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REVIEW PAPER

Extended reality in rehabilitation: innovative or just an illusion? A scoping review of interventions for complex regional pain syndrome

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Abstract

Purpose Extended reality (XR) technologies, incorporating virtual and augmented reality, are increasingly being explored as potential adjuncts in the management of complex regional pain syndrome (CRPS). However, the appropriateness of these interventions in terms of their alignment with CRPS symptomatology, patient experiences, and rehabilitation principles remains unclear. This scoping review aimed to critically examine the current approaches used in XR-based rehabilitation for CRPS and assess their suitability for managing this condition.

Methods A systematic search was conducted in several health databases for articles describing the use of XR for management of people with CRPS. Data were extracted on study characteristics and intervention details, and the intervention was critiqued using a custom framework designed to evaluate the incorporation of rehabilitation principles.

Results Sixteen studies met the inclusion criteria. There was considerable diversity in study methodologies, participant characteristics, and technological approaches. All studies provided appropriate theoretical justifications of their intervention and were suitable for clinical use, while most showed potential for CRPS symptom reduction. However, there were significant gaps in the interventions related to fostering independence, feasibility of home use, potential for progression, and cultural considerations.

Conclusions XR interventions show promise in certain aspects of CRPS management but opportunities exist for more comprehensive intervention delivery formats that address key rehabilitation principles. Future development and evaluation studies should place greater emphasis on fostering independent use, integration of user feedback, and overtly incorporate cultural considerations.

Keywords Extended reality · Rehabilitation · Complex regional pain syndrome · Virtual reality

1 Introduction

Complex regional pain syndrome (CRPS) is a chronic and debilitating pain condition primarily impacting the limbs. The pathophysiology of CRPS is not completely understood; however, it is associated with a dysfunction of both central and peripheral nervous systems as well as neuro-immune mechanisms. It presents with a constellation of symptoms including heightened sensitivity to noxious stimuli (hyperalgesia), pain from non-noxious stimuli (allodynia), oedema and vasomotor instability, motor disturbances, and psychological sequalae such as negative affect, kinesiophobia, and catastrophising [1–3]. Additionally, people with CRPS often have body perception disturbances (BPD) whereby the individual mis-perceives the affected body part, leading to feelings of detachment or alienation from the affected limb [4, 5]. Together, these symptoms can profoundly impact quality of life and result in substantial activity limitations [5, 6].

Treatment for CRPS typically adopts a multidisciplinary approach, including pharmacotherapy, physical therapy, occupational therapy, and psychological therapy [7]. Specific therapeutic modalities such as graded motor imagery [8], graded exposure [9], and pain exposure physical therapy

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[10] have shown benefits. However, there are currently no universal or gold standard treatments for CRPS, primarily due to the heterogenous presentation of the disease, the complexity of multiple systems involved, and the limited quality of evidence currently available for any treatments [11].

Virtual reality technologies allow users to experience and interact with virtual environments, creating the potential for users to engage in tasks that are more controllable, more engaging, or not possible in the real world. The incorporation of additional tools can provide sensory feedback or may enable capture of whole body or segmental movement. These extended reality (XR) technologies, incorporating both virtual and augmented reality, have shown promising results in the management of several chronic pain conditions [12–16]. The body perception disturbances, allodynia, and kinesiophobia associated with CRPS may make it well suited to XR-based rehabilitation. However, while several systematic reviews show that XR-based interventions show promise for CRPS rehabilitation [16–18], the current body of research is limited by small sample sizes, inadequate description of interventions, and a lack of appropriate controls. A further concern regarding the implementation of XR therapy is the issue of equitable access to treatment, particularly for marginalised and underserved populations. The decreasing cost, increasing quality, and improving accessibility of XR technologies facilitates broader application in clinical settings [19, 20] but there remains a need to promote equity of access and outcomes. Additionally, XR-based rehabilitation interventions in other fields have frequently been developed without adequately considering end-user input or established therapeutic protocols [21–23]. This approach has the potential to develop technologies that, while innovative, may not fully align with the complex needs of patients or integrate seamlessly with existing treatment paradigms. In support of this, the use of XR in healthcare has previously been described as favouring engaging technology at the expense of rehabilitation theory [24]. This technological-centric approach potentially limits the validity, applicability, and overall effectiveness of XR interventions.

