REVIEW ARTICLE

VIRTUAL REALITY-BASED SYSTEMS AND THEIR ANALGESIC EFFECTS IN THE TREATMENT OF PHANTOM LIMB PAIN: A SCOPE REVIEW

Crisley da Silva Guenin[1], Beatriz Cristina de Freitas[2]
Rosa Maria Esteves Moreira da Costa[3]

Highlights: (1). Virtual reality is an innovative approach to treating phantom limb pain. (2). Virtual Reality can contribute to improving patients' quality of life. (3). The wide variety of protocols analyzed hinders the comparison of results. (4). Evidence suggesting pain relief requires robust study methodologies.

PRE-PROOF

(as accepted)

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[1] Rio de Janeiro State University - UERJ. Rio de Janeiro/RJ, Brazil.
https://orcid.org/0009-0006-9655-6127

[2] Rio de Janeiro State University - UERJ. Rio de Janeiro/RJ, Brazil.
https://orcid.org/0000-0002-3042-4192

[3] Rio de Janeiro State University - UERJ. Rio de Janeiro/RJ, Brazil.
https://orcid.org/0000-0001-6165-1649

VIRTUAL REALITY-BASED SYSTEMS AND THEIR ANALGESIC EFFECTS IN THE TREATMENT OF PHANTOM LIMB PAIN: A SCOPE REVIEW

ABSTRACT

Objective: To synthesize the available scientific evidence on treatment of phantom limb pain using virtual reality and its effects on pain. **Method:** This systematic review was conducted in accordance with the Joanna Briggs Institute (JBI) guidelines and the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) instructions. The search was conducted using five databases, as well as sources of unpublished studies and gray literature. The selection was done by two independent researchers and observed the following inclusion criteria: full-text primary articles; freely available (open-access); with no restrictions on time, language, or country; and which applied virtual reality to adult amputees with phantom pain. The results were analyzed qualitatively regarding the outcome of interest – pain – and presented descriptively in tables and graphs. **Results:** A total of 29 articles published between 2006 and 2024 were selected for the evidence synthesis. Most of the studies analyzed applied the concepts of mirror therapy and phantom limb movement. The immersive experience favored the use of 3D gamification. There is a tendency to assess its use in the home setting. The customized games and equipment used hamper the replication of the intervention in clinical practice. **Conclusions:** Although the studies under review show that virtual reality reduces phantom limb pain, their design limits the ability to determine causal relationships between virtual reality and pain reduction. Future research must employ more rigorous methodologies and larger sample sizes.

Keywords: virtual reality, virtual reality exposure therapy, phantom limb pain.

INTRODUCTION

Phantom limb pain (PLP) is defined as a painful sensation that affects an amputated part of the body[1]. It is a clinical condition of intense pain and often dramatic course, posing a major challenge for pain specialists and the entire team involved in the care of these patients. By the year 2050, approximately 3.6 million people will be living with amputations in the United States[2]. Statistics show that in Brazil, in 2023, approximately 72,000 amputations were performed[3]. It is estimated that the prevalence of PLP exceeds 80% among amputees[1], which negatively impacts their mental health and increases the risk of depression and anxiety in these patients, compromising their quality of life, socialization, and professional reintegration[4-5].

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Painful sensations occur most frequently in the distal parts of the missing limb, such as the foot, hand, and fingers. These sensations may be continuous or intermittent and can last from seconds to hours[6]. The therapeutic strategies established for the treatment of the clinical condition initially include a pharmacological approach; however, a large number of patients are refractory to the treatment. Among the most widely disseminated non-pharmacological techniques are sensory discrimination, mirror therapy, graded motor imagery, phantom motor execution, prosthetic strategies, neuromodulation, bionic reconstruction, and virtual reality (VR)[6], which emerges as a promising therapeutic option.

