = 3.30) to 1 hour before the session (M = 3.50). One hour after the session, however, average pain ratings decreased (M = 2.78). Participants' pain increased 2 hours after the session (M = 2.90), but remained below the average pain of either hours before the session. A paired-samples t-test showed no statistically significant difference ($p < 0.08$) between average pain 1 hour before and 1 hour after the session. Despite the lack of a statistically significant effect, many participants' pain ratings were notably lower 1 hour after exposure to DREAMS. Two participants (20%) rated 0 on the DVPRS across all time points. Three participants' (30%) pain increased 1 hour after our session; two participants' pain increased by 1 and another participant's pain increased by 4. When asked at a later date, the participant whose DVPRS increased by 4 indicated that their worsened pain was due to the medical nature of their ICU admission and not because of their DREAMS session. The remaining five participants (50%) rated lower pain 1 hour after our session. One of these participants' pain rating decreased slightly (1 point), three participants' pain decreased moderately (3 points), and one participants' pain decreased substantially (5 points). These decreases in pain generally diminished 2 hours after the session.

C. Sleep

Participant sleep quality was measured using the RCSQ which is scored from 0 (worst sleep) to 100 (best sleep). Of the 10 participants who completed the first session, only 3 went on to complete the second session. The RCSQ was unable to be completed for 1 of these 3 due to a program error; complete sleep quality data are only available for 2 of the 10 participants. Both participants' RCSQ improved after the first DREAMS session. One participant's sleep quality increased slightly (33.8 to 38.6) while the other participant's sleep was markedly better (20.2 to 68) after DREAMS exposure.

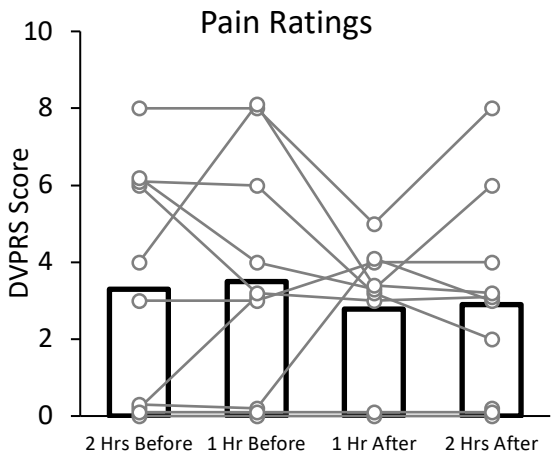

Figure 2. Average pain ratings (bars) with individual patient data (lines) pre-post VR exposure.

D. Affect

Participant affect was measured using the HADS and IES. The HADS produces scores for anxiety and depression for which 0-7 is normal, 8-10 is borderline, and 11-21 is abnormal. The IES yields scores ranging from 0 to 88; 24-33 indicate that post-traumatic stress disorder (PTSD) symptoms may be common, 33-36 indicate that diagnosis of PTSD is likely, and 37 or above indicate that stress is high enough to negatively impact the participant's immediate and long-term health. Of the 3 participants who completed the second session, one participant did not wish to complete the HADS questionnaire. Depression scores did not change across sessions for the other participants (0 [normal] and 9 [borderline]) while anxiety scores increased slightly within the normal range (1 to 4 and 5 to 7, respectively). Administration of the IES was terminated after numerous patients expressed a strong dislike of its questions.

E. Delirium

Delirium status was measured using the CAM-ICU which yields a case-positive or case-negative result. All participants were CAM-ICU negative (i.e., no delirious symptoms) upon admission and remained CAM-ICU negative until discharge. The mean patient ICU stay was for 15.78 days (range: 5 to 49 days).

F. Vital Signs

Participants' heart rate and respiration rate were recorded by healthcare staff and entered into an integrated data repository (Figure 3).

