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Review

Review

Use of extended reality in sleep health, medicine, and research: a scoping review

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Abstract

Study Objectives: This scoping review explores the use of extended reality (virtual, augmented, and mixed reality) within sleep health, sleep medicine, and sleep research. It aims to provide insight into current uses and implementation considerations whilst highlighting directions for future research.

Methods: A systematic scoping review was undertaken informed by the preferred reporting items for systematic reviews and meta-analyses for scoping reviews and Johanna Briggs Institute.

Results: The use of virtual reality (VR) as a research tool in the investigation of areas such as dreaming and memory reactivation is growing. Thirty-one articles were identified in total with 20 utilizing VR to improve sleep as a clinical intervention.

Conclusions: Research exploring the utility of VR as a clinical intervention in various patient populations and clinical settings is therefore warranted. Researchers and clinicians should ensure that extended reality interventions are developed based on clinical reasoning and informed by evidence of both sleep medicine and the effects of virtual and augmented reality. Where possible future research should utilize up-to-date technology and reporting frameworks to assist in the translation of research into clinical practice.

Key words: virtual reality; augment reality; sleep medicine; scoping review

Introduction

Extended reality is increasingly being utilized within all facets of healthcare and medicine as a research tool and to assist in the provision of education (professional and patient) and clinical assessments and interventions [1–4]. As a research tool virtual reality (VR) has been successfully utilized by researchers to undertake otherwise unfeasible investigations into risky pedestrian behaviors in sleep-deprived university students [5]. Clinically, VR has also seen significant success in a range of pain and psychological disorders relating to anxiety and trauma that have the potential to influence sleep [6–9]. Extended reality technology, therefore, presents opportunities to further our understanding of the effects of sleep disorders as well as provide potentially cost-effective solutions to clinical challenges commonly encountered within sleep medicine to improve the patient, caregiver, and clinician experience. While the sleep medicine field is used to using novel and innovative technology a lack of understanding regarding the potential applications of XR within sleep medicine currently poses a significant barrier to its widespread adoption [10].

Defining extended reality

VR refers to a computer-generated digital three-dimensional environment with immersive properties that allow users to experience, interact and, or navigate a virtual and/or physical environment through the use of specialized devices such as head-mounted displays with the optional addition of auditory and/or haptic equipment [11–13]. Augmented reality differs in that it superimposes virtual elements onto the surrounding physical environment [14]. VR and augmented reality are not mutually exclusive categories and therefore have been proposed as two ends of a spectrum. Mixed reality is a term utilized within the literature to describe systems, which combine aspects of both virtual and augmented reality [11].

Risk associated with extended reality use in sleep medicine

To facilitate the widespread use and implementation of XR within sleep medicine high-quality research must address concerns regarding the safety of XR and its effect on sleep. For example, a lack of validated cleaning protocols raises potential concerns regarding patient safety for use of XR devices within healthcare settings. Additionally, sleep disorders are commonly comorbid with a range of neurodevelopmental disorders which increase the patients' risk of epilepsy [15, 16]. Within clinical trials involving XR technology, participants are commonly excluded if they possess a history of epilepsy despite some guidance outlining XR to be of little to no concern in

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individuals with or without a history of photosensitive epilepsy [17, 18]. Cybersickness, a term utilized to describe the transient symptoms of nausea, disorientation, headache, vertigo, fatigue, and eye strain sometimes associated with XR has been studied extensively [19, 20]. Recent advances in hardware, as well as the application of techniques to minimize sensory conflicts, have significantly reduced the incidence and severity of cybersickness [19–21]. However, the recognition and management of cybersickness may be of concern in patients who have an impaired ability to communicate. The potential effect of light exposure from XR use on sleep are complex and has yet to be fully elucidated. Existing literature suggests light characteristics (intensity and wavelength), as well as exposure conditions (duration, timing), have varying impacts on sleep latency and quality [22]. Despite concerns regarding light exposure research suggests XR can have positive effects on sleep [23, 24].

Rationale

The purpose of this review was to provide insights into this new area of research through an exploration of the research contexts, uses of XR, the experiences of individuals who have utilized XR in sleep medicine, patient populations, safety considerations, and adverse effects. To the best of the authors knowledge, no review has been undertaken investigating the uses of XR technology in sleep health, medicine, and research. A scoping review methodology was therefore chosen to map the themes and concepts relating to the use of XR and understand the quality of current research in order to assist in the translation of existing literature, inform future research and the development of clinical protocols guided by the following research questions.

Primary research question:

1. What research has been conducted on the use of XR in sleep health, medicine, and research and what is its quality?

Secondary research questions:

2. How and where has XR been utilized to investigate sleep and what effects does its usage have on sleep?
3. What are the experiences of individuals, caregivers and healthcare providers who have undergone, observed or delivered an XR intervention to improve sleep health, medicine, and research?
4. What types of XR hardware and software have been utilized within sleep health, medicine, and research?
5. What are the patient characteristics of individuals who have utilized XR within sleep health, medicine, and research to date and what populations have been excluded from research?

Methods

Protocol and registration

A priori protocol was developed utilizing the framework outlined by the Joanna Briggs Institute and in accordance with the Prisma extension for scoping reviews reporting guidance (preferred reporting items for systematic reviews and meta-analyses for scoping reviews) [25, 26]. The protocol was registered prospectively with Open Science Framework on August 15, 2022 and updated Septemeber 07, 2022 (DOI: 10.17605/OSF.IO/SM4PR).

Eligibility criteria

In line with the Joanna Briggs Institute methodology, a predetermined eligibility criteria was developed informed by the population (unrestricted), concept (any XR technology), and context (any area of sleep health or sleep medicine) framework [26]. Only articles published in English were included. To ensure a broad scope of the literature was undertaken qualitative, quantitative, and mixed methods research was included. The following types of articles were excluded as outlined within the priori registration: conference abstracts and proceedings, perspective papers, editorials, or commentaries, not related to XR or sleep health, medicine, and research.

Search strategy

A search strategy was developed in accordance with the following three-step methodological approach outlined by the Joanna Briggs Institute and with the assistance of a health sciences and medicine librarian [26]. Firstly, a preliminary literature search utilizing search terms identified incorporating the population (any population), concept (extended reality), and context framework (sleep) was undertaken in PubMed, and Google Scholar. Second, further search terms were identified and translated with the assistance of a validated search engine translation software (SRpolyglot) and further MESH terms were identified within individual databases [27]. Third, an execution of the final search strategies was undertaken within four databases (PubMed, CINAHL, EMBASE, and PsychInfo) and identification of gray literature through manual searching of the reference lists of included systematic reviews. The full search strategies can be found in Appendix 1.

Information sources

Results from the database searches were exported into Endnote X9 [28]. Duplicates were removed utilizing the systematic review accelerator deduplication cautious algorithm on August 18, 2022 and reviewed manually.

Sources of evidence selection

Articles were independently screened by two authors (AG and SG) initially by title and abstract within Screenatron [29] and then by full text against a predefined set of exclusion criteria within Covidence [30]. Discrepancies were identified and resolved by a single author (OB) within Covidence [30].

Data charting process

A draft extraction table was developed, piloted, and refined within Microsoft Excel prior to final data extraction commencing by two authors (AG and SG). Prior to data extraction included articles were checked to ensure no retracted articles were included within the data analysis in line with the recommendations of Cooper et al. 2021 [31]. Final extraction of data were undertaken by two authors (AG and SG). The study design of included articles was determined utilizing the algorithm suggested by Hong et al. 2018 for use with the MMAT [32].

Data items

The extracted data items can be found within the data extraction template (Appendix 2). Only data relating to sleep and/or XR interventions were extracted.

Critical appraisal

In line with current guidance on scoping review methodology and recommendations to improve the quality of scoping review a critical appraisal [33] of included articles was undertaken by two authors (AG and JB) with discrepancies resolved by a third author (SG) using the mixed methods appraisal tool (MMAT) [32]. All critical appraisal decisions were determined in line with the recommendations and guidance provided by Hong et al. 2018 [32].

Synthesis of results

Data pertaining to the frequency of countries, year of publications, setting, research context, and TIDieR checklist [34] were where possible tabulated using excel formulae and checked manually.

Results

Selection of sources of evidence

Database searching led to the retrieval of 396 articles. A summary of the selection and management of articles has been provided within the PRISMA flow diagram (Figure 1). A total of 31 articles were included in this review.

Critical appraisal within sources of evidence

Seven out of the 31 included articles fulfilled all relevant criteria of the MMAT [32] (Table 1). Articles were found to be of variable quality. MMAT [32] evaluation was unable to be completed for two articles as they did not fulfill the screening question requirements. Agreement between authors on decisions was substantial (Cohens Kappa 0.724) [35].

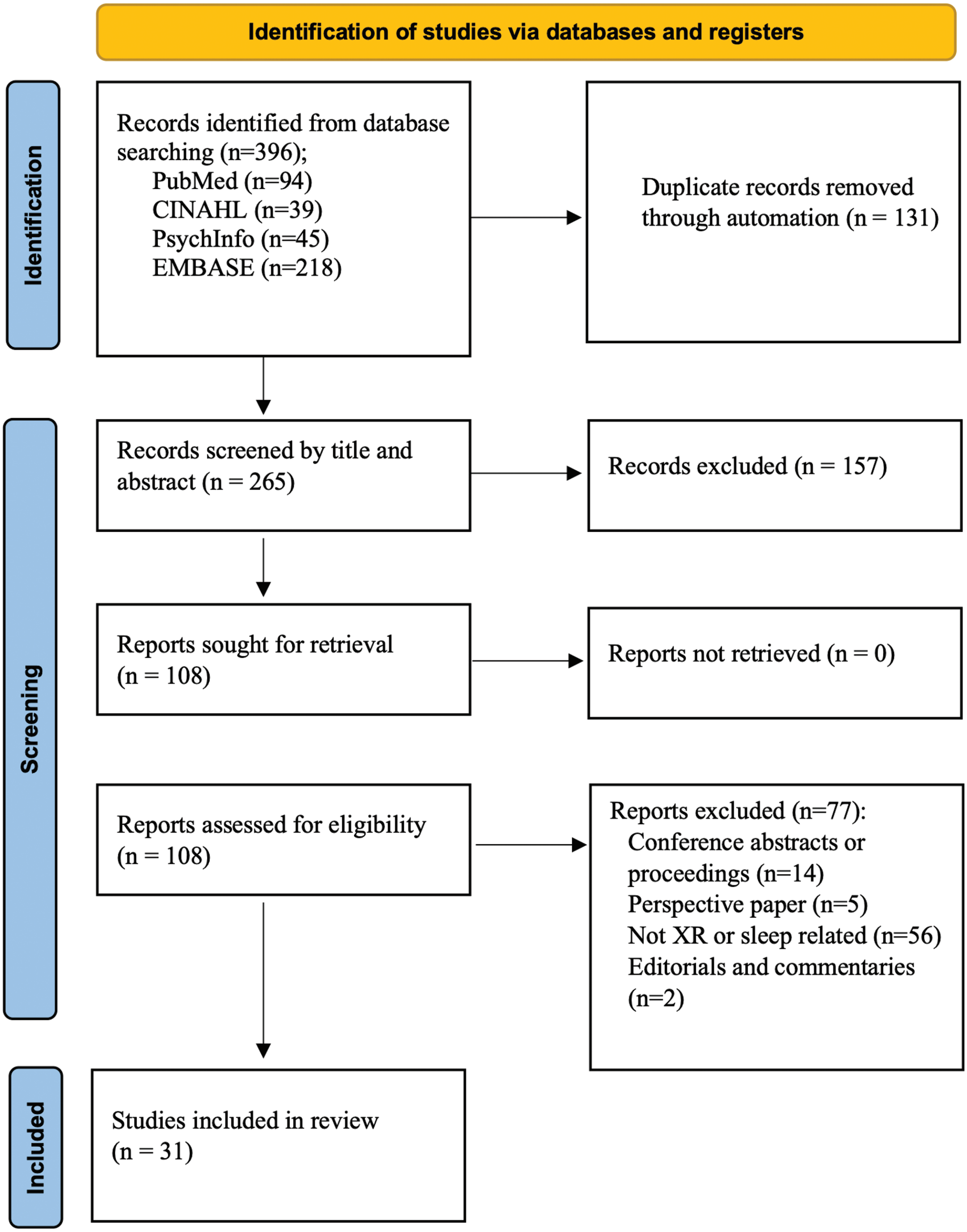

Figure 1. PRISMA flow diagram.

