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ALTERNATIVE TREATMENTS FOR PAIN MEDICINE (C ROBINSON, SECTION EDITOR)

The Role of Virtual Reality and Artificial Intelligence in Cognitive Pain Therapy: A Narrative Review

Maria Victoria Mazzolenis[1] · Gabrielle Naime Mourra[5] · Sacha Moreau[2] · Maria Emilia Mazzolenis[6] · Ivo H. Cerda[4] · Julio Vega[8] · James S. Khan[7] · Alexandra Thérond[3]

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Abstract

Purpose of Review This review investigates the roles of artificial intelligence (AI) and virtual reality (VR) in enhancing cognitive pain therapy for chronic pain management. The work assesses current research, outlines benefits and limitations and examines their potential integration into existing pain management methods.

Recent Findings Advances in VR have shown promise in chronic pain management through immersive cognitive therapy exercises, with evidence supporting VR's effectiveness in symptom reduction. AI's personalization of treatment plans and its support for mental health through AI-driven avatars are emerging trends. The integration of AI in hybrid programs indicates a future with real-time adaptive technology tailored to individual needs in chronic pain management.

Summary Incorporating AI and VR into chronic pain cognitive therapy represents a promising approach to enhance management by leveraging VR's immersive experiences and AI's personalized tactics, aiming to improve patient engagement and outcomes. Nonetheless, further empirical studies are needed to standardized methodologies, compare these technologies to traditional therapies and fully realize their clinical potential.

Keywords Immersive technology · Pain management · Machine learning · Cognitive pain therapy · Chronic pain · Cognitive behavioral therapy

Introduction to Cognitive Therapy in Chronic Pain Treatment

Pain is an unpleasant sensory and emotional experience associated with actual or potential tissue damage, as defined by the International Association for the Study of Pain (IASP) [1]. Chronic pain (CP), described by the persistence or recurrence of pain for more than 3 months, is often associated with significant emotional distress, as delineated in the International Classification of Diseases, Eleventh Revision (ICD-11) [2]. The complexity of this condition is multifactorial, stemming from biological, psychological, and social determinants. Approximately 21% of U.S. adults in 2021 reported experiencing CP, thereby establishing it as a notable public health concern [1, 2]. Considering the complex and multidimensional characteristics of chronic pain, the guidelines provided by the National Institute for Health and Care Excellence (NICE) serve as a prime example of an effective approach to its management. These guidelines recommend a diverse array of interventions, including exercise

Maria Victoria Mazzolenis, Gabrielle Naime Mourra and Sacha Moreau contributed equally to this study.

✉ Alexandra Thérond
therond.alexandra@courrier.uqam.ca

1 Favaloro University, Buenos Aires, Argentina

2 Massachusetts Institute of Technology, Boston, MA, USA

3 Department of Psychology, Université du Québec À Montréal, 100 Sherbrooke St W, Montréal, QC, Canada

4 Harvard Medical School, Cambridge, MA, USA

5 Department of Marketing, Haute Ecole de Commerce Montreal, Montreal, QC H2X 3P2, Canada

6 John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA, USA

7 University of California, San Francisco, CA, USA

8 Mount Sinai Hospital, University of Toronto, Toronto, ON, Canada

programs, physical activity, acupuncture, pharmacological management, and psychological therapy [3]. Within the domain of psychological interventions, cognitive-behavioral therapy (CBT), alongside psychodynamic psychotherapy, acceptance, and commitment therapy (ACT), mindfulness-based practices, and cognitive therapy, have been thoroughly investigated and identified as efficacious modalities to augment the management of CP [4, 5].