The objective of this scoping review was to critically examine the current approaches used in XR-based rehabilitation for CRPS to assess their suitability for managing CRPS-related symptoms. Specifically, we aimed to evaluate the extent to which existing research integrates clinical and theoretical perspectives in the development of XR tools, aiming to contribute to the existing literature by identifying gaps, synthesising recent findings, and providing insights needed for further high-quality research in the use of XR for CRPS rehabilitation.

2 Methods

This scoping review was conducted and reported in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews (PRISMA-ScR) statement [25] along with guidance from Peters et al. [26]. A scoping review was chosen for its flexibility in handling broad research inquiries and its ability to accommodate various study designs. Given the relatively understudied nature of this specific field, much of the available literature remains in the pilot stage. Additionally, the scoping review method is valuable in situations where the existing literature may have limitations, as it does not involve a critiquing element. This aspect is particularly pertinent considering the challenges associated with the current quality of available research. The review authors included physiotherapists (CW, NS), a health psychologist with clinical experience in managing CRPS (DB), and experienced pain researchers (GL, DB).

2.1 Search strategy

A systematic search was conducted on February 12, 2025, utilising EBSCO (Medline, CINHAL, SportDiscus), Ovid (Medline, Allied and Complementary Medicine, PsychInfo), and Scopus databases. The search strategy consisted of the following terms:

("virtual reality" OR "augmented reality" OR "extended reality" OR "mixed reality" OR immersi* OR "virtual body" OR "virtual rehab*" OR "artificial reality" OR "virtual technology" OR simulat* OR "head mounted display")

AND

("complex regional pain syndrome" OR CRPS OR "reflex sympathetic dystrophy" OR causalgia).

2.2 Study selection

The study selection process was conducted in two stages. Initially, titles and abstracts were screened by one author and irrelevant articles excluded. Full texts of the remaining articles were then screened by two authors independently. Any disagreements on inclusion were resolved through discussion and, where consensus could not be reached, a third author made the final decision.

The articles were required to be quantitative or qualitative studies that examined a XR intervention designed for management of CRPS symptoms. All types of primary study designs were considered, including prototypes and feasibility studies. Studies were additionally required to be published in English and have full text available. Studies were excluded if they use XR for distraction or relaxation purposes rather than in a rehabilitative context.

2.3 Data extraction

Following study selection, relevant data were extracted from each study and entered into an Excel spreadsheet. Extracted information included publication details (title, year of publication, study design), participant details (age, sex, ethnicity, diagnosis), intervention details (type of XR, hardware, software), and any outcome measures used.

2.4 Critical appraisal

The primary focus of this review was to evaluate the appropriateness of XR interventions for CRPS rehabilitation. To achieve this objective, an evaluation framework was developed that provides a comprehensive evaluation across seven key domains: justification, clinical efficacy, user experience, functional progression, fostering independence, home use, clinical integration, and cultural consideration (Table 1). The evaluation framework allowed for the analysis of each intervention's strengths and limitations in addressing the complex needs of people with CRPS in a way that aligns with rehabilitation principles. While these domains are not derived from a pre-existing validated tool, they were identified from previous reviews as reflecting important components of CRPS management and rehabilitation technology implementation [17, 24, 27].

Two authors independently assessed each article using the evaluation framework. Any disagreements on inclusion were resolved through discussion and, where consensus could not be reached, a third author made the final decision.