Table 1. Results of Critical Appraisal Utilizing the Mixed Methods Assessment Tool (MMAT) [32]

Study reference	Screening questions		Qualitative					Quantitative RCTs					Quantitative nonrandomized					Quantitative descriptive					Mixed methods				
	S1	S2	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5	5.1	5.2	5.3	5.4	5.5
Abd-Elsayed et al. [36]	Y	Y																CT	Y	Y	Y	Y					
Borghese et al. [37]	Y	Y						CT	Y	Y	N	CT															
Cheng et al. [38]	Y	Y						CT	CT	N	CT	CT	CT	CT	N	CT	CT										
Darnall et al. [39]	Y	Y						Y	Y	Y	N	N															
Garcia et al. [40]	Y	Y						Y	Y	Y	Y	CT															
Garcia et al. [41]	Y	Y						Y	Y	Y	Y	Y															
Garcia et al. [42]	Y	Y						Y	Y	Y	Y	CT															
Glavare et al. [43]	Y	Y	Y	Y	Y	Y	Y						Y	Y	Y	Y	Y						Y	Y	Y	Y	Y
Huang et al. [44]	Y	N																									
Kleim et al. [45]	Y	Y											Y	Y	Y	Y	Y										
Lee and Kang [24]	Y	Y						Y	Y	N	CT	Y															
Ong et al. [46]	N	N																									
Orakpo et al. [47]	Y	Y											CT	Y	Y	N	Y										
Pan et al. [48]	Y	Y	Y	Y	N	Y	N						Y	Y	Y	N	Y						N	N	N	CT	N
Park et al. [49]	Y	Y											Y	Y	Y	Y	Y										
Trahan et al. [50]	Y	Y											CT	Y	CT	N	CT										
Ulas and Semin [51]	Y	Y						N	N	Y	N	CT															
Zhang et al. [52]	Y	Y						Y	Y	Y	CT	CT															
Cumpanas et al. [53]	Y	Y											Y	Y	Y	Y	Y										
Picard-Deland et al. [54]	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y											CT	Y	Y	CT	N
Picard-Deland and Nielson [55]	Y	Y	Y	Y	Y	CT	N	Y	Y	Y	Y	Y											Y	Y	Y	Y	N
Pilly et al. [56]	Y	Y						Y	Y	Y	Y	CT															
Izullah et al. [57]	Y	Y						CT	N	Y	CT	Y															
Ribeiro et al. [58]	Y	Y	Y	Y	Y	Y	N	CT	N	Y	N	Y											Y	Y	Y	Y	Y
Rothacher et al. [59]	Y	Y						CT	CT	N	N	Y															
Sarkar et al. [60]	Y	Y											Y	Y	Y	N	Y										
Shimizu et al. [61]	Y	Y											Y	Y	Y	Y	Y										

Table 1. Continued

Study reference	Screening questions		Qualitative					Quantitative RCTs					Quantitative nonrandomized					Quantitative descriptive					Mixed methods				
	S1	S2	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5	5.1	5.2	5.3	5.4	5.5
Solomonova et al. [62]	Y	Y	Y	Y	Y	Y	Y	CT	Y	Y	Y	CT											Y	Y	Y	Y	CT

Abbreviations: S1: Are there clear research questions?; S2: Do the collected data allow to address the research questions?; 1.1: Is the qualitative approach appropriate to answer the research question?; 1.2: Are the qualitative data collection methods adequate to address the research question?; 1.3: Are the findings adequately derived from the data?; 1.4: Is the interpretation of results sufficiently substantiated by data?; 1.5: Is there coherence between qualitative data sources, collection, analysis, and interpretation?; 2.1: Is randomization appropriately performed?; 2.2: Are the groups comparable at baseline?; 2.3: Are there complete outcome data?; 2.4: Are outcome assessors blinded to the intervention provided?; 2.5: Did the participants adhere to the assigned intervention?; 3.1: Are the participants representative of the target population?; 3.2: Are measurements appropriate regarding both the outcome and intervention (or exposure)?; 3.3: Are there complete outcome data?; 3.4: Are the confounders accounted for in the design and analysis?; 3.5: During the study period, is the intervention administered (or exposure occurred) as intended?; 4.1: Is the sampling strategy relevant to address the research question?; 4.2: Is the sample representative of the target population?; 4.3: Are the measurements appropriate?; 4.4: Is the risk of nonresponse bias low?; 4.5: Is the statistical analysis appropriate to answer the research question?; 5.1: Is there an adequate rationale for using a mixed methods design to address the research question?; 5.2: Are the different components of the study effectively integrated to answer the research question?; 5.3: Are the outputs of the integration of qualitative and quantitative components adequately interpreted?; 5.4: Are divergences and inconsistencies between quantitative and qualitative results adequately addressed?; 5.5: Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?; Y: yes; N: no; CT: can't tell.

Synthesis of results

Twenty-seven of the thirty-one included articles have been published since 2020 demonstrating an increasing trend in the investigation and use of XR technology relating to sleep health, medicine, and research (Figure 2). Included articles originated from 11 countries all of which are within the Northern hemisphere. Twelve (40%) of the 30 articles originated from the United States. Four methodologies were identified: quantitative (n = 18), mixed methods (n = 10), systematic reviews (n = 2), and a protocol (n = 1).

Use of extended reality in sleep medicine.

All articles utilized VR. No uses of AR or mixed reality were identified. Nine articles utilized VR as a research tool with eight of these articles stipulating the use of VR was located within a research facility (Figure 3A). Twenty articles utilized VR for the purposes of a clinical intervention (Table 2). These 20 articles utilized VR within the participants' home (n = 7) [36,39–42,50,63], hospital (n = 5) [24, 45, 48, 49, 52], research facilities (n = 4) [37, 44, 45, 60], group exercise (n = 1) [51], a rehabilitation facility (n = 1) [43], and a nursing home (n = 1) [38]. All articles that described the use of XR for research purposes stated the use of VR was within a research facility (n = 8) [53–59,61,62].

Clinical applications for the use of extended reality to improve sleep.

VR was utilized with a wide range of patient populations including psychiatric disorders (social anxiety disorders, posttraumatic stress disorder) acute and chronic pain (back pain, neck pain, and fibromyalgia), and chronic tinnitus (Table 2). Sleep was most commonly assessed as a secondary outcome measure. Healthy populations which utilized VR included university students, health professionals during the COVID-19 pandemic, and nursing home residents. Two articles investigated the benefits of VR for non-intubated patients in an intensive care unit [24, 46]. No articles investigated populations under the age of 16. VR interventions commonly included experiences designed to help patients undertake or develop proficiency in meditation [24], mindfulness [39–42, 48, 63], progressive relaxation [38–42, 44, 46], and breathing control [40–42, 60]. Three studies used VR for the purposes of exposure therapy [37, 45, 50]. One of these studies played a tone during a VR public speaking task and again during REM sleep [37]. Two of the twenty articles utilized a protocol where patients wore the head-mounted display as they were falling asleep [24, 44].

Research applications for the use of extended reality within sleep medicine.

The majority of articles utilizing XR as a research tool investigated healthy populations [53–57, 62]. Commonly VR is utilized to investigate the consequences of sleep manipulations. VR was utilized most commonly as a tool to assist in the investigation of memory reactivation during sleep and its potential effect on task performance [37, 54, 55, 61]. One article included individuals with and without parasomnias to assist in investigating the motor networks in sleepwalkers [59].

Types of hardware and software within sleep medicine.

Eight brands of XR hardware devices were identified: Meta, PICO, HTC, Cybermind, da Vinci, Samsung, FXGear, and Google (Figure 3B). The PICO G2 4K was the most utilized device (n = 4) [40–42,63]. The majority of head-mounted displays were utilized only within a single article (Table 3). EaseVRx developed by AppliedVR was the most widely utilized software (n = 4) [40–42,63]. Only four articles detailed software was identifiable and commercially available [36, 46, 50, 59] (Table 3).

Adverse effects and safety considerations in the use of extended reality within sleep medicine.

Nineteen exclusion criteria were identified (Table 4) relating to active medical conditions, medical history, and practical considerations. No articles investigated or reported on the potential for light pollution from XR devices to disrupt the quantity or quality of sleep or its underlying physiological processes. Cleaning and infection control procedures were reported within two articles which detailed protocols including disposable covers [46], alcohol [48], and the use of ultraviolet light wands [46]. One article highlighted the potential for experiences to cause emotional distress [42].

Experiences of individuals using extended reality within sleep medicine.

The experience of utilizing VR was generally positive, in terms of being easy to implement [46, 52, 67] and well-accepted by patients [36, 67]. A full list of barriers and facilitators can be found in Table 5.