The significance of initiating psychological interventions at an early stage in the management of CP has gained growing acknowledgment, as demonstrated by recent reviews highlighting the benefits of implementing pain education and CBT for chronic pain (CBT-CP) from the outset of treatment [4–6]. Pain catastrophizing significantly predicts pain outcomes, yet there is a marked deficiency in specialized pain psychology training among healthcare providers [7–9]. A global needs assessment underscores this gap, highlighting the urgent need for enhanced pain education and access to pain psychology to improve CP management [5, 10, 11]. This perspective is supported by a review, that recommends pain education and CBT-CP from the outset of treatment [4, 5, 12]. CBT-CP is a psychotherapeutic approach grounded in the principles of CBT. CBT-CP focuses on two main targets: identifying, evaluating and redefining negative thoughts related to pain, the self, and the future as well as enhancing problem-solving skills [5]. Despite its effectiveness, the application of CBT-CP faces challenges due to variability in clinical practice and limited patient accessibility, stemming from the absence of standardized methodologies, a shortage of trained professionals, and financial barriers [5, 13].

In response to these challenges, virtual reality (VR) and artificial intelligence (AI) each present distinctively innovative solutions and, when integrated, may offer transformative interventions in CP management strategies [14]. VR provides immersive environments that not only divert patients' attention from their pain experiences for immediate relief but also facilitate rehabilitation via interactive 3-dimensional (3D) simulations that engage cognitive resources towards learning long-term self-management strategies [15–18]. Meanwhile, AI employs sophisticated algorithms to enhance human cognition in the analysis, interpretation, and understanding of complex medical and healthcare data. This includes the utilization of machine learning to enhance diagnostic precision and optimize treatment protocols [19, 20]. Reinforcement learning (RL) further advances AI's decision-making capabilities by facilitating the identification of optimal actions through iterative reward-and-penalties [21]. Moreover, natural language processing (NLP) analyzes and interprets human language data, enabling the extraction of valuable insights from clinical notes and medical literature [22, 23]. Collectively, these AI-driven approaches are pioneering personalized patient care, extending the frontiers of medical research, and evolving clinical practice [24, 25].

Virtual Reality in Cognitive Pain Therapy

VR has recently emerged as a promising novel component in the management of CP, supporting a wide range of applications from exercise and physical rehabilitation to comprehensive psychological therapy [26]. While much of the research on VR has concentrated on its efficacy for acute pain, a growing interest has been noted in its application for CP [27] particularly regarding its potential to support fully integrated psychological treatment, extending beyond its use as a virtual analgesic. This emerging focus is evidenced by a growing yet compelling collection of studies exploring the effectiveness of VR-based applications in this context [28].

Additional research has highlighted VR's capacity to reconfigure neurocognitive pathways and augment physical functionalities, thus contributing significantly to the evolving domain of pain therapy [29]. VR-based interventions leverage two key mechanisms: one, providing a distraction that transiently shifts focus from pain to an engaging stimulus; and two, inducing neuroplasticity, which reflects sustained structural changes within neural circuits [30, 31]. Emerging consensus in research suggests that the principal mechanism by which VR promotes neuroplasticity in the management of CP is by captivating attention, emotion, and memory through embodiment, which alter body perception and consequently, the pain experience [28]. For instance, a pilot feasibility study focusing on youth (mean age of 13.24 years) aimed at enhancing lower extremity movement reported high immersion in the virtual world (mean = 28.98, standard deviation = 4.02) which led to significant improvements in pain ($p < 0.001$), fear ($p = 0.003$), avoidance ($p = 0.004$), and functional limitations ($p = 0.01$), alongside other benefits for distraction, mobility, and reducing observed pain behaviors (Table 1) [32].

As compared to controls, numerous investigations have documented significant improvements in the reduction of pain and increased satisfaction with the treatment modality, as well as enduring long-term benefits when the VR-based intervention is adequately designed (Table 1) [28]. Moreover, VR has been instrumental in augmenting the efficacy of various psychological treatment components. For instance, the RelieveVRx software by AppliedVR, a 56-day VR skills-based therapy program incorporating CBT, mindfulness, and biofeedback for chronic low back pain, demonstrated significant reductions at 18 months in pain intensity ($p = 0.003$, effect size = 0.65), pain-related stress ($p = 0.043$, effect size = 0.32), pain interference with activity ($p = 0.020$, effect size = 0.54), and sleep ($p = 0.015$, effect size = 0.36) compared to a sham VR group. These findings contribute to a deeper understanding of VR's potential impact on CP management, hinting at its capability to influence neurological processes, which warrants further exploration [39••].