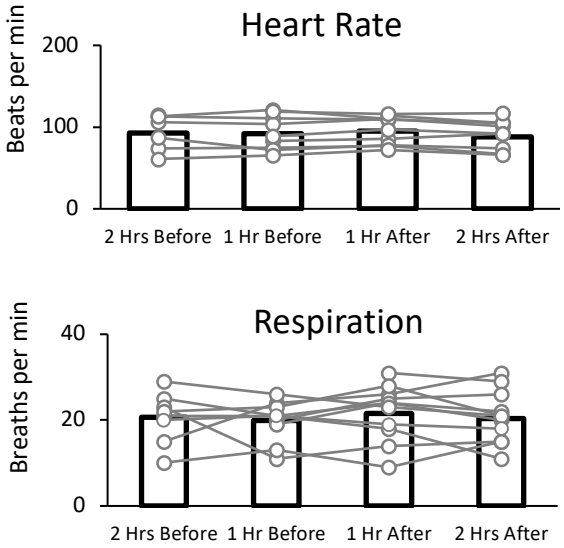

Figure 3. Average heart rate and breath rate (bars) with individual data (lines).

The researchers hypothesized that both heart rate and breath rate would decrease as a function of the VR meditation after initial observations that both measures decreased dramatically during the DREAMS sessions. However, these observations were not detected on the scale of the hour. Average heart rate (92.3 to 95.3 beats per minute) and breath rate (19.8 to 21.6 breaths per minute) slightly increased in the hour after the DREAMS sessions. These increases were likely due to the high amount of vocalization the researchers prompted from patients during questionnaires and interviews.

G. DREAMS Questionnaire

Researchers asked participants to rate how much they agreed with statements about their experience with the DREAMS (Figure 4).

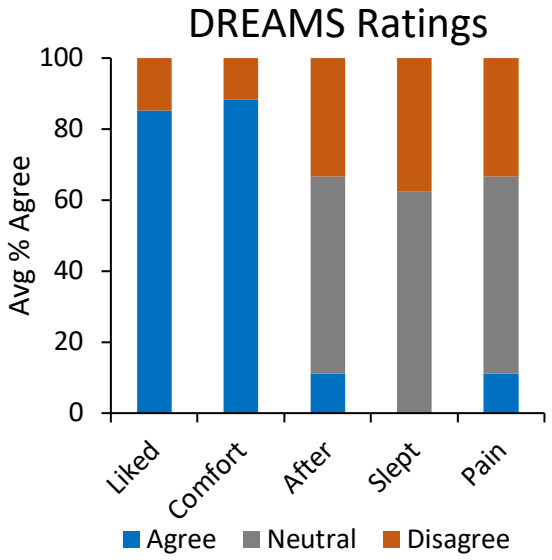

Figure 4. Responses to DREAMS questionnaire. *Liked* = "I liked using the DREAMS," *Comfort* = "I thought the DREAMS was comfortable to use," *After* = "I found myself thinking about the DREAMS after the session had ended," *Slept* = "I think I slept better last night because I used the DREAMS," *Pain* = "I felt that I experienced less pain yesterday because I used the DREAMS."

Few participants reported thinking about the DREAMS after exposure. Participants also generally did not think that the DREAMS helped improve their quality of sleep or their pain management. However, patients universally enjoyed engaging with the DREAMS and found its use to be comfortable. When asked to elaborate on their responses, many participants noted that their enjoyment of DREAMS may have been limited due to the nature of their ICU status (i.e., injury or illness).

Participants' open-ended responses to the DREAMS questionnaires were thematically analyzed. Based on participant responses, we provide the following insights and recommendations for future research using VR in the ICU.

Patients in the ICU have little tolerance for frustration. Patients admitted to the ICU are in generally perilous states of health. They may be subjected to frequent, necessary, but unpleasant medical procedures in prolonged states of exhaustion, isolation, and discomfort. They are mostly immobile in an unfamiliar environment away from their friends, family, homes, jobs, and daily lives. These patients can be quick to both frustrate and disengage from intervention. This low tolerance for frustration is no fault of the patient and should be accounted for when planning and conducting research in the ICU. We initially included *Bait!* as a VR app for participants to sample. *Bait!* provides a relaxing, leisurely environment with no time limits and simple controller inputs. However, most participants chose to not engage with *Bait!* on the mere notion that it required them to use the controller. Participants who did sample *Bait!* irritated quickly during the game's tutorial sequence which introduced the control scheme. One participant removed the DREAMS during the *Bait!* tutorial and stated, "I'm in pain and I don't want to deal with this." Participants also expressed frustration with questionnaire formats. The CAM-ICU, DVPRS, RCSQ, HADS, and IES consisted of multiple questions each. Each questionnaire used different question and response formats which the participants found annoying and difficult to keep track of. Interventions in the ICU should minimize the amount of exertion and learning required of participants and questionnaires should be standardized and simplified to ease participant response effort.