Table 1 Assessment framework for appropriateness of the interventions

Domain	Criteria
Justification of XR treatment	Clear theoretical framework based on CRPS pathophysiology, integration of established rehabilitation principles, consideration of specific CRPS symptoms in intervention design, or rationale for the chosen XR modality
Evidence of clinical efficacy	Evidence of a meaningful improvement in a relevant outcome, e.g. pain intensity, emotional distress, body perception disturbances, physical function, oedema or vasomotor disturbances, quality of life
Positive user experience or evidence for acceptability	Reported positive user experience, enjoyment, or engagement with the intervention; low dropout rates due to discomfort or dissatisfaction
Feasible for clinical environment	Reported effective and safe integration into clinical practice, compatible with existing clinical workflow and infrastructure, low clinician training requirement, or consideration of cost-effectiveness
Feasible for home use	Use of commercially available, low cost, easily accessible equipment, or potential for effective and safe integration into a home rehabilitation programme
Potential for treatment progression	Incorporated or described protocols for adapting intervention difficulty or complexity over time, such as increasing task complexity or introducing novel movement patterns
Potential to foster independence and self-efficacy	Potential for self-administered exercises or interventions and a reduction in reliance on therapist-led interventions over time
Cultural consideration	Inclusion of diverse patient populations, consideration of cultural beliefs or practices in intervention design, language accessibility, modifiable physical characteristics, or acknowledgment of potential cultural barriers to XR use

XR extended reality; *CRPS* complex regional pain syndrome

3 Results

The initial database search yielded 458 records (Fig. 1). After removing 178 duplicates, 280 unique records were screened based on their titles and abstracts. This screening process resulted in the exclusion of 258 records that did not meet the inclusion criteria. The remaining 22 full-text articles were assessed for eligibility, leading to the exclusion of 7 further articles. One additional article was found through citation tracking, leaving 16 articles for inclusion in the final synthesis.

3.1 Characteristics of the studies

A summary of the study characteristics is shown in Table 2. The 15 studies encompassed a diverse array of study designs, including randomised trials [28–30], uncontrolled studies [31–35], case studies or series [36–39], and developmental studies yet to be implemented with clinical populations [32, 40, 41]. Sample sizes ranged from a single case study [39] to a cohort of 45 participants with CRPS [28]. Most studies focused on adult populations with unilateral upper limb CRPS, although some included lower limb and bilateral cases [29, 33, 36] and one study included adolescents from 13 to 17 years [37]. Two studies involved piloting the XR intervention with healthy participants [32, 40] and one described the system without involvement of any participants [41].

Most studies that included participants with CRPS adhered to formal diagnostic criteria for inclusion, such as the Budapest Criteria [3]. However, detailed demographic information was often limited and no studies provided data on participants' ethnicity. Age and sex were more commonly reported, with a tendency towards a higher proportion of female participants (63%).