Table 1 Applications of Cognitive Pain Therapy for Chronic Pain in Virtual Reality

Author	Study Design	Study Goals	N	Study Group	Intervention	Comparator	Results	Conclusions
McGirt et al., 2023 [33]	Remote active treatment concurrent control	Reduce pain, anxiety, and depression in patients with spondylitis pain compared to treatment as usual	145	Adults with chronic cervical and lumbar spondylitis pain	The Vx Therapy is a 3-month, physician-prescribed program combining VR therapy with weekly CBT phone sessions. Patients use a PICO VR headset with 20 h of content in education, meditation, distraction, and entertainment, customized by a clinician for each patient's symptoms and recovery goals, VR audio-visual sessions last 3 to 20 min	Retrospective historical review of patients treatment as usual	Vx Therapy significantly improved PROMIS scores: pain intensity (36 ± 24 to 28 ± 21), interference (39 ± 25 to 24 ± 21), behavior (35 ± 21 to 25 ± 16), anxiety (51 ± 28 to 41 ± 26, $p < .05$), and depression (58 ± 32 to 48 ± 32, $p < 0.05$). VR reduced pain by 33% (4.5 ± 2.5 vs. 6.7 ± 2.2, $p < 0.05$) and anxiety by 46% (3.5 ± 3 vs. 6.4 ± 2, $p < 0.05$), with relief lasting 2.8 h initially, extending to 4.5 h	At home VR + CBT is effective for managing CP, anxiety and depression, presenting a non-invasive alternative to opioids
Griffin et al., 2020 [32]	Pilot feasibility study	Develop and assess VR for enhancing function in youth with CP through increased engagement with physical exercises	17	Youth with chronic pain	Leveraging the VIVE VR System, patients averaged 3.71 sessions with 1 session a week for 30 min, with a range between 1 to 8 sessions. It featured the engaging game Fruity Feet, designed to improve lower extremity movement. Customizable for different mobility levels, refined through feedback, enhancing inclusivity and effectiveness for both standing and seated participants	No control group	The study reported high immersion (mean 28.98, max 40, SD 4.02). Among 8 with multisession data, significant improvements were noted: pain ($p < 0.001$), fear ($p = 0.003$), avoidance ($p = 0.004$), functional limitations ($p = 0.01$). Further benefits for distraction, mobility, and reducing observed pain behaviors were reported	The intervention demonstrated high engagement and feasibility, suggesting its benefits for CP rehabilitation in youth. Further refinement and assessment are needed

Table 1 (continued)

Author	Study Design	Study Goals	N	Study Group	Intervention	Comparator	Results	Conclusions
Darnall et al., 2020 [34]	Randomized control trial	Assess the feasibility and preliminary efficacy of a self-administered, skills-based VR intervention for chronic pain	97	Adults with chronic low back pain or fibromyalgia	The VR intervention encompassed a 21-day program with sessions on pain CBT, relaxation training enhanced by visual biofeedback, and mindfulness, leveraging an Oculus Go VR headset. Sessions varied from 1 to 15 min, focusing on cognitive, emotional, and physiological self-regulation related to pain and stress management	Comparable audio only control group	VR participants with no nausea: 76%. Satisfaction: VR 83%, audio 72%. Significant improvements displayed for all pain variables ($p < 0.001$). Significant benefits in VR group for pain intensity ($p = 0.04$), pain interference with activity ($p = .005$), sleep, mood, and stress ($p < 0.001$ to $p = 0.003$). Trends showed decreasing pain catastrophizing, increasing pain self-efficacy in both groups	The intervention showed promise as an effective and acceptable treatment for CP, warranting further research
Igna et al., 2014 [35]	Two arm clinical trial	Compare the effectiveness of Mindfulness-based Cognitive Behavioral Therapy (MCBT), Virtual Reality-enhanced Cognitive Behavioral Therapy (VR-CBT), and Treatment as Usual (TAU) for chronic back pain	68	Adults with chronic back pain	The VR-CBT intervention included classical CBT strategies and a brief VR session each meeting, totaling six sessions. The VR component involved a 5-min exposure to "SnowWorld," focusing on attention diversion from pain, followed by discussions on the impact of attention shift on pain intensity. This approach aimed to combine traditional CBT methods with immersive VR experiences to enhance pain management	Treatment as usual group received physiotherapy and pharmacotherapy without additional psychological interventions	ANOVA showed no significant differences between groups except in pain intensity (McGill, $p = 0.05$; VAS, $p = 0.027$), with a significant VAS difference between MCBT and PHM ($MD = 1.35$, $p = 0.04$). Pre-post analyses revealed significant improvements in pain, anxiety, depression, and distress across conditions	MCBT and VR-CBT are effective in managing chronic back pain, with MCBT showing a significant reduction in pain intensity compared to TAU