Patients in the ICU can be in emotionally sensitive states. Although generally appreciative of the healthcare services they were receiving, participants frequently stated that being in the ICU was one of the worst times of their life. The experiences in the ICU can be stressful as previously described. However, the experiences which lead to the patient's admission to the ICU can also carry traumatic burden in addition to each patient's unique life events. We chose *Google Spotlight Stories' Pearl* as an initial orientation to VR because it depicted a calm, family-friendly story from a perspective many people are familiar with: the inside of a car. However, several participants experienced negative emotional reactions to the perspective. Two patients reported feeling anxious while viewing the VR film because the characters were not wearing seatbelts and they anticipated a "jump scare" such as a sudden car crash. Another patient had previously lost a close family member in a car crash and the family road trip in *Pearl* caused emotional distress in recalling the event. Participants also had negative reactions to the questionnaires. Participants especially disliked the IES

for its specific and emotionally evocative questions of recent traumatic events. Several patients withdrew from the study explicitly because of their aversion to questions in the IES. Patients are likely to have experienced traumatic events which lead to their admission to the ICU. Individual patients may also have unique past experiences that should be accounted for. Interventions, from immersive VR to questionnaires, must be tailored to the patient and population to plan for emotionally evocative situations.

Patients in the ICU are quickly immersed into VR. Only one of our participants had previous experience with VR. However, despite differences in age and experience with games, all participants said they enjoyed the DREAMS and would like to use it frequently during their ICU stay. Several participants who initially wanted only brief exposure to the DREAMS later requested longer session times. One participant stated that they wanted to use *Relax VR* for up to an hour and, "about one minute in, I knew this was going to be good." Participants generally rated the DREAMS as both comfortable and enjoyable. Only one participant disliked using the DREAMS during the first session, but highly enjoyed the DREAMS on the second session and went on to state that the DREAMS helped them sleep better and remain calm in the ICU. Participants were also eager to propose improvements for future versions of the DREAMS. Suggestions ranged from improving the current VR meditation environment (e.g., adding seagulls to the beach), adding entirely new VR meditation environments (e.g., scuba diving in the ocean), to different content in the guided meditation (e.g., greater focus on breath control instead of bodily sensation). Three participants asked if they could purchase the DREAMS to use outside our sessions. Regardless of the suggestion, the feedback from participants was in excitement for the potential of VR meditation in the ICU.

IV. *Discussion*

We found support for the preliminary feasibility of the DREAMS Health VR to prevent delirium in the ICU. Patients found the DREAMS to be enjoyable, comfortable, and immersive. While DREAMS exposure did not result in clinically significant changes in pain, sleep, or vital signs, patients were ultimately exposed to only 5-10 minutes of VR per day. It seems likely that greater exposure to VR, which was requested by many patients, would be more likely to produce a meaningful effect on patient physiology and sleep quality.

The reduction in pain and zero rate of delirium are remarkable given the short duration of VR exposure. Participants in this pilot study experienced approximately 10-20 minutes of cumulative time in VR over two days. The remainder of session time consisted of questionnaires and setup. It will be important to evaluate potential dosage effects of VR exposure duration. Future research should prescribe various durations of VR exposure to assess for differential effects. Longer or more frequent exposure to VR meditation may provide greater or more durable benefits to ICU patients.