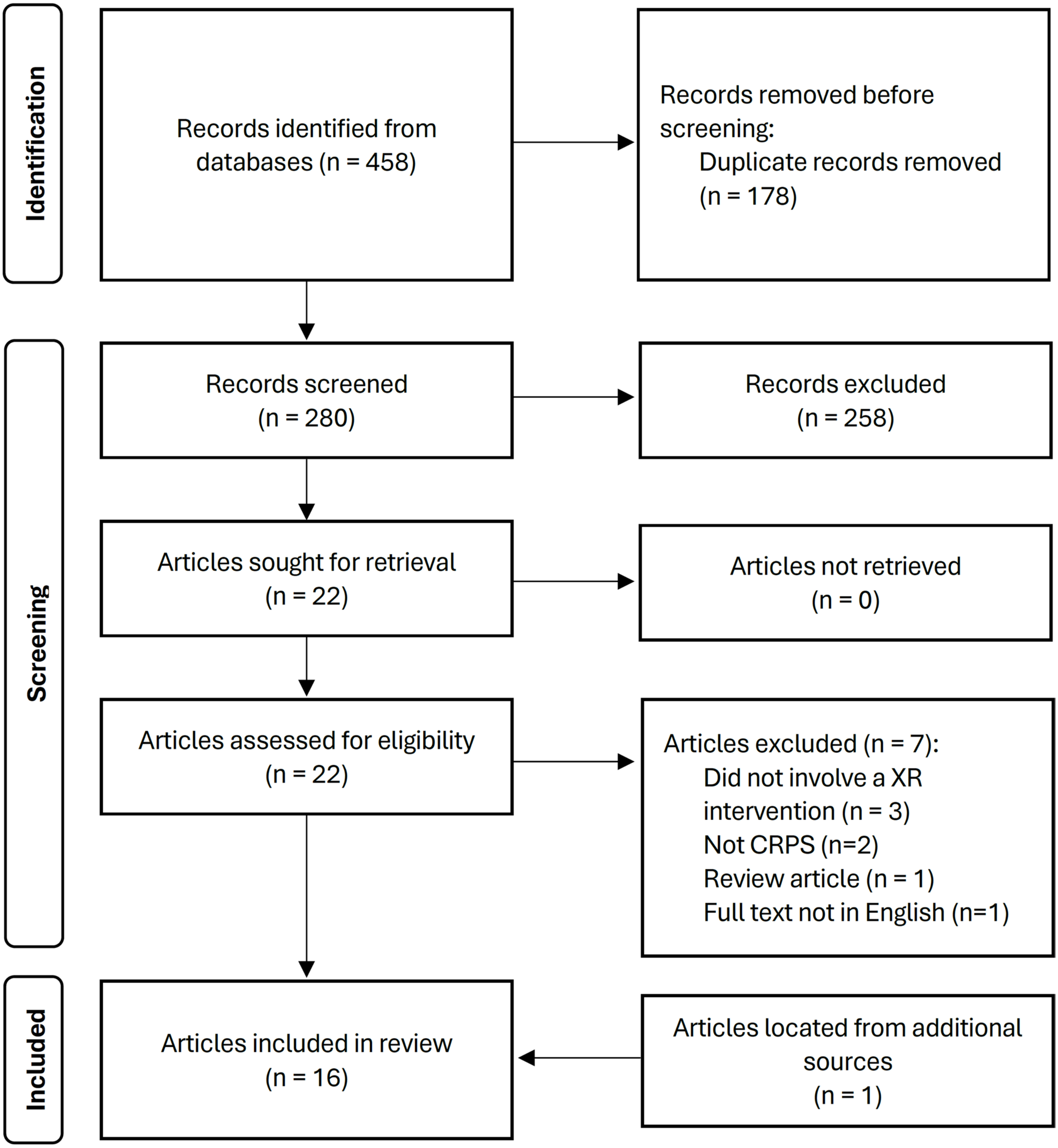

Fig. 1 PRISMA flow diagram showing selection of the final articles. XR = extended reality; CRPS = complex regional pain syndrome.

3.2 Characteristics of the interventions

The interventions varied significantly in their approach and technological implementation. Fully immersive virtual reality (VR) systems were prevalent, with multiple studies using commercially available head mounted displays (HMDs) [30, 31, 33, 34, 39, 43]. Most studies that used commercially available hardware also used commercially available software. However, some studies incorporated custom software or video recordings [29, 30, 33, 37, 40], or integrated the devices with additional hardware [29, 30, 32, 34, 37, 40]. Non-immersive approaches were also explored, particularly in earlier studies, which utilised desktop-based systems with input devices such as gloves and joysticks [36, 41].