Table 1 (continued)

Author	Study Design	Study Goals	N	Study Group	Intervention	Comparator	Results	Conclusions
Venuturupalli et al., 2019 [36]	Pilot study	To assess the feasibility of implementing VR in a rheumatology clinic for CP reduction using guided meditation and biofeedback	20	Adults with physician-diagnosed autoimmune disorders, stable medication regimen, pain VAS ≥ 5 for ≥ 4 days in the past 30 days	The VR intervention utilized Samsung Gear VR with Galaxy S7, Nubwo N2 headphones for 3D visuals and breath tracking. It featured two modules: guided meditation (GM) and respiratory biofeedback (BFD), each lasting 10–15 min. BFD included visual breath cues and a pacing guide; GM involved meditation without interactive feedback. Sessions were 30 min, with participants randomized to the sequence of GM and BFD modules	Within-group comparison pre and post-intervention	ANOVA showed significant pain reduction after both BFD ($p = 0.01$) and GM ($p = 0.04$). Anxiety decreased significantly after GM ($p < 0.05$), with no intervention order effect on outcomes. Acceptance was high; 100% would participate again, citing interest in non-medical pain management. Most found VR relaxing, with notable ease in pain and anxiety during sessions. Some reported the device as heavy/bulky	VR is a feasible method for managing pain and anxiety in rheumatology patients, warranting further trials
Abdelazim et al., 2016 [37]	Randomized controlled trial	To compare the effectiveness of Virtual Reality Training (VRT), Sensory Motor Training (SMT), and Conventional Exercise Training (CET) in treating Unilateral Chronic Osteoarthritis	60	35–65 years old with unilateral chronic osteoarthritis	The study examined VRT, SMT, and CET for osteoarthritis. VRT used "Light Race" for 15–30 min focusing on strength and balance, SMT involved balance and walking exercises across stages, and CET combined warm-up, walking, and cool-down. Sessions were thrice weekly for 8 weeks	Comparison among VRT, SMT, and CET groups	After 8 weeks, VRT showed the most improvement in pain (VAS: 6.81 to 2.9), position sense (118.9 to 134), WOMAC (71.65 to 14.65), and HRQOL (1.35 to 4.5) scores. SMT and CET also improved, but VRT had significantly better outcomes. Improvements in all groups were statistically significant ($p < 0.05$)	VRT combined with CET was more effective in improving pain, proprioception, functional level, and quality of life in OA patients than SMT + CET or CET alone

Table 1 (continued)