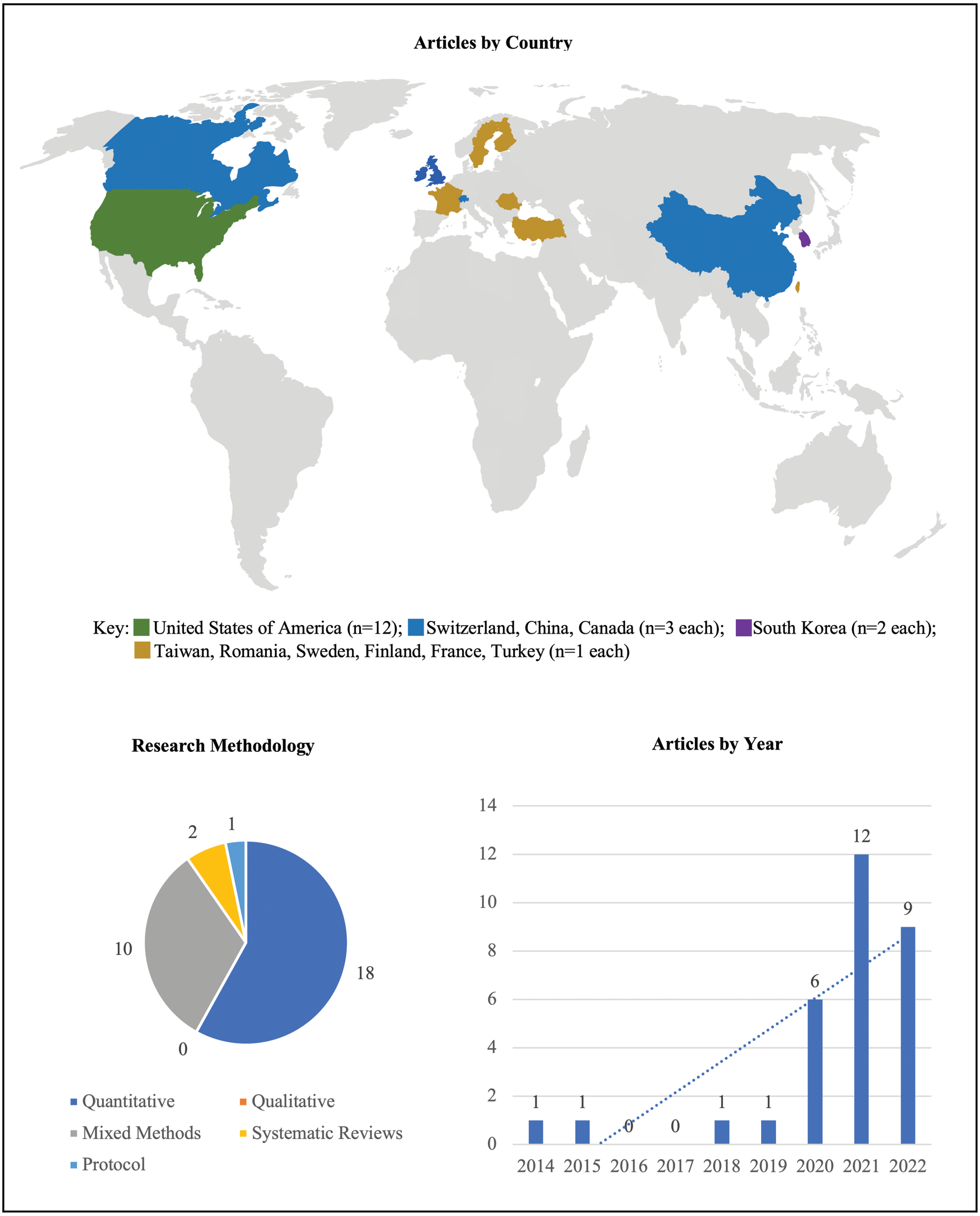

Figure 2. Included articles' country of origin, research methodology, and year of publication.

Reporting quality of interventions utilizing extended reality within sleep medicine.

The reporting quality of interventions was poor according to the TIDieR Checklist (Table 4). Only 16% of articles reported details relating to the hardware and software utilized completely. Seventy-nine percent of articles did not provide details relating to the qualifications or familiarization that clinicians and researchers had with utilizing VR with patients.

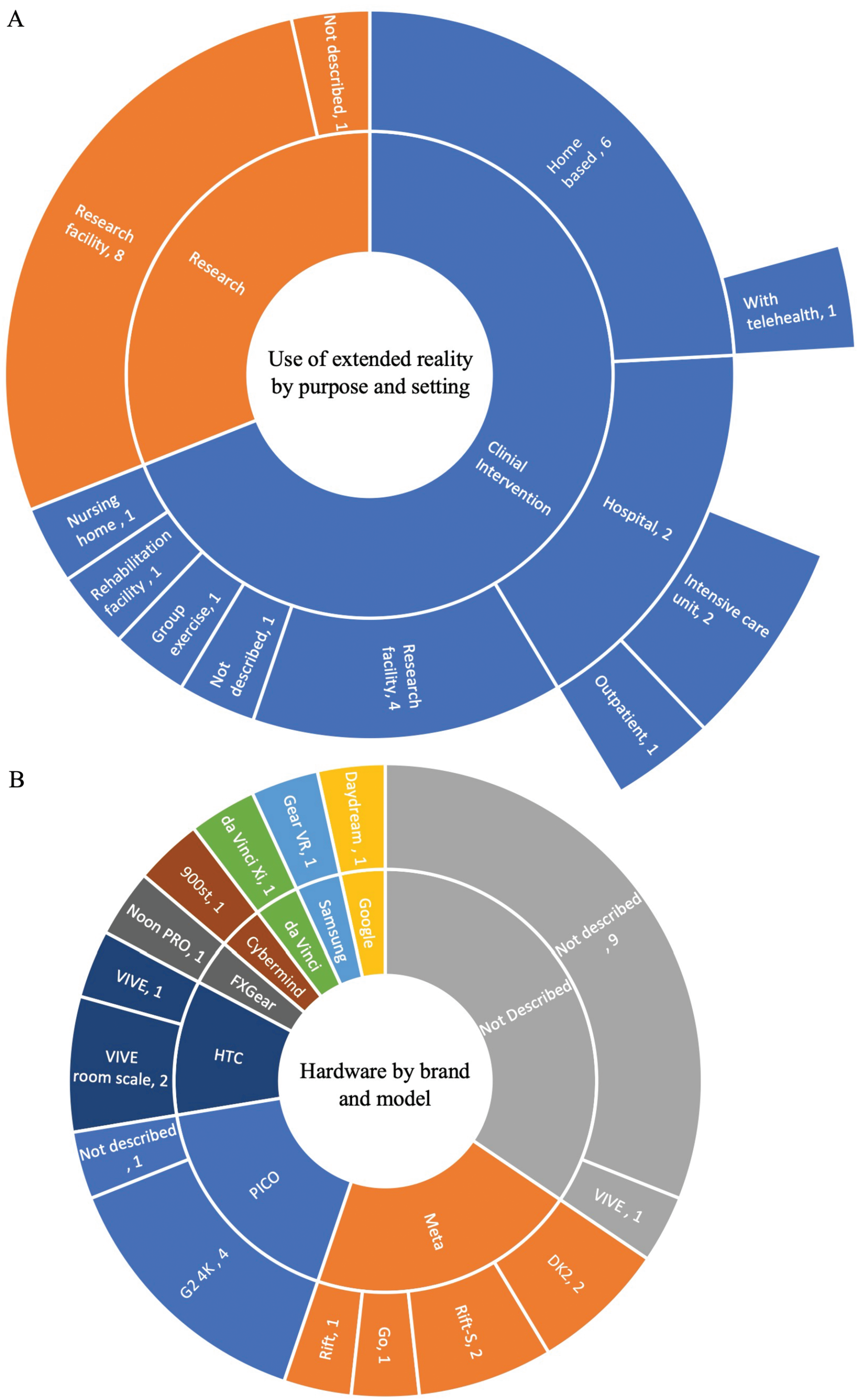

Figure 3. (A) Use of extended reality by purpose and setting. (B) Use of extended reality by hardware brand and model.

Discussion

Summary of evidence

To the best of our knowledge, this is the first review to provide insights into the utilization of XR technology within sleep health, medicine, and research. The results of this scoping review indicate that whilst the use of XR in sleep medicine is rapidly increasing it remains confined to the Northern hemisphere. Articles within this review utilized XR for two purposes. Firstly, as a research tool and secondly, as a clinical intervention to improve sleep in a variety of populations, especially those with acute and chronic pain. Sleep was most commonly assessed as a secondary outcome measure within included articles. None of the included articles utilized XR for the purposes of medical or patient education to

Table 2. Details of Included Articles Excluding Reviews Relating to Aim(s), Methodology, Context, Setting, and Participant Characteristics

Author (year) country	Aim(s) research question(s) of study	Methodology (methods)	Context and setting of XR use	Participant characteristics
Abd-Elsayed et al. [36] United States	Aim 1: Evaluate the effectiveness of the Harvard MedTech Vx Pain Relief Program on adult patients with acute and chronic pain. Aim 2: Evaluate the effectiveness of the Harvard MedTech Vx Pain Relief Program on opioid consumption, pain perception, and the behavioral aspects of pain.	Quantitative (Retrospective Cohort Study)	Context: Intervention Setting: Home-based with telehealth	Vx pain relief (*n* = 36): M/F: 16/20 Age: Mean 45, range 20–65 Population: Acute and chronic pain secondary to workplace injuries
Birckhead et al. [63] United States	Aim 1: Assess the efficacy of immersive skills-based VR and distraction VR in decreasing pain interference compared with placebo VR among patients with chronic lower back pain. Aim 2: Assess the efficacy of VR to improve perceptions of sleep quality and anxiety, self-reported pain catastrophizing, and reduce use of opioids.	Protocol	Context: Intervention Setting: Home-based	Prospective participants: M/F: N/A Age: >13 years old Population: Chronic back pain lasting greater than 3 months
Borghese et al. [37] Switzerland	Aim: Investigate whether targeted memory reactivation during rapid eye movement sleep may enhance exposure therapy in social anxiety disorder	Quantitative (RCT)	Context: Intervention Setting: VR is provided in research facility. Participants slept at home	VR exposure therapy (*n* = 44): M/F: Not described Age: Range 16–40 Population: 22 healthy controls, 22 with a diagnosis of social anxiety disorder
Cheng et al. [38] Taiwan	Aim: Explore the effectiveness of a combined program of 3D VR and hands-on aromatherapy in improving institutionalized older adult's psychological health	Quantitative (Quasi Experimental Design)	Context: Intervention Setting: Nursing Home	Intervention (*n* = 30): M/F: Not described Age: Mean 83.03 ± 7.6 Population: Nursing home residents
Darnall et al. [39] United States	Aim 1: Evaluate a skills-based behavioral medicine VR program for chronic low back pain and fibromyalgia	Quantitative (RCT)	Context: Intervention Setting: Home-based	VR intervention (*n* = 35): M/F: 26/9 Age: Range 18–75 Population: Self-reported history of >6 months of chronic nonmalignant low back pain or fibromyalgia with pain intensity >4/10 over past 1/12
Garcia et al. [40] United States	Aim: Conduct a placebo-controlled RCT in community-based individuals with chronic lower back pain assigned to receive one of the two 56-day treatment programs: therapeutic VR (EaseVRx) or Sham VR	Quantitative (RCT)	Context: Intervention Setting: Home-based	VR intervention (*n* = 89): M/F/Other: 22/67 Age: Mean 51.5 ± 13.5, range 18–81 Population: Self-report chronic lower back pain Control VR: *n* = 90 M/F/Other: 19/70/1 Age: Mean 51.4 ± 2.9, range 25–81 Population: Self-reported lower back pain
Garcia et al. [41] United States	Aim: Answer critical questions about the extended efficacy, magnitude of efficacy, and clinical importance for home-based therapeutic virtual reality at 3 months posttreatment	Quantitative (RCT)	Context: Intervention Setting: Home-based	EaseVRx intervention (*n* = 94): M/F: 23/71 Age: 52.1 ± 13.5, range 18–81 Population: Self-reported chronic lower back pain
Garcia et al. [42] United States	Aim: Investigate the durability of VR treatment at 6-month follow-up and investigate if VR engagement differs by socioeconomic status	Quantitative (RCT)	Context: Intervention Setting: Home-based	VR intervention (*n* = 94): M/F/Other: 23/71 Age: Mean 52.1 ± 13.5, range 18–81 Population: Self-report chronic lower back pain Control VR: *n* = 94 M/F/Other: 20/73/1 Age: Mean 51.3 ± 12.9, range 25–81 Population: Self-reported lower back pain