Table 2 Characteristics of the included studies

Study	Study design	Participants (population, *n*, % female, age range)	XR system hardware	XR system software	Intervention	Outcome measures
Chau 2020 [31]	Uncontrolled experimental study	CRPS, 8, 88%, 15–61 yrs	Immersive commercial VR system (HMD, 2 handheld motion controllers, 2 tripod-mounted base stations), VR capable computer with monitor	Commercial software with 2 virtual kitchen simulations, able to mirror hand movements & adjust limb characteristics	Virtual object manipulation through tasks representative of daily activities, guided visualisation exercises	SFMPQ, pain VAS, Wong-Baker Faces, user comments
Diers 2015 [32]	Uncontrolled experimental study	Healthy, 20, 75%, 23–53 yrs	Immersive commercial MRI-compatible HMD, custom fibreglass data glove	Commercial software to provide virtual mirror box system	Unilateral hand movements paced by auditory cue, display presented bilateral virtual hand movement	Vividness, illusion authenticity, brain blood flow
Feintuch 2009 [41]	System development	NA	Non-immersive system with commercial flat screen, laptop with webcam, mouse, trackball, joystick, blue background, white robe, black sleeveless vest	Custom programming using commercial software, altered movement gain	Provided image of self in virtual environment, control virtual arm while undertaking 3 unilateral upper limb games	NA
Harvie 2022 [39]	Case report	Neuropathic pain, 1, 0%, 43 yrs	Immersive commercial HMD with hand tracking technology, tablet	Commercial software with inbuilt scenarios	Self-guided virtual exposure of hand to hierarchy of visual stimuli	Time to pain, pain intensity, fear, expectation of pain, BPD, kinesiophobia, physical function, GPE, ownership
Holly 2017 [38]	Case series	CRPS & PTSD & post-concussion syndrome, 3, NA, NA	Commercial system with room-size 3D monitors, moving platform, remote-controlled treadmill, motion analysis system, harness	Custom programming of commercial software	Graded exposure to virtual sensory triggers, coaching to consciously control autonomic symptoms using specific breathing and relaxation techniques	Pain NRS, swelling, vertigo, sweating, lower extremity function, sleep, visual attention
Hwang 2014 [29]	Randomised experimental study	CRPS, 39, 30%, 32–48 yrs	Immersive commercial HMD, digital single-lens reflex camera, computer	Video clip, voice recording	Virtual body swapping - watched video of limb movements while mentally rehearsing same movements	Pain intensity, BPD
Jeon 2014 [33]	Uncontrolled experimental study	CRPS, 10, 0%, mean 39 yrs	Immersive commercial HMD	Video clip	Virtual body swapping - watched video of limb movements while mentally rehearsing same movements	Pain intensity, BPD, immersion ratings
Lewis 2021 [28]	RCT	CRPS, 45, 58%, 20–78 yrs	Non-immersive custom camera and mirror set-up, computer	Custom programming using commercial software to alter limb characteristics	Digitally altered desired shape, size, colour of the affected limb	Pain NRS, BPD, immersion ratings
Matamala-Gomez 2019 [34]	Uncontrolled experimental study	CRPS & peripheral nerve injury, 19, 74%, 40–55 yrs	Immersive commercial HMD, vibrators	Custom programming using commercial software to alter limb characteristics and integrate with vibrators	Virtual exposure to varying levels of hand transparency and size, synchronised vibrotactile stimulation of finger	Pain NRS, ownership ratings
Palmer 2014 [42]	Exploratory qualitative feedback study	CRPS, 10, NA, NA	NA	NA	Manipulation of position, surface texture, scale of body segments	Structured questionnaire on views and experiences of the device
Sato 2010 [36]	Uncontrolled pilot study	CRPS, 5, 80%, 46–74 yrs	Computer and monitor, commercial glove, commercial motion tracker	Custom programming using commercial software to provide mirror images	Virtual mirror visual feedback therapy	Pain VAS, informal user experience

Table 2 (continued)

Study	Study design	Participants (population, *n*, % female, age range)	XR system hardware	XR system software	Intervention	Outcome measures
Solca 2018 [30]	Cross-over trial	CRPS & healthy, 24 & 24, 58%, 23–71 yrs	Immersive commercial HMD, commercial ECG system	Custom software to alter limb characteristics and integrate with ECG system	Virtual hand illuminated synchronously with heartbeat	Pain VAS, embodiment, proprioceptive drift, grip strength, HRV
Trojan 2014 [40]	Pilot study	Healthy, 7, 86%, 22–53 years	Commercial VR HMD with integrated cameras, computer	Custom software to mirror upper limb	Several upper limb unilateral training task games mirrored to appear bilateral	Game performance indicators
Wilson 2018 [43]	Pilot study	Healthy, 30, NA, 18–40+yrs	Immersive commercial HMD, laptop, hand controllers	Custom programming using commercial software to provide mirrored hand images	Virtual balls thrown onto targets	System Usability Scale
Won 2015 [37]	Case series	CRPS, 4, 50%, 13–17 yrs	Immersive commercial HMD, head motion tracker, optical ankle trackers	Custom software to provide avatar images and games, integrated with audio and haptic feedback, altered movement gain	Lower and upper limb movement games involving avatar	Leg movement distance, user experience feedback
Won 2021 [35]	Uncontrolled experimental study	CRPS, 9, 67%, 19–60 yrs	Immersive commercial HMD, hand controller, laptop	Commercial software to provide avatar image and task game, integrated with audio feedback	Upper limb unilateral movement mirrored to appear bilateral	Pain, physical activity, mood, sleep, cybersickness, usability feedback