Author	Study Design	Study Goals	N	Study Group	Intervention	Comparator	Results	Conclusions
Garcia et al., 2021 [38]	Double-blind randomized placebo-controlled trial	To evaluate an 8-week self-administered, behavioral skills-based VR program for chronic low back pain	179	Adults with low back pain	The EaseVRx VR program for CP management combines CBT, mindfulness, pain education, and biofeedback in a 56-day course. It features activities like diaphragmatic breathing, relaxation exercises, and cognitive games to enhance pain and stress management, with VR experiences lasting 2–16 min. The content aims to minimize emotional distress and cybersickness	Sham VR group	EaseVRx vs. sham VR: higher satisfaction, significant improvements in pain, mood, stress (effect sizes 0.40–0.49), physical function, and sleep ($p = 0.022$, .013). No change in pain mindset or opioid use. Analgesic use decreased with EaseVRx ($p < 0.01$)	EaseVRx demonstrated superior, clinically meaningful symptom reduction and high user satisfaction, supporting further research on VR for CP management
Maddox et al., 2022 [39••]	Randomized placebo-controlled clinical trial	Examine the 18-month durability of VR therapy for chronic low back pain	188	Adults with chronic low back pain	RelieveVRx by AppliedVR is a 56-day VR skills-based therapy for chronic low back pain, incorporating CBT, mindfulness, and biofeedback. Sessions, lasting 2–16 min (average 6 min), aim to improve relaxation, pain perception, and stress	Sham VR (non-immersive 2D nature content)	At 18 months, VR therapy showed significant reductions in pain intensity ($p = 0.003$, effect size = 0.65), pain-related stress ($p = 0.043$, effect size = 0.32), pain interference with activity ($p = 0.020$, effect size = 0.54), and sleep ($p = 0.015$, effect size = 0.36) compared to sham VR	Skills-Based VR therapy demonstrated long-term efficacy in managing chronic low back pain, suggesting a durable, non-pharmacological treatment option

In another randomized controlled trial, a self-administered, skills-based VR program was evaluated for efficacy against an audio-only version among 97 adults with chronic non-malignant low back pain or fibromyalgia [34]. The program consisted of 4–8 treatment sessions delivered at home over 21 days, with content categories including CBT-CP, relaxation training, and mindfulness. The pain CBT component focused on educating participants about the impact of thoughts and emotions on pain, as well as restructuring thoughts and regulating pain-related cognition and emotion. The VR group exhibited significant improvements over time in every pain variable, with outcomes intensifying after two weeks, including 76% of VR participants reporting no nausea, and higher satisfaction rates in the VR group (83%) compared to audio (72%). Significant enhancements were observed in pain intensity ($p = 0.04$), pain interference with activity ($p = 0.005$), sleep ($p < 0.001$), mood ($p < 0.001$), and stress ($p = 0.003$) [34]. The initial results are encouraging for VR's role in pain management and invite more comprehensive study.

Additionally, a randomized placebo-controlled trial compared the EaseVRx, a 3D immersive pain skills training program, with sham VR in 179 participants with chronic low back pain. The EaseVRx program lasted 6 min for each group and included modules for pain education, relaxation/interoception, mindfulness exercises, pain distraction games, and dynamic breathing. The sham VR group watched 2D nature footage with neutral music in their VR headset [38]. Participants in the EaseVRx group reported significant improvements in pain intensity (effect size = 0.49), pain interference with mood (effect size = 0.42), pain interference with stress (effect size = (0.40). The Patient-Reported Outcomes Measurement Information System (PROMIS) revealed an improvement in physical function (effect size = 0.34) and sleep disturbances (effect size = 0.37) and a decrease in over-the-counter analgesic use ($p < 0.01$), with no statistical difference in pain catastrophizing, pain self-efficacy, pain acceptance or opioid use. In a 6-month follow-up, participants assigned to the EaseVRx group maintained statistically significant and clinically meaningful effects, remaining superior to the sham VR program in reducing pain intensity and pain-related interference with activity, stress, and sleep [38].

VR-CBT demonstrates substantial benefits in treating anxiety and depression, with effects comparable to traditional CBT and without significant differences in attrition rates, suggesting high patient retention [39••, 40]. In CP management, VR-CBT yielded significant improvements, with pain and anxiety acutely reduced by 33% and 46%, respectively, highlighting VR's potential to maintain patient engagement over traditional methods [33] while also reducing dependence on opioids [38, 39••, 41]. However, despite equivalent attrition, and with some studies showing improved attrition rates, further research in VR-CBT for CP is warranted to fully understand its advantages over in-person CBT in terms of maintaining patient participation [40, 42–44].