Table 2. Continued

Author (year) country	Aim(s) research question(s) of study	Methodology (methods)	Context and setting of XR use	Participant characteristics
Glavare et al. [64] Sweden	Aim: Investigate the feasibility of VR exercise interventions as part of an interdisciplinary rehabilitation program for persons with chronic neck pain.	Mixed Methods Convergent Design (Qualitative Narrative Research, Quantitative Cohort Study)	Context: Intervention Setting: Interdisciplinary Rehabilitation Facility	VR exercise program (*n* = 12): M/F: 3/9 Age: Mean 42 years Population: Chronic neck pain; mean history of pain 4.5 years
Huang et al. [44] China	Not clearly described.	Concurrent Mixed Methods (Qualitative Descriptive And Quantitative RCT)	Context: Intervention Setting: Research Facility	Participants using VR are not accurately described.
Kleim et al. [45] Switzerland	Hypothesis: Sleep following an exposure therapy session compared with wakefulness leads to greater reductions in subjective anxiety and catastrophic spider-related cognitions, as well as greater increases in behavioral approach toward a live spider	Quantitative (RCT)	Context: Intervention Setting: Research Facility	Sleep Group (*n* = 21): M/F: 3/18 Age: Mean 25.81 ± 6.96
Lee and Kang. [24] South Korea	Aim: Investigate the effects of VR meditation on the sleep of ICU patients to assess its potential as a sleep intervention	Quantitative (RCT)	Context: Intervention Setting: Cardiac Intensive Care Unit	VR meditation (*n* = 24) M/F: 15/9 Age: Mean 69.46 ± 16.27 Population: Adults admitted o ICU with cardiovascular disease such as; angina pectoris, myocardial infarction, heart failure, and cardiomyopathy. Control group (*n* = 24): M/F: 17/7 Age: Mean 68.38 ± 16.53 Population: As per VR intervention
Ong et al. [46] United States	Aim: Evaluate the feasibility of VR relaxation therapies for intensive care unit patients	Mixed Methods Convergent Design (Qualitative Case Study, Quantitative Cohort Study)	Context: Intervention Setting: Hospital (Intensive Care Unit)	VR intervention (*n* = 46): M/F: 30/16 Age: Mean 50 ± 18 Population: Non-intubated ICU patients without delirium
Orakpo, Vieux, and Castro-Nunez [65] United States	Aim: Evaluate the effectiveness of VR neurofeedback as a treatment modality and its sustained analgesia for centralized pain.	Mixed Methods Convergent Design (Qualitative Case Study, Quantitative Descriptive Case Report)	Context: Intervention Setting: Not described	Case study participant (*n* = 1): M/F: 0/1 Age: 55 years old Medical history: Cervical spine stenosis with radiculopathy, post-concussive syndrome, sciatica, status post motor vehicle accident, past psychiatric history or depression, anxiety, chronic pain syndrome, posttraumatic stress disorder (relating to MVA)
Pan et al. [48] China	Aim: Address the needs of first-line health professionals using mindfulness-based stress reduction in VR.	Mixed Methods Convergent Nonrandomized Case Series (Qualitative Case Series, Quantitative Descriptive Studies)	Context: Intervention Setting: Hospital	VR mindfulness-based intervention (*n* = 4): M/F: 0/4 Age: Mean 32, range 29–37 Population: Front-line health professionals during the outbreak of COVID-19 pandemic
Park et al. [49] South Korea	Aim: Determine the usefulness of VR as a treatment to reduce tinnitus and related symptoms	Quantitative (Cohort Study)	Context: Intervention Setting: Hospital (Outpatient)	VR tinnitus intervention (*n* = 19): M/F: 9/10 Age: Range 33–64 Population: 3-month history of chronic non-pulsatile tinnitus for 3 months or longer
Sarkar, Edwards, and Baker [60] United States	Aim: Evaluate the feasibility and effectiveness of VR meditation as a clinical treatment option for older adults with chronic osteoarthritis knee pain	Mixed Methods (Qualitative Narrative Research, Quantitative Cohort Study)	Context: Intervention Setting: University Research Facility	VR meditation (*n* = 19): M/F: 6/13 Age: 67.9 ± 4.6, range 63–77 Population: Chronic knee osteoarthritis
Trahan et al. [50] United States	Aim: Assess the effectiveness of virtual reality exposure therapy in increasing tolerance to anxiety-based cues and decreasing symptoms	Quantitative Descriptive Study (Case Report)	Context: Intervention Setting: Home-based	Case study participant (*n* = 1): M/F: 1/0 Age: 36 years old Population: Participant is a military veteran and university student

Table 2. Continued

Author (year) country	Aim(s) research question(s) of study	Methodology (methods)	Context and setting of XR use	Participant characteristics
Ulas and Semin [51] Turkey	Aim: Determine the effect of virtual reality exercises on health services students' health promotion and academic success	Quantitative (RCT)	Context: Intervention Setting: Community Group Exercise Program Within a University Setting	VR exercise group (*n* = 30): M/F: 14/16 Age: 19 ± 0.72 Population: University undergraduate health services students
Zhang et al. [52] China	Aim: Compare effects VR-CALM experience to usual care on symptom management and psychological distress in breast cancer survivors	Quantitative (RCT)	Context: Intervention Setting: Hospital	VR-CALM intervention (*n* = 38): M/F: Not described Age: 52.29 ± 7.69 Population: Breast cancer patients who had completed at least 2 cycles of regular chemotherapy with no intolerable side effects
Cumpanas et al. [66] Romania	Aim 1: Evaluate how sleep deprivation influences the surgeon's performance on robotic virtual reality simulator exercises Aim 2: Compare the results with studies performed on laparoscopic virtual simulators	Quantitative nonrandomized (Cohort study)	Context: Research Setting: Not Described	VR surgical simulator (*n* = 20): M/F: 16/4 Age: Mean 29 years, range 27–32 Population: Residents in surgery
Picard et al. [54] Canada	Aim 1: Determine if targeted memory reactivation administered during slow wave sleep or rapid eye movement sleep benefits complex procedural learning Aim 2: Investigate if dreaming about kinesthetic aspects of a VR task is related to improved task performance Aim 3: Assess if targeted memory reactivation promotes direct and indirect dreaming about the VR task	Mixed Methods Convergent Design (Qualitative Narrative, Quantitative Randomized Control Study)	Context: Research Setting: Research Facility	Non-REM sleep group (*n* = 20): M/F: 7/13 Age: 23.60 (±4.21) REM sleep group (*n* = 20): M/F: 7/13 Age: 24 (±4.2) Non-sleep (control) group (*n* = 13): M/F: 5/8 Age: 23.46 (±4.05)
Picard-Deland and Nielson [55] Canada	Aim 1: Assess if targeted memory reactivation produces delayed dream reactivations of memories of a pre-sleep VR task and of its contextual setting	Mixed Methods Convergent Design (Qualitative Narrative Research, Quantitative RCT)	Context: Research Setting: Research Facility	Total participants (*n* = 137) M/F: 52/84 Age: 24.01 ± 4.03, range 18–35 Population: Healthy participants
Pilly et al. [56] United States	Aim: Assess if coarser noninvasive transcranial electrical stimulation is sufficient to effectively modulate complex episodic memories in humans	Quantitative (RCT)	Context: Research Setting: Research Facility	Participants (*n* = 24): M/F: 9/15 Age: 23.96 ± 6.08 Population: Healthy participants
Rashid-Izullah et al. [57] Finland	Aim: Determine the effects of aging and sleep deprivation on spatial perception and driving ability in a virtual driving environment.	Quantitative (Cross-sectional Study)	Context: Research Setting: Research Facility	Young Group: *n* = 22 M/F: 22/0 Age: Mean 22, range 18-35 Population: Self-reported healthy participants Old group (*n* = 22): M/F: 22/0 Age: Mean 71, range 65–79 Population: Self-reported healthy participants
Ribeiro et al. France [58]	Aim 1: Evaluate how a full night of sleep contributes to spatial memory performance for items displayed in a VR environment Aim 2: Evaluate the likelihood of items from the task being incorporated into participants' dreams	Mixed Methods Convergent Design (Qualitative Narrative Research, Quantitative RCT)	Context: Research Setting: Research Facility	All participants (*n* = 57): M/F: 13/44 Age: Mean 21.42, range 19–26 Population: Undergraduate students
Rothacher et al. [59] Switzerland	Aim: Examine the neural underpinnings of altered motor agency in sleepwalkers by measuring EEG modulation during redirected walking in VR	Quantitative (Cohort Study)	Context: Research Setting: Research Facility	VR Cohort (*n* = 15): M/F: 8/7 Age: Mean 30.6, range 22–47 Population: Sleepwalking ± NREM parasomnia

Table 2. Continued

Author (year) country	Aim(s) research question(s) of study	Methodology (methods)	Context and setting of XR use	Participant characteristics
Shimizu et al. (2018) [61] United States	Aim 1: Develop a robust methodology for reliably delivering stimuli during down-state to up-state transitions Aim 2: Demonstrate that closed-loop memory reactivation can be used to drive performance gains in complex learning tasks over longer periods of time	Quantitative (Nonrandomized Controlled Trial)	Context: Research Setting: Research Facility	Closed loop memory reactivation (n = 17): M/F: 11/6 Age: 23.82 years ± 4.02
Solomonova et al. [62] Canada	Aim 1: Demonstrate day-residue and dream-lag incorporations in prospectively collected home dreams, while tracking the appearance of these two effects as a function of the lab and VR experiences Aim 2: Investigate whether, in addition to incorporations of specific experience-related elements, dream content also reacts with generic changes - with shifts in dream locus of control in particular	Mixed Methods Convergent Design (Qualitative Narrative Research, Quantitative RCT)	Context: Research Setting: Research Facility	All participants (n = 26) M/F: 10/16 Age: Mean 26.2 ± 3.7, range 21–3 Population: Self-reported healthy population

Abbreviations: M, Male; F, Female; XR, Extended Reality; VR, virtual reality; AR, augmented reality.

improve understanding or facilitate engagement in diagnostic studies or treatment for sleep-disordered breathing.

Clinical applications for the use of extended reality to improve sleep.

No research identified in this scoping review included pediatric populations and only one intervention was designed to specifically improve sleep [24]. Instead, the current clinical applications were primarily focused on decreasing experiences of pain and anxiety in adults through mindfulness, relaxation, exposure therapy, and breathing exercises. The effects of, which were commonly evaluated through surveys such as the Pittsburgh Sleep Quality Index [38, 49–52]. Despite sleep being only a secondary outcome measure it is encouraging that emerging evidence suggests these interventions have the potential to improve sleep outcomes in healthy and unhealthy adult populations (Table 3).

Lee and Kang found that using VR for meditative purposes prior to sleep in intensive care patients had significantly improved sleep suggesting that utilized correctly and in the right circumstance VR may be beneficial in improving sleep [24]. Garcia et al., utilized VR devices to provide a home-based intervention for individuals with self-reported chronic lower back pain [40–42]. During the intervention patients could access assistance via telehealth and were provided education regarding their condition and content designed to enable relaxation and teach mindfulness [40–42]. At 6-month follow up patients maintained clinically meaningful gains in sleep [42].

Further research is required to understand if XR is useful during the set-up of diagnostic sleep studies to decrease anxiety, improve compliance, and ultimately the success rate and quality of diagnostic testing. Additionally, elements of experiences, which provide visual cues for breathing in and out may assist children with neurodevelopmental disorders to tolerate positive airway pressure titration studies.

Research applications for the use of extended reality within sleep medicine.

Sleep disorders affect a variety of cognitive processes (e.g. emotional regulation, attention, and threat perception) the assessment of which in real-world environments can be challenging within research. Extended reality currently provides opportunities to investigate the effects of treatment within virtual real-world environments in a manner previously not feasible. So far VR has been utilized to standardize experiences and tasks to assist in the investigation of areas such as dreaming [62] and closed loop memory reactivation [55, 56, 61] as well as motor control in sleepwalkers [59] and task performance following sleep deprivation during laparoscopic surgery [53] and driving simulations [57]. However, no research identified in this review used XR technology to investigate the effects of treatment in individuals with sleep-disordered breathing. While investigation may at times require the design of specific software experiences researchers may be able to utilize preexisting applications. For example, StreetWizeVR [69] simulates pedestrian crossing situations providing an opportunity for researchers and clinicians to investigate the effects of effective treatment on pedestrian risk in children with sleep-disordered breathing. When utilizing XR for research purposes we recommend researchers still consider the implementation of appropriate safety and infection control protocols.