Also remarkable was the relative simplicity of VR exposure in our pilot study. We used commercially available VR apps which were neither highly immersive nor designed to prevent delirium. *Pearl* and *RelaxVR* were static VR apps in which the patients' inputs did not affect the experience. Previous research has shown that interactivity can improve immersion into VR experiences [24] which may alter effects upon participants. The ICU is a unique setting and delirium prevention entails many clinical nuances which were not likely to be optimized in the apps trialed here. Future research should evaluate the effectiveness of VR specifically developed for delirium prevention in the ICU. For example, VR meditation may be more effective if the VR experience changed in response to the patient's control over breath or heart rate.

The DREAMS exposure did not produce clinically significant effects on vital signs of heart rate or breath rate. One would have expected these metrics to change given the relaxation-focused approach of meditation. However, our procedures involved numerous questionnaires and open-ended interviews among the VR exposures. It seems likely that the timing, amount, and format of participant responding interfered with our ability to detect physiological changes as a function of the VR. Breath rate, for example, may have been affected by the VR experience. However, because we asked participants to speak with us after the VR exposure, their breath rate may have increased and masked the effect of the VR exposure. Future research should evaluate physiological measures in ways that minimize or eliminate the irrelevant effects of participant responses to other session components.

To date, there are no commercially available VR apps designed for the unique needs of ICU patients. In fact, even the most suitable commercially available VR apps for relaxation include a number of features or designs that limit their usability for ICU patients. These limitations included complex or highly precise motions required to use menu options, visual stimuli that would have required patients to get out of their beds or move around, or audio content that was not relevant to their hospital settings or arrangements.

Despite these limitations of commercial relaxation apps, in our preliminary research we still found support for VR to prevent delirium. We believe that the observed effects of our preliminary research can be made significantly stronger with a commercial-grade software specifically developed for ICU patients. We plan to develop DREAMS with simple menus and controls to provide patients with effortless access to the therapeutic effects. Our DREAMS will include visual stimuli that patients can comfortable engage with while remaining in their hospital beds and audio content specific to their ICU settings and bodily sensations. Designing our prototype of DREAMS will provide patients with the many demonstrated benefits of VR meditation to potentially prevent them from developing delirious symptoms while improving upon the usability and immersion of previous research.

The ICU can be a noisy, necessary, and often scary place to be for patients undergoing critical care. Delirium is a common occurrence in ICU admission. However, many cases of delirium have no known direct medical cause. It is likely that various aspects of the ICU environment itself may contribute to the development of delirium and related psychological conditions. This makes the ICU an ideal environment for the deployment of VR and other technological innovations towards the improvement of patients' hospital stays and long-term outcomes.

V. Conclusion

We found promising initial evidence in support of VR meditation for preventing delirium in the ICU. Ten

participants exposed to VR experienced benefits to their pain management and sleep quality, enjoyed and promoted the DREAMS VR platform, and remained CAM-ICU-negative throughout their stay in the ICU. The DREAMS was low-cost, simple to administer, and welcomed by participants.

This pilot study adds to the growing literature on VR for medical therapy. Delirium is prevalent in the ICU and carries serious negative health outcomes for patients, the healthcare system, and the community at large. Clear causes of delirium have yet to be identified but manipulation of the ICU environment has been shown to reduce existing delirium and prevent its development in patients. It will be important to continue evaluating VR as a platform for clinical treatment in support of the healing process.

VI. Acknowldedgements

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Appendix

DREAMS Questionnaire

Please rate how much you agree with the following statements.

1. I liked the experience of using the DREAMS.	**Strongly Agree** 1 2 3 4 5 **Strongly Disagree**
2. I thought using the DREAMS was comfortable.	**Strongly Agree** 1 2 3 4 5 **Strongly Disagree**
3. I found myself thinking about DREAMS after the session was over.	**Strongly Agree** 1 2 3 4 5 **Strongly Disagree**
4. I feel that I slept better last night because of the DREAMS.	**Strongly Agree** 1 2 3 4 5 **Strongly Disagree**
5. I feel that I experienced less pain yesterday because of the DREAMS.	**Strongly Agree** 1 2 3 4 5 **Strongly Disagree**