CRPS=complex regional pain syndrome; SFMPQ=Short-Form McGill Pain Questionnaire; BPD=body perception disturbance; HMD=head mounted display; VR=virtual reality; VAS=visual analogue scale; NA=not available; PTSD=post-traumatic stress disorder; GPE=global perceived effect; RCT=randomized controlled trial; NRS=numerical rating scale; HRV=heart rate variability; ECG=electrocardiogram

Some studies introduced novel technological approaches. Solca et al. [30] developed a heartbeat-enhanced virtual reality system using a commercial headset integrated with electrocardiography signal acquisition, aiming to modulate pain perception through multisensory integration. Lewis et al. [28] diverged from the use of a HMD with a custom developed augmented reality system that allowed real-time digital alteration of the user's hand appearance, targeting body perception disturbances.

3.3 Outcome measures

Pain was an outcome in most studies, typically measured using a standardised visual analogue scale or numeric rating scale. Several studies also assessed aspects of physical function [30, 35, 37–39], body perception disturbance [28, 29, 33, 39], and immersion or embodiment [28, 30, 32–34, 39]. A handful of studies included assessments of psychosocial factors [35, 39], autonomic function [30, 38], sleep [35, 38], and motion sickness [35].

3.4 Criteria for appropriateness of rehabilitation

Table 3 provides a summary of the assessment framework for the 16 studies. All of the studies provided some type of theoretical justification for the XR intervention. The theoretical foundations included virtual adaptations of established therapeutic techniques (e.g., mirrored limb movements) [32, 35, 36, 40, 43], manipulation of body characteristics to address body perception disturbances [28, 34, 42], game-based movement tasks designed to enhance engagement and adherence [37, 41], and graded exposure to virtual visual and sensory stimuli [38, 39]. All systems were also deemed feasible for clinical use. This was largely due to the potential to integrate the system into existing clinical practice with minimal clinician training time. Probably the most complex system involved a moving platform, remote-controlled treadmill, and a room-sized motion analysis system [38]. However, it was a commercial system that came with support and safety features that were appropriate for clinical use. In contrast to the high level of clinical integration, only half of the interventions were assessed as being suitable for home use (n = 8, 50%). The main reasons for not meeting this criterion were the use of non-commercial systems or equipment that was not easily accessible. Studies that did meet the criteria commonly incorporated commercial HMDs with minimal additional hardware [29, 31, 33, 35, 39, 40, 43].

Half of the studies incorporated an assessment of user experience (n = 8, 50%), although all of these reported

Table 3 Summary of scores on the assessment framework

Study	Justification	Evidence of efficacy	Positive experience or acceptability	Feasible for clinical use	Feasible for home use	Enables progression	Fosters independence	Cultural considerations
Chau 2020	Y	Y	Y	Y	Y	Y	Y	Y
Diers 2015	Y	NA	NA	Y	N	N	Y	N
Feintuch 2009	Y	NA	NA	Y	Y	Y	N	Y
Harvie 2022	Y	N	Y	Y	Y	Y	Y	N
Holly 2017	Y	NA	NA	Y	N	Y	N	N
Hwang 2014	Y	Y	NA	Y	Y	N	N	N
Jeon 2014	Y	Y	NA	Y	Y	N	N	N
Lewis 2021	Y	Y	Y	Y	N	N	N	Y
Matamala-Gomez 2019	Y	Y	NA	Y	N	N	N	N
Palmer 2014	Y	Y	Y	Y	N	N	N	N
Sato 2010	Y	Y	Y	Y	N	Y	Y	N
Solca 2018	Y	Y	NA	Y	N	N	N	Y
Trojan 2014	Y	N	NA	Y	Y	Y	Y	N
Wilson 2018	Y	NA	Y	Y	Y	Y	Y	N
Won 2015	Y	NA	Y	Y	N	Y	N	N
Won 2021	Y	Y	Y	Y	Y	N	N	Y