Experiences of individuals using extended reality within sleep medicine.

Extended reality interventions were found to be simple and easy to adopt interventions [52] with easily implemented infection control procedures [46] that were well accepted by patients [36, 67]. Whilst the head-mounted displays were reported to be easy to use and comfortable [67] during use patients found it uncomfortable to sleep whilst wearing the devices [44]. The patient experience was reported to be facilitated by patients being able to

Table 3. Details of Included Articles Excluding Reviews Relating to Hardware, Software, Outcome Measures, and Relevant Findings

Author (year) country	AR/ VR/ MR	Hardware B: Brand M: Model CA: Commercial availability	Software C: Company S: Software CA: Commercial availability	XR-related intervention details F: Frequency T: Time I: Intervention	Sleep- and XR-related outcome measures	Sleep-related findings
Abd-Elsayed et al. [36] United States	VR	B: Pico M: Not described CA: Not described	C: Harvard Medtech S: Vx Pain Relief Program CA: Accessible to patients via Harvard Medtech	F: 1–2/day for 12 weeks T: 45 minutes I: Preloaded experiences from 4 categories (knowledge of pain, meditation techniques, escape from pain, distraction from pain) with additional weekly telehealth consult to provide guidance and outline goals for following week	Sleep-related outcome measures: • Pittsburgh sleep quality index • Short posttraumatic stress disorder rating interview	Sleep-related key findings: • 115% increase in the duration of their sleep • 280% increase in the subjective quality of their sleep • 85% reduction in sleep interruptions. • Patients that experienced sleep interruptions, however, 92% were able to fall back asleep more quickly
Birckhead et al. [63] United States	VR	B: PICO M: G2 4K CA: Not described	C: AppliedVR S: EaseVRx CA: Not described	F: 1/day for 56 days T: 2–16 minutes I: Intervention 1: skills-based VR incorporating evidenced-based principles of cognitive behavioral therapy, mindfulness meditation, and physiologic biofeedback therapy; Intervention 2: distraction-based VR consisting of 360-degree videos; Intervention 3: Sham VR involving 2D nature scenes.	Sleep-related outcome measures: • PROMIS sleep disturbance • Fitbit weekly total sleep time and sleep efficiency XR-related outcomes measures: • Simulator sickness questionnaire	Protocol only
Borghese et al. [37] Switzerland	VR	B: Meta M: Meta Rift CA: Not described	C: Virtual reality & robotics facility of the Human Neuroscience Platform, Fondation Campus Biotech Geneva. S: Not described. CA: Not described	F: 3 × single VR sessions over 9 days T: 15 minutes (5 minutes VR) I: Participants undertook public speaking tasks in virtual reality. Feedback was provided whilst a tone was played which was provided to participants while in REM sleep for 8 consecutive nights via a headband.	Sleep-related outcome measures: • Polysomnography	Sleep-related key findings: • Targeted memory reactivation during REM did not modulate the effect of exposure therapy on anxiety-related distress
Cheng et al. [38] Taiwan	VR	B: Not described M: Not described CA: Not described	B: Not described S: Not described CA: Not described	F: 1/week for 9 weeks T: Not described I: VR relaxation combined with facilitated preparation and use of aromatherapy throughout the week	Sleep-related outcome measures: • Pittsburgh Sleep Quality Index	Sleep-related key findings: • VR + aromatherapy resulted in significant improvements in sleep quality compared to no intervention.
Darnall et al. [39] United States	VR	B: Meta M: Meta Go CA: Not described	C: AppliedVR S: Not described CA: Not described	F: 1/ day for 21 days T: Ranging 1–15 minutes I: VR content designed to improve self-regulation of cognitive, emotional, and physiological responses to stress. Content relating to 3 major categories; skills in pain CBT, relaxation training, mindfulness. Brief orientation provided via phone initially. Further assistance is available from study staff if required via phone	Sleep-related outcome measures: • Pain interference on activity, mood, sleep, and stress • Defence and veterans pain rating scale XR-related outcome measures: • Satisfaction with treatment • Motion sickness and nausea	Sleep-related key findings: • Reductions in sleep interference were greater in VR group. XR-related key findings: • 83% VR participants reported high satisfaction. • 76% of participants reported no nausea or motion sickness.

Table 3. Continued

Author (year) country	AR/ VR/ MR	Hardware B: Brand M: Model CA: Commercial availability	Software C: Company S: Software CA: Commercial availability	XR-related intervention details F: Frequency T: Time I: Intervention	Sleep- and XR-related outcome measures	Sleep-related findings
Garcia et al. [40] United States	VR	B: Pico M: G2 4K CA: Not described	C: AppliedVR S: EaseVRx CA: Not described	F: 1/day for 8 weeks T: 2–16 minutes (average 6 minutes) I: 56-day standardized program involving prescribed sequence of VR experiences relating to 8 themes (pain education, relaxation, and interoception, mindfulness escape, pain distraction games, dynamic breathing)	Sleep-related outcome measures: • Pain-related sleep interference score • PROMIS sleep disturbance score XR-related outcome measures: • Motion sickness and nausea • VR device use • System usability	Sleep-related findings: • Intervention group has lower sleep disturbance compared to the control VR group. XR-related key findings: • EaseVRx had higher levels of user satisfaction compared to Sham VR.
Garcia et al. [41] United States	VR	B: Pico M: G2 4K CA: Not described	C: AppliedVR S: EaseVRx CA: Not described	F: 1/day for 8 weeks T: 2–16 minutes (average 6 minutes) I: 56-day standardized program involving prescribed sequence of VR experiences relating to 8 themes (pain education, relaxation, and interoception, mindfulness escape, pain distraction games, dynamic breathing)	Sleep-related outcome measures: • Pain-related sleep interference score • PROMIS sleep disturbance score	Sleep-related key findings: • No significant difference was found between sham and intervention for sleep disturbance at 3 months. • A moderate clinical meaningfulness remained for pain interference with sleep.
Garcia et al. [42] United States	VR	B: Pico M: G2 4K CA: Not described	C: AppliedVR S: EaseVRx CA: Not described	F: 1/day for 8 weeks T: 2–16 minutes (average 6 minutes) I: 56-day standardized program involving prescribed sequence of VR experiences relating to 8 themes (pain education, relaxation, and interoception, mindfulness escape, pain distraction games, dynamic breathing)	Sleep-related outcome measures: • Pain-related sleep interference score • PROMIS sleep-disturbance score	Sleep-related key findings: • Reduction in pain-related interference with sleep in intervention group compared to control.
Glavare et al. [64] Sweden	VR	B: Not described M: Not described CA: Not described	C: RecoVR S: Not described CA: Not described	F: 2/week for 6 weeks T: ~10 minutes I: Interdisciplinary program consisting of pain education, coping with pain, self-management, interaction of pain, emotions, behavior, and exercise performed daily. VR exercises involved range of motion and eye tracking tasks.	Sleep-related outcome measures: • Insomnia severity index • Neck disability index XR-related outcomes measures: • Patient interviews	Sleep-related key findings: • Significant improvements in insomnia as measured by insomnia severity index. XR-related key findings: • VR exercises are safe and feasible for patients with chronic neck pain. • Symptoms may increase during intervention which stresses the importance of individual adjustments.
Huang et al. [44] China	VR	B: Not described M: Not described CA: Not described	C: Not described S: VR-CALM CA: Not described	F: Not accurately described. T: 30 minutes I: Participants watched VR relaxation beach experience with a head-mounted display as they were going to sleep.	Sleep-related outcome measures: • Electroencephalogram • Custom questionnaire	XR-related findings: • Participants complained about wearing the head-mounted displays whilst trying to sleep.
Kleim et al. [45] Switzerland	VR	B: Not described M: Not described CA: Not described	C: Virtual reality medical center, San Diego, CA, USA S: Not described CA: Not described	F: Single VR exposure T: 45 minutes I: Participants exposed to spiders in VR environment	Sleep-related outcome measures: • Questionnaires • Total sleep time, sleep latency, and sleep stage duration determined by portable electroencephalogram	Sleep-related key findings: • Sleep following exposure therapy improved therapeutic effectiveness

Table 3. Continued

Author (year) country	AR/ VR/ MR	Hardware B: Brand M: Model CA: Commercial availability	Software C: Company S: Software CA: Commercial availability	XR-related intervention details F: Frequency T: Time I: Intervention	Sleep- and XR-related outcome measures	Sleep-related findings
Lee and Kang. [24] South Korea	VR	B: FXGear M: NOON PRO CA: Yes	C: Not described S: Relaxing music for meditation CA: Not described	F: Single VR exposure T: 20 minutes practice, 30 minutes intervention I: VR meditation program 30 minutes before bedtime. Participants could sleep with headset if desired.	Sleep-related outcome measures: • Korean Sleep Scale • Fitbit Charge 2	Sleep-related key findings: • Subjective sleep quality was significantly higher in VR group. • No difference in total sleep time • VR significantly improved sleep efficacy, and deep sleep whilst reducing light sleep.
Ong et al. [46] United States	VR	B: Google M: Daydream CA: Yes	B: RelaxVR S: Pearl CA: Yes	F: 1/day for up to 7 days T: Orientation 5 minutes, VR Meditations 5–20 minutes I: Guided VR meditation for breath control and progressive relaxation	Sleep-related outcome measures: • Richards-Campbell sleep questionnaire • Structured interviews	Sleep-related key findings: • No effect on sleep observed XR-related key findings: • Easy to implement
Orakpo, Vieux, and Castro-Nunez [65] United States	VR	B: Meta M: Rift-S CA: Not described	C: BeeMe3dic S: Cygnet Software CA: Not described	F: 20 sessions over 10 weeks T: Not described I: VR neurofeedback sessions	Sleep-related outcome measures: • Sleep deprivation due to pain	Sleep-related findings: • 20% improvement in sleep deprivation due to pain
Pan et al. [48] China	VR	B: Not described M: Not described CA: Not described	C: Shanghai Zan Tong Medtech Limited Co Ltd. S: Not described CA: Not described	F: 1/day for 7 days T: 30 minutes I: Participants self-selected a VR mindfulness-based stress reduction experience	Sleep-related outcome measures: • Patient health questionnaire • Generalized anxiety disorder – 7 • Patient Health Questionnaire – 15 • Athens insomnia scale	Sleep-related key findings: • Athens insomnia scale scores improved by 67.44% on average • All four participants qualitatively reported improvements in sleep quality
Park et al. [49] South Korea	VR	B: Not described M: VIVE CA: Not described	C: Not described S: Not described CA: Not described	F: 4 sessions over 4–8 weeks T: Not described I: A tinnitus avatar was developed which participants proceeded to trash	Sleep-related outcome measures: • Pittsburgh sleep quality index • Tinnitus handicap inventory • Tinnitus handicap questionnaire • World health organization quality of life	Sleep-related key findings: • Pittsburgh sleep quality index showed statistically significant improvements. • Tinnitus handicap inventory significantly improved • No change in tinnitus handicap questionnaire and world health organization quality of life was reported
Sarkar, Edwards, and Baker [60] United States	VR	B: Meta (Meta) M: Meta Rift-S CA: Not described	C: Cubicle ninjas S: Guided meditation VR version 2.2.1 CA: Not described	F: Single session T: 10 minutes I: Guided meditation involving breathing paired with arm movements designed to encourage focus on the body and here and now	Sleep-related outcome measures: • Brief pain inventory short form • Pain interference scale XR-related outcome measures: • Simulator sickness questionnaire • Igroup presence questionnaire • User engagement scale	Sleep-related key findings: • Improved pain interference with sleep ($p = 0.01$) • Participants reported improved sleep quality XR-related key findings: • Low levels of simulator sickness reported
Trahan et al. [50] United States	VR	B: Not described M: Not described CA: Yes	C: Not described S: Not described CA: Yes	F: 3/week for 4 weeks T: 12–15 minutes I: Provided tutorial on use within VR environment. Participant asked to walk around VR grocery store	Sleep-related outcome measures: Pittsburgh sleep quality index	Sleep-related findings: • Overall global Pittsburgh sleep quality index improved from 10 to 6