Artificial Intelligence in Cognitive Pain Therapy

The field of CP management has been substantially enriched by advances in AI, particularly in its sophisticated ability to assess and quantify the intensity and characteristics of pain symptoms [45]. AI's contributions extend beyond simple measurement; it is pivotal in the development of instruments that enhance treatment protocols and self-management tactics, as well as in the analysis of patient data to improve prognostications related to health trajectories and risk evaluations [46, 47]. Despite these innovations, the direct utilization of AI in the therapeutic interventions for CP requires additional investigation [6].

A recent study tested a hybrid program that combined therapist-delivered CBT-CP with an AI-based interactive voice response (IVR) supporting system (AI-CBT-CP) [46]. Patients were randomly assigned to either AI-CBT-CP or standard CBT-CP delivered by phone and received 10 weekly CBT-CP sessions. In the AI-CBT-CP group, the AI model used RL to make recommendations based on patient feedback gathered during a short 5-min daily IVR phone call, which included information on step counts, pain intensity, interference, functioning, and CBT-CP skill practice. The study showed AI-CBT-CP noninferiority to standard CBT-CP with a -0.72 to -1.24 point difference in the Roland-Morris Disability Questionnaire (RMDQ) scores at 3 and 6 months ($p < 0.001$), nonetheless both groups indicated significant clinical improvements irrespective of each other as well as greater efficiency in therapist time utilization [46]. These findings underscore the potential of AI to enhance clinician effectiveness and patient support through adaptive treatment recommendations [4, 45, 48]

Moreover, integrating AI into CBT through innovative machine learning approaches, such as a Transformer-Convolutional Neural Network (CNN) hybrid models, demonstrates significant improvements in diagnostic accuracy and treatment efficiency [49••]. A CNN is a type of deep learning model primarily used for processing data with a grid-like topology, to detect patterns and features automatically [4]. By leveraging both architectures' strengths, this model achieves an impressive 97% accuracy in diagnosing psychiatric disorders, potentially offering more accurate therapy strategies compared to standard practices[50]. This precision underscores AI's potential in enhancing CBT delivery and patient outcomes in mental health care, especially within the context of CP management where psychological comorbidities are prevalent [5, 6, 24, 45, 51].

Moreover, an investigation into Wysa, a digital health application founded on the principles of CBT, employed an artificial intelligence-driven conversational agent to facilitate cognitive reframing, mindfulness meditations, and bespoke exercises designed to meet user-specific requirements [52]. This research applied inductive thematic analysis for the evaluation of conversational content to discern user needs and implemented comparative macro-analyses of conversational dynamics to quantify user engagement with the application. Participants with CP expressed issues pertaining to health, socioeconomic status, and pain management strategies. In this mixed-methods retrospective observational study, participants with CP demonstrated significantly higher engagement with the application ($p < 0.001$) compared to those with no CP. They also reported substantive enhancements in mental health outcomes (improvements in Patient Health Questionnaire-9 (PHQ) (effect size = 0.60) and Generalized Anxiety Disorder-7 (GAD-7) scores (effect size = 0.62)). These findings imply that AI-mediated digital interventions have the potential to effectively address the needs of users, thereby narrowing the divide between the need for mental health support and the resources that are currently accessible [24, 52, 53•, 53].

NLP is catalyzing a transformation in CP management by extracting actionable insights from clinical narratives and electronic health records, thereby tailoring therapeutic approaches to individual patient profiles [23, 46, 53•, 54]. NLP allows for the identification of patterns within symptom narratives and treatment responses, thereby increasing the specificity of cognitive therapies. By processing extensive volumes of unstructured data, NLP bolsters diagnostic precision and therapeutic effectiveness, indicating AI's substantial prospective contribution to pain management [22, 55]. AI's transformative impact on CBT-CP is becoming increasingly evident [22, 55]. AI not only augments traditional therapeutic approaches but also introduces novel pathways for patient engagement and treatment customization. AI's impact on treatments is evident through AI-CBT-CP's clinical improvements with reduced therapist involvement and Wysa's user engagement [52]. However, most AI interventions are in pilot phases, highlighting the need for more trials before widespread adoption. AI promises to enhance cognitive therapy for chronic pain, yet still necessitates further validation [5, 22, 55].