Y yes; *N* no; *NA* not assessed

positive feedback from participants. Only one study used a validated questionnaire to assess experience [43], while none incorporated formal interviews or qualitative data specifically related to experience. Palmer et al. [42] used a "structured questionnaire" to obtain participant views and three studies [31, 36, 37] enabled participants to provide subjective reports that included comments about experience. Additionally, Won et al. [35] noted that all participants were keen to use the system at home, while two other studies demonstrated high levels of engagement [28, 39]. Most studies that evaluated efficacy of the intervention reported a meaningful improvement in at least one key outcome (n = 9/11, 82%), although two did not show any clinically meaningful change [39, 40]. One study did not provide any evidence of improvement following analysis of quantitative data; however, there were qualitative comments that indicated some participants experienced benefits [35].

Half of the systems were deemed to be able to enable treatment progression (n = 8, 50%). These incorporated or had the potential to incorporate progressively more difficult tasks in terms of movement [36, 37, 40, 41, 43], exposure to different levels of visual stimuli [38, 39], or more complex virtual environments [31]. Fewer than half of the studies had the potential to foster independence (n = 6, 38%). Systems that involved complex or custom-made equipment [28, 30, 34, 35, 37, 38], custom software [29, 33], or required clinician input [41, 42] did not meet this criterion.

Only five studies (31%) included any cultural considerations. Three studies [28, 31, 35] met this criterion by having adjustable skin tones on the virtual images, while Solca et al. [30] enabled choices of skin colour and sex. Additionally, the model used by Feintuch et al. [41] to detect skin was trained on several skin colours. None of the studies provided any considerations of cultural suitability of the VR environment or tasks for people of different cultures.

4 Discussion

This scoping review aimed to examine the appropriateness of XR interventions for the rehabilitation of people with CRPS. We assessed whether the systems used in existing research integrate clinical and theoretical frameworks, focusing on criteria such as clinical applicability, end-user engagement, and fostering independence. Our analysis of 16 studies revealed a diverse range of XR applications with varying degrees of appropriateness across the key domains. The findings suggest that while XR interventions show promise in addressing certain aspects of CRPS management, there are significant gaps in some areas that should be addressed in future developments or new systems. The remaining discussion will explore these findings in depth and propose directions for future research.

The diversity in study designs incorporated within the review reflects the evolving nature of XR research in CRPS rehabilitation. The variety of commercial and custom hardware and software used, which was often integrated with other sensory or stimulatory devices (e.g. data gloves, motion trackers), highlights the innovative approaches being explored. All studies provided relevant justification for their chosen interventions, grounding them in well-established theoretical foundations. The ubiquitous alignment with evidence-based frameworks is encouraging and reflects the researchers' integration of CRPS symptomology and current management practices within intervention designs. These findings are supported by the universal feasibility for clinical use of the interventions and improvements in pain or other symptoms that were observed in most studies involving participants with CRPS. Reports of intervention efficacy are consistent with the findings of systematic reviews showing that XR interventions may offer a promising adjunct to traditional CRPS management strategies [16, 17, 27]. However, the lack of efficacy in some studies and the limited range of outcome measures utilised suggest it is crucial to consider how these interventions may integrate within a holistic approach to CRPS care.