Table 3. Continued

Author (year) country	AR/ VR/ MR	Hardware B: Brand M: Model CA: Commercial availability	Software C: Company S: Software CA: Commercial availability	XR-related intervention details F: Frequency T: Time I: Intervention	Sleep- and XR-related outcome measures	Sleep-related findings
Ulas and Semin [51] Turkey	VR	B: Samsung M: Gear VR CA: Not described	C: Not described S: Not described CA: Not described	F: 3/week for 8 weeks T: 30 minutes I: Moderate (self-monitored via modified Borg scale) aerobic activity consisting of step aerobics, sit-to-stand, sit, and reach	Sleep-related outcome measures: Pittsburgh sleep quality index	Sleep-related key findings: • Sleep quality improved in both traditional exercise and VR exercise groups (not significantly in VR group).
Zhang et al. [52] China	VR	B: Not described M: Not described CA: Not described	C: Not described S: VR-CALM CA: Not described	F: 6 sessions over 3 months T: 30 minutes I: Patients immersed in beautiful interactive environment with audio and visual qualities. Intermittent guidance provided by experience.	Sleep-related outcome measures: Pittsburgh sleep quality index	Sleep-related key findings: • Participants had significant improvements in Pittsburgh sleep quality index scores.
Cumpanas et al. [66] Romania	VR	B: da Vinci M: da Vinci Xi CA: Not described	C: da Vinci S: Not described CA: Not described	F: 2 × single sessions (1 × sleep deprived, 1 × rested) T: Varied, not restricted I: Completion of 3 tasks of increasing difficulty (peg board, energy dissection, suture sponge) within the surgical simulator under sleep-deprived and later well-rested conditions.	**XR-related outcomes measures:** • Time to complete • Economy of motion • Instrument collizion • Excessive force • Instruments out of view • Drops • Master workspace	**Sleep-related key findings:** • Sleep deprivation leads to impaired surgical skills within a robotic virtual simulator. The more complex the task the greater difference between sleep-deprived and rested conditions
Picard et al. [54] Canada	VR	B: HTC M: VIVE room-scale CA: Not described	C: Designed and programmed “in-house” S: Designed and programmed “in-house” CA: Not described	F: 2 × sessions (single day) T: VR lasting ~1 minute per session I: Sessions separated by 5 various sleep/wake conditions determined through randomization. VR experience consisted of flying experience requiring participants to hit green circles whilst avoiding red circles	Sleep-related outcome measures: • Polysomnography • Dream logs XR-related outcome measures: • Time to complete VR task	Sleep-related key findings: • Learning benefits most from targeted motor reactivation when applied in rapid eye movement sleep.
Picard-Deland and Nielson [55] Canada	VR	B: HTC M: VIVE room-scale CA: Not described	C: Designed and programmed “in-house” S: Designed and programmed “in-house” CA: Not described	F: 2 × sessions (single day) T: VR lasting ~15 minutes per session I: Sessions are separated by five various sleep/wake conditions determined through randomization. VR experience consisted of flying experience where the scenery changed	Sleep-related outcome measures: • Dream logs	Sleep-related key findings: • Targeted memory reactivations have a delayed effect on task dream reactivations
Pilly et al. [56] United States	VR	B: HTC M: VIVE CA: Not described	C: Self-designed experiences S: Self-designed experiences CA: Not described	F: 3 sessions (1 orientation 2 testing) T: Approximately 14 minutes I: Individuals were asked to look at VR environments under various electrical stimulation/sham stimulation conditions.	Sleep-related outcome measures: • Memory performance following electrical stimulation applied during sleep. Sleep characteristics were measured utilizing polysomnography.	Sleep-related key findings: • Transcranial electrical stimulation applied as brief pulses during slow wave oscillations improves metamemory of targeted episodes at 48 hours
Rashid-Izullah et al. [57] Finland	VR	B: Not described M: Not described CA: Not described	C: Not described S: NeuroCar driving simulation CA: Not described	F: Single session T: 20 minutes I: Sleep deprivation group was not allowed to sleep or drink caffeine the night prior to testing. Participants drove within simulation while responding to auditory or visual information by pressing the corresponding button.	XR-related outcome measures: • Lane border crossings • Correct responses • Reaction times • Erroneous response • Response omissions	Sleep-related key findings: • Sleep deprivation significantly increased the number of lane border crossings. • Age and sleep deprivation together increased the number of response omissions.

Table 3. Continued

Author (year) country	AR/ VR/ MR	Hardware B: Brand M: Model CA: Commercial availability	Software C: Company S: Software CA: Commercial availability	XR-related intervention details F: Frequency T: Time I: Intervention	Sleep- and XR-related outcome measures	Sleep-related findings
Ribeiro et al. [58] France	VR	B: HTC head-mounted display connected to an HP Zbook 17 G3 with Intel Core i7, 8GB RAM, and an NVIDIA Quadro M5000M graphic card. M: Vive room-scale CA: Not described	C: Not described S: Associative and Spatialized Memory Room (ASMR) CA: Not described	F: Single testing episode T: Not described I: Participants navigated a recall task within a VR environment	Sleep-related outcome measures: • Dream report	Sleep-related key findings: • A full night sleep in a home setting provided a protective effect on associative and relational memory performance.
Rothacher et al. [59] Switzerland	VR	B: Meta (Meta) M: Meta DK2 CA: Not described	C: Not described S: Not described CA: Yes (link to software provided)	F: Single session I: Virtual reality redirected walking task	Sleep-related outcome measures: • Electroencephalogram	Sleep-related key findings: • No significant interaction between the study groups and conditions
Shimizu et al.[61] United States	VR	B: Meta M: DK2 CA: Not described	C: Intific, Inc. S: Custom-built VR navigation task CA: Not described	F: Testing procedure is undertaken over three days. T: Not described I: Virtual reality navigation task utilized as a testing paradigm to enable the testing of participants memory under various wake/sleep and memory reactivation conditions. Participants were provided with introduction session	Sleep-related outcome measures: • Electroencephalogram • Electrooculogram • Electromyogram (mastoid sites) XR-related outcome measures: • Time to navigation task in VR	Sleep-related key findings: • Sensory stimulation during down-state to up-state transitions in REM sleep improve performance in a realistic navigation task within VR
Solomonova et al.[62] Canada	VR	B: Cybermind M: 900st CA: Not described	C: Software designed "in house" S: VR maze task CA: Not described	F: Single testing episode T: Average time to complete maze task 23.3 minutes ±8.2, range 8.7–43 I: Participants were randomly assigned to navigate a maze in VR	Sleep-related outcome measures: • 10 daydream journals • Dream locus on control	Sleep-related key findings: • Laboratory and VR experiences showed independent and opposite temporal incorporation patterns. Different incorporation patterns may reflect separate underlying processes of memory consolidation.

Abbreviations: XR, extended reality; VR, virtual reality; AR, augmented reality; B, brand; M, model; CA, commercial availability; S, software; C, company; F, frequency; T, time; I, intervention.

put on and take off the equipment quickly and independently [60] whilst still using their normal glasses [60]. Clinicians should be aware that technical difficulties [46] and cybersickness [39] can negatively impact on the patient experience and potential effectiveness and take actions to ensure that they are competent in the utilization of XR as a clinical tool.

Types of hardware and software within sleep medicine.

A variety of XR brands and models are currently utilized within the literature. The majority of these devices have now been superseded by new hardware from manufacturers such as HTC, PICO, and Meta. Characteristics of the head-mounted displays have significant implications in terms of reducing cybersickness [20] and epilepsy risk [18] It is therefore important that this is considered when clinicians and researchers attempt to evaluate the literature.

Future directions.

The ability of extended reality to influence factors such as pain and anxiety which otherwise complicate the management of patients with sleep disorders and comorbid neuropsychiatric and chronic pain conditions presents new opportunities to sleep

Table 4. Reporting Quality of Interventions According to TIDieR Checklist

TIDieR checklist		Variables	
		No. of articles	% of articles
1. Do the authors provide the name or a phrase that describes the intervention?	Yes, complete	19	100
	Yes, incomplete	0	0
	No	0	0
2. Do the authors describe any rationale, theory, or goal of the elements essential to the intervention?	Yes, complete	18	95
	Yes, incomplete	1	5
	No	0	0
3. Materials: Do the authors describe any physical or informational materials used in the intervention, including those provided to participants or used in intervention delivery or in training of providers, or provide information on where the materials can be accessed (online appendix or URL)?	Yes, complete	3	16
	Yes, incomplete	15	79
	No	1	5
4. Procedures: Do the authors describe each of the procedures, activities, and/or processes used in the intervention, including any enabling or support activities?	Yes, complete	5	28
	Yes, incomplete	12	63
	No	2	11
5. For each category of intervention provider (psychologist and nursing assistant), describe their expertise, background, and any specific training given?	Yes, complete	2	11
	Yes, incomplete	2	11
	No	15	79
6. Do the authors describe the modes of delivery (face-to-face or by some mechanism, such as internet or telephone) of the intervention and whether it was provided individually or in a group?	Yes, complete	16	84
	Yes, incomplete	1	5
	No	2	11
7. Do the authors describe the type(s) of location(s) where the intervention occurred, including any necessary infrastructure or relevant features?	Yes, complete	9	47
	Yes, incomplete	7	37
	No	3	16
8. Do the authors describe the number of times the intervention was delivered and over what period of time including the number of sessions, their schedule, and their duration, intensity, or dose?	Yes, complete	14	74
	Yes, incomplete	4	21
	No	1	5
9. If the intervention was planned to be personalized, titrated, or adapted, do the authors mention so and then describe what, why, when, and how?	Yes, complete	4	21
	Yes, incomplete	2	11
	No	3	16
	N/A	10	53
10. Do the authors mention if the intervention was modified during the course of the study, and if so, describe the changes (what, why, when, and how)?	Yes, complete	2	11
	Yes, incomplete	0	0
	No	3	16
	N/A	14	74
11. Planned: If intervention adherence or fidelity was assessed, do they describe how and by whom, and if any strategies were used to maintain or improve fidelity, did the authors describe them?	Yes, complete	7	37
	Yes, incomplete	0	0
	No	2	11
	N/A	10	53
12. (If above answer was yes) Actual: If intervention adherence or fidelity was assessed, did the authors describe the extent to which the intervention was delivered as planned?	Yes, complete	5	26
	Yes, incomplete	0	0
	No	2	11
	N/A	12	63

physicians. Further research is required to understand if XR is useful during the set-up of diagnostic sleep studies to decrease anxiety, improve compliance, and ultimately the success rate and quality of diagnostic testing. Additionally, gamified experiences which provide fun and interactive visual cues for inspiration and exhalation may assist children with neurodevelopmental disorders to tolerate positive airway pressure titration studies and improve compliance.