Cutting Edge: The Combination of Virtual Reality and Artificial Intelligence in Cognitive Pain Therapy

Having explored the respective isolated applications of VR and AI, we now highlight emergent research illustrating the potential for the confluence of these technologies in enhancing the psychological treatment of CP (Table 1). A prominent recent innovation is the integration of AI avatars in VR that leverage NLP to distill key learnings while mimicking therapeutic conversations (Fig. 1) [53•].

Their innovation employs an AI-driven avatar, termed the eXtended-reality Artificial Intelligence Assistant (XAIA), operating within biophilic VR environments for bespoke mental health support, incorporating GPT-4 to facilitate therapeutic interactions. Demonstrated to be efficacious, secure, and frequently favored over human practitioners for its capacity to synchronize with the user's affective states, XAIA represents a pivotal advancement in refining VR-based interventions [51, 53•, 56]. Although more robust research is needed to further explore the effectiveness of VR-AI hybrid systems, including safety and long-term effects, the amalgamation of AI's analytical capabilities with the engaging experiential nature of VR portends an innovative paradigm in CP treatment, one that holds the promise of heightened patient engagement, superior outcomes, and greater accessibility in the realm of pain management [45, 46, 57].

Future Directions

In recent times, there has been a surge in research delving into the deployment of VR and AI for cognitive interventions in the context of CP (Table 1) [45, 46]. Nevertheless, there remains a pressing need for additional research, as the preponderance of existing studies emphasizes the utilization of VR predominantly for distraction or analgesic purposes, rather than as a medium for administering cognitive therapy [39••, 58, 59]. Further compounding this issue is the nature of VR environments themselves, which are often not discussed in-depth in existing literature. The intricacies of VR experience design are pivotal for generating therapeutic effects, yet there is a paucity of discussion around the various attributes of these environments, such as sensory complexity, interactivity, and the degree of user autonomy [60]. Future studies must delve into these aspects to better understand how VR can be effectively employed beyond distraction, to promote lasting cognitive and behavioral change [61].

Furthermore, the research concerning the psychological aspects of VR and AI is hampered by a lack of uniform protocols, methodologies, and the diversity of devices used [62]. This heterogeneity impedes the ability to draw comparisons across studies and to rigorously assess the therapeutic benefits of these technologies. Moreover, the current research landscape reveals a conspicuous lack of diversity within patient populations. This shortfall raises concerns regarding the generalizability of findings and underscores