The assessment of user experience was notably limited across the reviewed studies, and there were also limitations in the potential for home-use, ability to incorporate progression and independence, and cultural considerations. None of the studies involved users in the design of the XR intervention and less than half incorporated any form of user experience evaluation. Among those that did, the method for obtaining feedback was often informal and relied on anecdotal comments from participants. Incorporating user feedback early and frequently during the development of XR treatments helps ensure that interventions are patient-centred and enhances their therapeutic potential [24]. While all feedback that was obtained from users in the reviewed studies was positive, the limited use of standardised measures and formal end-user engagement limits our understanding of the interventions' acceptability and potential for long-term adherence.

None of the studies explicitly defined protocols for functional progression within their interventions. However, several studies implicitly incorporated elements that could facilitate progression. This included tasks that had the potential to be manipulated in terms of the extent or complexity of movement required or exposure to varying sensory stimuli. The use of XR interventions would seem ideal for incorporating progression and the absence of clearly defined progression strategies that align with patient improvement highlights a significant area for improvement to address one of the core principles of rehabilitation [44].

Ideally, XR interventions would also foster independence of users and be suitable for home use, so self-management can be facilitated. Interventions in the review that met these criteria were characterised by user-friendly interfaces, tasks that facilitated self-administration, and the use of commercially available hardware and/or software. This was exemplified by Harvie et al. [39], who reported on a 12-week home-based intervention involving self-administered virtual exposure therapy. Simple, home-based interventions have the potential to increase treatment frequency and consistency, promote independence, and address access issues that could promote health equity [45, 46].

Apart from changing limb colour, cultural considerations within the intervention designs and delivery were notably absent. This omission underscores the need for a more inclusive approach to XR research and development. In recent years, there has been a notable drive to reduce racism and promote inclusiveness in pain research and management [47–50]. Users may report more engagement in XR rehabilitation and ownership of virtual limbs if images, including avatars, are personalised and relate to the user's identity [51, 52]. It has been recommended that virtual worlds, avatars, and tasks are developed in collaboration with diverse and underrepresented communities, including Indigenous populations and those living in rural areas [46]. Failing to be culturally inclusive can lead to reduce potential for patient-centred care and give rise to limited generalisability of findings [53], which will likely confound attempts to promote health equity.

4.1 Future research implications

The review findings highlight several areas for improvement in future XR interventions for people with CRPS. Specifically, incorporating more user feedback throughout the design and testing process is essential. This includes incorporation of cultural aspects (e.g., language settings, physical characterises, virtual environments) as well as consultation and involvement of minority populations and those for whom access to technology is more difficult. This could involve consulting with community leaders, health organisations, or other stakeholders to ensure that interventions respect cultural values and address existing gaps in virtual care and telerehabilitation that contribute to the digital divide [46]. While researchers are targeting their interventions to CRPS symptomology well, there should be greater focus on the incorporation of rehabilitation principles. The means ensuring that the XR intervention can include progression of difficulty and foster less reliance on clinician input or feedback for use. Development of standalone devices that can be used at home would facilitate equity of access. Researchers should also directly consider how XR interventions could fit within a wider rehabilitation context, ensuring that treatment is delivered and outcomes are assessed in a way that reflects holistic care.

4.2 Strengths and limitations

This scoping review presents several strengths. The rigorous search strategy and independent selection process reduced the potential for missing articles or for bias in selection of included studies. The broad inclusion criteria allowed for 16 studies covering a wide range of XR interventions for CRPS rehabilitation to be included, offering insights into different research approaches and their potential applications. Additionally, the development of a standardised framework to assess the appropriateness of the interventions enabled an objective assessment based on rehabilitation principles and clinical usability.

Several limitations also warrant consideration. The limited demographic information provided in most studies restricted our ability to assess whether the interventions are appropriate for diverse CRPS populations. Inconsistent reporting across studies often made it challenging to extract pertinent information, although there was high agreement in the independent assessment using the framework. Finally, the large number of uncontrolled, feasibility, or prototype studies without involvement of people with CRPS meant that evaluating intervention efficacy and user experience were constrained and the outcomes reported in the studies may not reflect outcomes when trialled with a wider CRPS population.

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Code availability Not applicable.

Declarations

Conflicts of interest The authors have no conflicts or competing interests to disclose.

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