A range of experiences, which scaffold the development of skills such as relaxation and mindfulness in combination with experiences designed to provide important education could be created to widespread affordable age appropriate and

Table 5. Details Relating to Exclusion Criteria, Safety, Barriers, and Facilitators

Selected exclusion criteria useful in the consideration of the development of future screening protocols	Medical history	• History of epilepsy [40–42], or seizure disorder [60], seizure [63], or photo-sensitive epilepsy [58] • Migraines [40–42]. • Neurological diseases preventing the use of VR or predisposing the user to adverse effects [40–42]
	Active medical conditions	• Gross cognitive impairment [40–42] • Dementia [20, 40, 41] • Delirium [46] • Thalamic stroke [47] • Traumatic brain injury [47] • Intubated [24, 46] • Sedated [24]
Selected safety protocols useful in the consideration of future safety protocols	Cleaning and infection control	• Hardware disinfected [60] or sterilized with alcohol [48] and/or ultraviolet light [46] • Use of disposable sanitary covers for soft surfaces (e.g., face cushions, headphones) [46]
	Software Considerations:	• Content designed to minimize emotional distress and cybersickness [42]
	Intervention considerations:	• Users are advised prior to use to cease if experiencing symptoms of cyber-sickness [58]
Selected barriers and facilitators to the use of extended reality technology	Barriers	• Motion sickness and nausea decreased use of VR [39] • Head-mounted displays are not comfortable to sleep in [44] and heavy [24] • Technical and procedural difficulties can contribute to patient frustration [46] • Applications requiring the user to stand, walk, or rotate to fully engage with the experience is potentially unsafe or uncomfortable for ICU patients [46]
	Facilitators	Facilitating factors related to the use of extended reality equipment: • Easily implemented infection control procedures [46] • Head-mounted displays are easy to use and comfortable [67] • Patients able to don (within 45 seconds) and doff (within 10 seconds) head-mounted displays independently [60] • Users able to wear glasses during intervention [60] • Simple and easy-to-adopt interventions [52] • Well accepted [67, 68] and tolerated by patients with high = patient satisfaction [43] and only rare instances of mild cybersickness [49, 67] • Limited barriers to adherence [68] • VR therapy is less restrictive in that it does not require a specialized environment to undertake relaxation-based therapy [48] or exposure therapy [50] • VR allows for customized experiences which can be tailored to satisfy the individual requirements of individual users [46, 48] • Offers the option to produce and distribute identical standard simulated environments without the need for costly mock-ups of functional environments [56] • Allows for the occlusion of visual input relating to the surrounding physical environment [51]

engaging sleep interventions based on the principles of cognitive behavior therapy for insomnia (CBT-I) [70, 71]. Additionally, VR provides an opportunity to potentially assist in reorientating patients in intensive care to night and day whilst reducing anxiety and pain to facilitate improved sleep. The effectiveness of such interventions, however, is likely to be dependent on sound clinical reasoning and an understanding of both sleep disorders and XR interventions [34]. To assist in developing an understanding of the way in which XR interventions affect sleep sham studies and randomized control studies which compare both immersive 360 experiences with less with less immersive XR are required. Additionally, it is important therefore that researchers' description of interventions goes beyond stating hardware and software details to further describe how the intervention was undertaken. Use of reporting templates such as the TIDieR checklist [34] may be useful for researchers in future to ensure that interventions are adequately reported (Table 4) and are able to be easily translated into clinical practice. No cost analysis was identified within this scoping review. Moving forward it is important that the economic feasibility of sleep interventions is confirmed to enable its integration into healthcare models.

Limitations

Varied and at times contradictory findings prevent strong conclusions to inform policy and clinical practice from being drawn at this time. This is partially due to the diverse nature of patient populations and interventions identified within this scoping review. Additionally, only one article investigated sleep as a primary outcome. Reporting of research methods were at times flawed and methods inadequately reported. Clinicians and researchers should therefore utilize the findings in addition to their own strong clinical reasoning when designing interventions and research protocols.

Conclusion

The ability to modify and improve sleep is increasingly being recognized as important to improve health outcomes. Specialists continue to explore potential novel methods that may help to improve sleep quality and quantity for patients. Preliminary research suggesting XR may improve sleep in some adult populations posits XR as a potentially attractive option for clinicians and patients in the future. However, these fields remain in their infancy. Currently, a lack of research that has investigated the impact of light (intensity and wavelength) from VR devices as well as exposure conditions (duration, timing) on sleep latency and quality. Additionally, a lack of clinical trials designed specifically to improve sleep characteristics and outcomes in combination with a lack of pediatric research significantly limits the translation of research to practice. To progress further, clinicians and researchers should identify areas where the use of XR may assist in improving patient experience and increasing access to affordable treatment. This will assist in the development and careful design of new targeted approaches and clinical trials aimed at improving sleep for patient-specific populations. A close collaboration between clinicians, researchers, and industry partners will ensure current gaps in evidence and understanding are overcome as quickly and efficiently as possible.

Supplementary Material

Supplementary material is available at *SLEEP* online.

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Conflict of Interest

No financial or nonfinancial benefits have been received or will be received from any party related directly or indirectly to the participant of this article.

Author contributions

AG was involved in the conceptualization, protocol development, data extraction, data analysis, and manuscript drafting and editing. JC provided significant contributions to the data analysis, drafting, and editing of the manuscript. JB provided significant contributions to the protocol development, data extraction, data analysis, and manuscript drafting and editing. OB provided significant contributions to the protocol development, data extraction, data analysis, and manuscript drafting and editing. SG was involved in the conceptualization, protocol development, data extraction, data analysis, and manuscript drafting and editing.

Data Availability

No new data were generated or analyzed in support of this research.

References

1. Wittkopf PG, Lloyd DM, Coe O, Yacoobali S, Billington J. The effect of interactive virtual reality on pain perception: a systematic review of clinical studies. *Disabil Rehabil*. 2020;**42**(26):3722–3733. doi: 10.1080/09638288.2019.1610803
2. Joda T, Gallucci GO, Wismeijer D, Zitzmann NU. Augmented and virtual reality in dental medicine: a systematic review. *Comput Biol Med*. 2019;**108**:93–100. doi: 10.1016/j.compbiomed.2019.03.012
3. Cieslik B, Mazurek J, Rutkowski S, Kiper P, Turolla A, Szczepanska-Gieracha J. Virtual reality in psychiatric disorders: a systematic review of reviews. *Complement Ther Med*. 2020;**52**:102480. doi: 10.1016/j.ctim.2020.102480
4. Zhao GJ, Fan MJ, Yuan YB, Zhao F, Huang HX. The comparison of teaching efficiency between virtual reality and traditional education in medical education: a systematic review and meta-analysis. *Ann Transl Med*. 2021;**9**(3):252. doi: 10.21037/atm-20-2785
5. Fobian AD, Rouse J, Stager LM, Long D, Schwebel DC, Avis KT. The effects of sleep deprivation and text messaging on pedestrian safety in university students. *Sleep*. 2020;**43**(9). doi: 10.1093/sleep/zsaa057
6. Scapin S, Echevarria-Guanilo ME, Boeira Fuculo Junior PR, Goncalves N, Rocha PK, Coimbra R. Virtual reality in the treatment of burn patients: a systematic review. *Burns*. 2018;**44**(6):1403–1416. doi: 10.1016/j.burns.2017.11.002
7. Beidel DC, Frueh BC, Neer SM, *et al*. Trauma management therapy with virtual-reality augmented exposure therapy for combat-related PTSD: a randomized controlled trial. *J Anxiety Disord*. 2019;**61**:64–74. doi: 10.1016/j.janxdis.2017.08.005
8. Valmaggia LR, Latif L, Kempton MJ, Rus-Calafell M. Virtual reality in the psychological treatment for mental health problems: an systematic review of recent evidence. *Psychiatry Res*. 2016;**236**:189–195. doi: 10.1016/j.psychres.2016.01.015
9. Mallari B, Spaeth EK, Goh H, Boyd BS. Virtual reality as an analgesic for acute and chronic pain in adults: a systematic review and meta-analysis. *J Pain Res*. 2019;**12**:2053–2085. doi: 10.2147/JPR.S200498
10. Baniasadi T, Ayyoubzadeh SM, Mohammadzadeh N. Challenges and practical considerations in applying virtual reality in medical education and treatment. *Oman Med J*. 2020;**35**(3):e125. doi: 10.5001/omj.2020.43
11. Rauschnabel PA, Felix R, Hinsch C, Shahab H, Alt F. What is XR? towards a framework for augmented and virtual reality. *Comput Hum Behav*. 2022;**133**:107289. doi: 10.1016/j.chb.2022.107289
12. Kardong-Edgren S, Farra SL, Alinier G, Young HM. A call to unify definitions of virtual reality. *Clin Simul Nurs*. 2019;**31**:28–34. doi: 10.1016/j.ecns.2019.02.006
13. Lopreiato JO. *Healthcare simulation dictionary*. Rockville, MD: Agency for Healthcare Research and Quality; 2016. doi: 10.23970/simulationv2
14. Ro YK, Brem A, Rauschnabel PA. Augmented reality smart glasses: Definition, concepts and impact on firm value creation. *Augmented reality and virtual reality*. Springer; 2018:169–181. doi: 10.1007/978-3-319-64027-3_12
15. Record EJ, Bumbut A, Shih S, Merwin S, Kroner B, Gaillard WD. Risk factors, etiologies, and comorbidities in urban pediatric epilepsy. *Epilepsy Behav*. 2021;**115**:107716. doi: 10.1016/j.yebeh.2020.107716
16. McDonald A, Joseph D. Paediatric neurodisability and sleep disorders: clinical pathways and management strategies. *BMJ Paediatr Open*. 2019;**3**(1):e000290. doi:10.1136/bmjpo-2018-000290