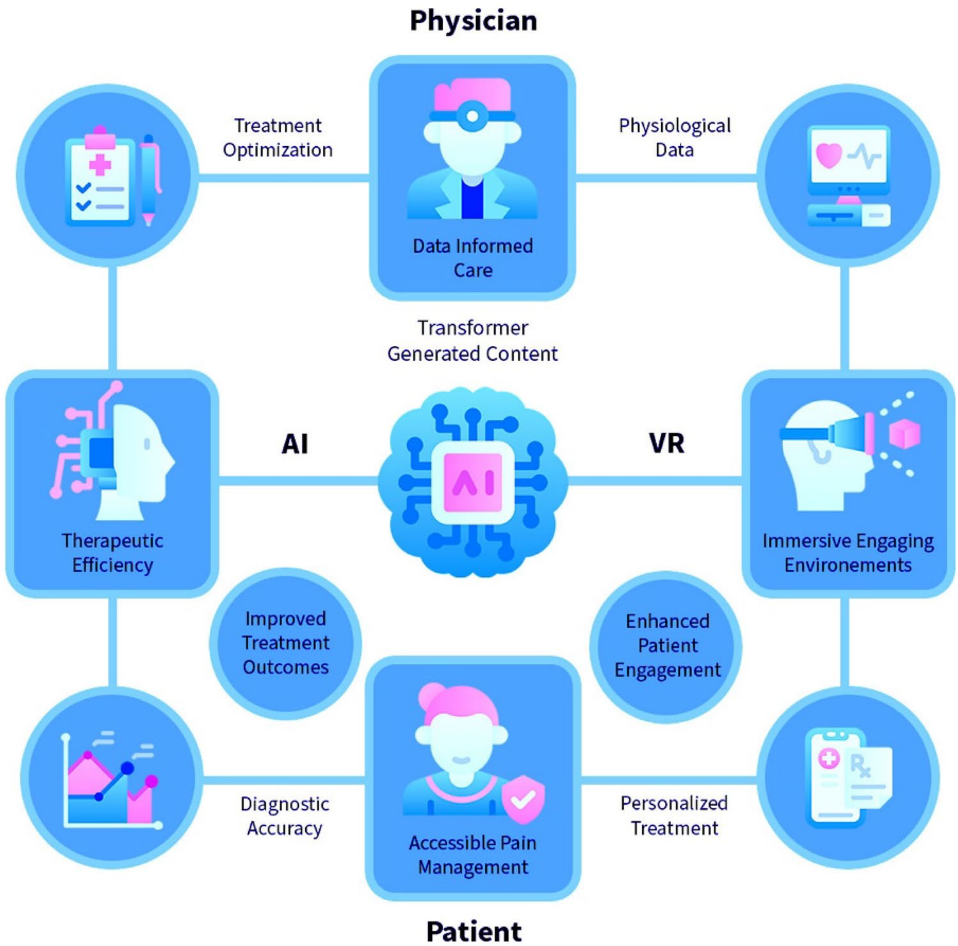

Fig. 1 The intersections and benefits of Artificial Intelligence and Virtual Reality in Cognitive Pain Therapy

the need for research that reflects a broader demographic spectrum to ensure that these technologies are effective across diverse cultural and socioeconomic groups.

The synergistic integration of AI with VR holds the promise of enriching CBT-CP with an expanded repertoire of strategies, facilitating its application and investigating alternative pathways through which VR can induce neuroplastic changes, distinct from those of distraction-based analgesia [46, 53•, 54, 63, 64]. Equally critical is the distinction between distraction-based VR applications and those that engage users in true skill training and CBT. While the former may offer immediate analgesic effects, the latter involve more complex psychological processes that can lead to sustained pain management and coping skills. Yet, to date, studies exploring the extensive use of VR for skill training and cognitive-behavioral applications are limited. AI may help standardize treatment and streamline certain tasks that patients can accomplish between visits, ultimately improving the efficiency and effectiveness of healthcare services [39••]. VR-CBT shows comparable effectiveness to traditional CBT in treating anxiety and depression with no significant differences in attrition rates, suggesting it is a viable and engaging alternative for both mental health and CP management [33, 40, 42–44]. Ethical considerations in the use of AI are also of paramount importance, particularly in terms of patient data management. The employment of federated learning models can offer a way forward, providing a framework for sharing insights derived from AI without compromising individual data privacy. This approach aligns with the need for greater transparency in AI healthcare applications, ensuring that patients and practitioners can trust the systems in use. However, such technologies remain largely in the experimental phase, necessitating rigorous trials and validation to ascertain their efficacy and ethical soundness in real-world clinical settings.

VR and AI are swiftly evolving technologies with the capacity to extend treatment access to remote and economically disadvantaged communities, bolster constrained clinical resources, and enhance healthcare services [52, 65, 66]. Yet, their full potential remains to be exhaustively tested through research. It is crucial that VR and AI's application in CBT-CP keeps pace not only in technological advancement but also in rigorous, ethical, and inclusive research methodologies [62].

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Data Availability No datasets were generated or analysed during the current study.

Compliance with Ethical Standards

Competing Interests SM and AT: Cofounders of AugMend Health. MVM and MEM: Contractors of AugMend Health. IHC: Receives consulting fees from Layer Health.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors. AI writing statement: AI was used to improve the quality and clarity of the writing.

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- • Of importance
- •• Of major importance

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