17. Fisher RS, Acharya JN, Baumer FM, *et al*. Visually sensitive seizures: an updated review by the Epilepsy Foundation. *Epilepsia*. 2022;**63**(4):739–768. doi: 10.1111/epi.17175
18. Tychsen L, Thio LL. Concern of photosensitive seizures evoked by 3D video displays or virtual reality headsets in children: current perspective. *Eye Brain*. 2020;**12**:45–48. doi: 10.2147/EB.S233195
19. Bockelman P, Lingum D. *Factors of cybersickness*. Springer; 2017:3–8. doi: 10.1007/978-3-319-58753-0_1
20. Caserman P, Garcia-Agundez A, Zerban AG, Gobel S. Cybersickness in current-generation virtual reality head-mounted displays: systematic review and outlook. *Virtual Real-London*. 2021;**25**(4):1153–1170. doi: 10.1007/s10055-021-00513-6
21. Harrington J, Headleand C. A somatic approach to combating cybersickness utilising airflow feedback. 2019:35–43. doi: 10.2312/cgvc.20191256
22. Cho Y, Ryu SH, Lee BR, Kim KH, Lee E, Choi J. Effects of artificial light at night on human health: a literature review of observational and experimental studies applied to exposure assessment. *Chronobiol Int*. 2015;**32**(9):1294–1310. doi: 10.3109/07420528.2015.1073158
23. de Zambotti M, Barresi G, Colrain IM, Baker FC. When sleep goes virtual: the potential of using virtual reality at bedtime to facilitate sleep. *Sleep.* 2020;**43**(12). doi: 10.1093/sleep/zsaa178
24. 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;**59**:102849. doi: 10.1016/j.iccn.2020.102849
25. Page MJ, McKenzie JE, Bossuyt PM, *et al*. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Syst Rev*. 2021;**10**(1):1–11.
26. Peters MDJ, Marnie C, Tricco AC, *et al*. Updated methodological guidance for the conduct of scoping reviews. *JBI Evid Synth*. 2020;**18**(10):2119–2126. doi: 10.11124/JBIES-20-00167
27. Clark JM, Sanders S, Carter M, *et al*. Improving the translation of search strategies using the polyglot search translator: a randomized controlled trial. *J Med Libr Assoc.* 2020;**108**(2):195–207. doi: 10.5195/jmla.2020.834
28. The Endnote Team. Version EndNote X9. Clarivate; 2013. https://endnote.com/
29. Clark J, Glasziou P, Del Mar C, Bannach-Brown A, Stehlik P, Scott AM. A full systematic review was completed in 2 weeks using automation tools: a case study. *J Clin Epidemiol.* 2020;**121**:81–90. doi: 10.1016/j.jclinepi.2020.01.008
30. Kellermeyer L, Harnke B, Knight S. Covidence and rayyan. *J Med Libr Assoc.* 2018;**106**(4):580–583. doi: 10.5195/jmla.2018.513
31. Cooper S, Cant R, Kelly M, *et al*. An evidence-based checklist for improving scoping review quality. *Clin Nurs Res.* 2021;**30**(3):230–240. doi: 10.1177/1054773819846024
32. Hong QN, Fabregues S, Bartlett G, *et al*. The Mixed Methods Appraisal Tool (MMAT) version 2018 for information professionals and researchers. *Educ Inform*. 2018;**34**(4):285–291. doi: 10.3233/Efi-180221
33. Tricco AC, Lillie E, Zarin W, *et al*. PRISMA Extension for Scoping Reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med*. 2018;**169**(7):467–473. doi: 10.7326/M18-0850
34. Hoffmann TC, Glasziou PP, Boutron I, *et al*. Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide. *BMJ.* 2014;**348**:g1687. doi: 10.1136/bmj.g1687
35. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics.* 1977;**33**(1):159–174.
36. Abd-Elsayed A, Hussain N, Stanley G. Combining virtual reality and behavioral health to promote pain resiliency: analysis of a novel biopsychosocial modality for solving pain in the workplace. *Pain Ther*. 2021;**10**(2):1731–1740. doi: 10.1007/s40122-021-00333-1
37. Borghese F, Henckaerts P, Guy F, *et al. Targeted memory reactivation during REM sleep in patients with social anxiety disorder*. 2022. doi: 10.3389/fpsyt.2022.904704
38. Cheng VY, Huang CM, Liao JY, *et al*. Combination of 3-dimensional virtual reality and hands-on aromatherapy in improving institutionalized older adults' psychological health: quasi-experimental study. *J Med Internet Res.* 2020;**22**(7):e17096. doi: 10.2196/17096
39. Darnall BD, Krishnamurthy P, Tsuei J, Minor JD. Self-administered skills-based virtual reality intervention for chronic pain: randomized controlled pilot study. *JMIR Form Res.* 2020;**4**(7):e17293. doi: 10.2196/17293
40. Garcia LM, Birckhead BJ, Krishnamurthy P, *et al*. An 8-week self-administered at-home behavioral skills-based virtual reality program for chronic low back pain: double-blind, randomized, placebo-controlled trial conducted during COVID-19. *J Med Internet Res.* 2021;**23**(2):e26292. doi: 10.2196/26292
41. Garcia LM, Birckhead BJ, Krishnamurthy P, *et al*. Three-month follow-up results of a double-blind, randomized placebo-controlled trial of 8-week self-administered at-home behavioral skills-based virtual reality (VR) for chronic low back pain. *J Pain.* 2022;**23**(5):822–840. doi: 10.1016/j.jpain.2021.12.002
42. Garcia L, Birckhead B, Krishnamurthy P, *et al*. Durability of the treatment effects of an 8-week self-administered home-based virtual reality program for chronic low back pain: 6-month follow-up study of a randomized clinical trial. *J Med Internet Res.* 2022;**24**(5):e37480. doi: 10.2196/37480
43. Glavare M, Stålnacke BM, Häger CK, Löfgren M. Virtual reality exercises in an interdisciplinary rehabilitation programme for persons with chronic neck pain: a feasibility study. *J Rehabil Med Clin Commun*. 2021;**4**:1000067. doi: 10.2340/20030711-1000067
44. Huang J, Ren L, Feng L, Yang F, Yang L, Yan K. AI empowered virtual reality integrated systems for sleep stage classification and quality enhancement. *IEEE Trans Neural Syst Rehabil Eng.* 2022;**30**:1494–1503. doi: 10.1109/TNSRE.2022.3178476
45. Kleim B, Wilhelm FH, Temp L, Margraf J, Wiederhold BK, Rasch B. Sleep enhances exposure therapy. *Psychol Med.* 2014;**44**(7):1511–1519. doi: 10.1017/S0033291713001748
46. Ong TL, Ruppert MM, Akbar M, *et al*. Improving the intensive care patient experience with virtual reality-a feasibility study. *Crit Care Explor*. 2020;**2**(6):e0122. doi: 10.1097/CCE.0000000000000122
47. Orakpo N, Vieux U, Castro-Nuñez C. Case report: virtual reality neurofeedback therapy as a novel modality for sustained analgesia in centralized pain syndromes. *Front Psychiatry.* 2021;**12**:660105. doi: 10.3389/fpsyt.2021.660105
48. Pan X, Zhang YC, Ren D, *et al*. Virtual reality in treatment for psychological problems in first-line health care professionals fighting COVID-19 pandemic: a case series. article in press. *J Nerv Ment Dis.* 2022;**210**(10):754–759. doi: 10.1097/NMD.0000000000001531
49. Park DH, Han SS, Han M, *et al*. A clinical trial of a patient-customized virtual reality intervention for tinnitus. *Sci Rep.* 2022;**12**(1):12441. doi: 10.1038/s41598-022-16764-5
50. Trahan MH, Morley RH, Nason EE, Rodrigues N, Huerta L, Metsis V. Virtual Reality exposure simulation for student veteran social anxiety and PTSD: a case study. *Clin Soc Work J*. 2021;**49**(2):220–230. doi: 10.1007/s10615-020-00784-7

51. Ulas K, Semin I. The biological and motivational effects of aerobic exercise with virtual reality. *Res Q Exerc Sport*. 2021;**92**(3):321–326. doi: 10.1080/02701367.2020.1729329
52. Zhang X, Yao S, Wang M, *et al*. The impact of VR-CALM intervention based on VR on psychological distress and symptom management in breast cancer survivors. Article. *J Oncol*. 2022;**2022**:1012813. doi: 10.1155/2022/1012813
53. Cumpanas AA, Ferician O, Lațcu S, Duță C, Bardan R, Lazăr FO. Does sleep deprivation alter virtual reality-based robotic surgical skills? *Wideochir Inne Tech Maloinwazyjne*. 2020;**15**(1):97–105. doi: 10.5114/wiitm.2019.90565
54. Picard-Deland C, Aumont T, Samson-Richer A, Paquette T, Nielsen T. Whole-body procedural learning benefits from targeted memory reactivation in REM sleep and task-related dreaming. *Neurobiol Learn Mem*. 2021;**183**:107460. doi: 10.1016/j.nlm.2021.107460
55. Picard-Deland C, Nielsen T. Targeted memory reactivation has a sleep stage-specific delayed effect on dream content. *J Sleep Res*. 2022;**31**(1):e13391. doi: 10.1111/jsr.13391
56. Pilly PK, Skorheim SW, Hubbard RJ, *et al*. One-shot tagging during wake and cueing during sleep with spatiotemporal patterns of transcranial electrical stimulation can boost long-term metamemory of individual episodes in humans. *Front Neurosci*. 2019;**13**:1416. doi: 10.3389/fnins.2019.01416
57. Rashid Izullah F, Af Schulten A, Koivisto M, Nieminen V, Luimula M, H HA. Differential interactions of age and sleep deprivation in driving and spatial perception by male drivers in a virtual reality environment. *Scand J Psychol*. 2021;**62**(6):787–797. doi: 10.1111/sjop.12762
58. Ribeiro N, Gounden Y, Quaglino V. Enhancement of spatial memories at the associative and relational levels after a full night of sleep and likelihood of dream incorporation. Psychoanalytic Theory 3143. *Int J Dream Res*. 2021;**14**(1):67–79.
59. Rothacher Y, Nguyen A, Efthymiou E, *et al*. Dissociation of motor control from motor awareness in awake sleepwalkers: an EEG study in virtual reality. *Cortex*. 2022;**149**:165–172. doi: 10.1016/j.cortex.2021.12.016
60. Sarkar TD, Edwards RR, Baker N. The feasibility and effectiveness of virtual reality meditation on reducing chronic pain for older adults with knee osteoarthritis. *Pain Pract*. 2022;**22**(7):631–641. doi: 10.1111/papr.13144
61. Shimizu RE, Connolly PM, Cellini N, *et al*. Closed-loop targeted memory reactivation during sleep improves spatial navigation. *Front Hum Neurosci*. 2018;**12**:28. doi: 10.3389/fnhum.2018.00028
62. Solomonova E, Stenstrom P, Paquette T, Nielsen T. Different temporal patterns of memory incorporations into dreams for laboratory and virtual reality experiences: Relation to dreamed locus of control. Consciousness States 2380. *Int J Dream Res*. 2015;**8**(1):10–26.
63. Birckhead B, Eberlein S, Alvarez G, *et al*. Home-based virtual reality for chronic pain: protocol for an NIH-supported randomised-controlled trial. *BMJ Open*. 2021;**11**(6):e050545. doi: 10.1136/bmjopen-2021-050545
64. Glavare M, Stalnacke BM, Hager CK, Lofgren M. Virtual reality exercises in an interdisciplinary rehabilitation programme for persons with chronic neck pain: a feasibility study. *J Rehabil Med Clin Commun*. 2021;**4**:1000067. doi: 10.2340/20030711-1000067
65. Orakpo N, Vieux U, Castro-Nunez C. Case report: virtual reality neurofeedback therapy as a novel modality for sustained analgesia in centralized pain syndromes. specialized interventions 3350. *Front Psychiatry*. 2021;**12**:660105. doi: 10.3389/fpsyt.2021.660105
66. Cumpanas AA, Ferician O, Latcu S, Duta C, Bardan R, Lazar FO. Does sleep deprivation alter virtual reality-based robotic surgical skills? *Wideochir Inne Tech Maloinwazyjne*. 2020;**15**(1):97–105. doi: 10.5114/wiitm.2019.90565
67. Hill JE, Twamley J, Breed H, *et al*. Scoping review of the use of virtual reality in intensive care units. *Nurs Crit Care*. 2022;**27**(6):756–771. doi: 10.1111/nicc.12732
68. Abd-Elsayed A, Hussain N, Stanley G. Combining virtual reality and behavioral health to promote pain resiliency: analysis of a novel biopsychosocial modality for solving pain in the workplace. *Pain Therapy*. 2021;**10**(2):1731–1740. doi: 10.1007/s40122-021-00333-1
69. StreetWizeVR. Virtual Road Safety Training. https://www.streetwizevr.com/.Accessed January 16, 2023.
70. Levac DE, Galvin J. When is virtual reality “therapy?”. *Arch Phys Med Rehabil*. 2013;**94**(4):795–798. doi: 10.1016/j.apmr.2012.10.021
71. Vincent C, Eberts M, Naik T, Gulick V, O’Hayer CV. Provider experiences of virtual reality in clinical treatment. *PLoS One*. 2021;**16**(10):e0259364. doi: 10.1371/journal.pone.0259364