In the simulated environment of the immersive experience provided by VR, the patient experiences the illusion of having a virtual body that they see from a first-person perspective and feel as if it were their own[7]. Augmented Reality (AR) technology is part of the VR framework and provides an experience in which scenes blend real-world images with computer-generated images. The Gate Control Theory of Pain, the production of endogenous opioids, the activation of mirror neurons and of descending inhibitory pathways are among the many hypotheses to explain the analgesia caused by VR. However, the literature on the use of VR in the treatment of PLP is scarce, and studies are scattered. The lack of understanding of this topic limits the widespread use of this technology.

The purpose of this scope review is to synthesize the evidence available in the literature on the use of VR systems in the pain management of PLP. Specific objectives include analyzing how these technologies are being applied and the results obtained in reducing pain.

MATERIAL AND METHODS

This Scope Review was conducted in accordance with the review method proposed by the Joanna Briggs Institute (JBI)[8] and the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)[9] instructions. This is an exploratory, descriptive research with a qualitative approach. This type of review provides a systematic and comprehensive overview of the literature, covering a wide range of study types and methods. This Scoping Review was registered on the Open Science Framework (OSF) platform (https://osf.io/) and is available at https://doi.org/10.17605/OSF.IO/UBS49. The guiding question of the study was: “What are the virtual reality systems used in the treatment of phantom limb pain, and what are their effects on pain levels?”.

This question guided the organization, search strategy, and exploration of the electronic databases used in this research. It was defined according to the components of the acronym PICo (Population, Phenomenon of Interest, and Context), where Population = Adults with amputated limbs; Phenomenon of Interest = Virtual Reality Systems; and Context = Treatment of phantom limb pain.

The most recent literature search was conducted by the team of librarians at a public university library in the state of Rio de Janeiro in October 2024, using the following databases: PubMed, the Medical Literature Analysis and Retrieval System Online (MEDLINE); Latin American and Caribbean Health Sciences Literature (LILACS); Scientific Electronic Library Online (SciELO); Web of Science; and PEDro. The sources of unpublished studies and gray literature searched were Oasis and RCAAP. Other studies were identified through reverse searching based on the references of the selected articles.

The search strategy included DeCS/MeSH terms, and in order to modulate the search, the Boolean operators “OR”, “AND”, “NOT” and “AND NOT” were also used (Table 1). The data were entered into an Excel file (Microsoft, USA) for screening and registration of eligibility criteria.

Table 1 – Search strategy used in this Scoping Review

Database	Strategy	Number of references retrieved
PUBMED https://www.ncbi.nlm.nih.gov/pubmed	(((((("virtual reality") OR ("virtual reality exposure therapy")) AND (phantom limb pain)) NOT (child)) NOT (children)) NOT (pediatric)) NOT (pediatrics)	82
LILACS https://pesquisa.bvsalud.org	(("realidade virtual") OR ("realidades virtuais") OR ("terapia de exposição à realidade virtual") Or ("terapia com exposição à realidade virtual") OR ("virtual reality") OR ("virtual reality exposure therapy")) AND (("dor fantasma") OR ("phantom limb pain")) AND NOT (child) AND NOT (pediatric) AND NOT (pediatrics)	71
SCIELO http://www.scielo.org/php/index.php	("realidade virtual") OR ("realidades virtuais") OR ("terapia de exposição à realidade virtual") OR ("virtual reality") OR ("virtual reality exposure therapy") AND ("dor fantasma") OR ("phantom limb pain") AND NOT (children) AND NOT (child) AND NOT (pediatric) AND NOT (pediatrics)	23
WOS https://www.webofscience.com	"virtual reality" OR "virtual reality exposure" (Title) AND "phantom limb pain" (Title) NOT "children" OR "child" OR "pediatric" OR "pediatrics" (Title) OR "virtual reality" OR "virtual reality exposure" (Keyword Plus ®) AND "phantom limb pain" (Keyword Plus ®) NOT "children" OR "child" OR "pediatric" OR "pediatrics" (Keyword Plus ®) OR "virtual reality" OR "virtual reality exposure" (Abstract) AND "phantom limb pain" (Abstract) NOT "children" OR "child" OR "pediatric" OR "pediatrics" (Abstract)	86
PEdro https://pedro.org.au/	“virtual reality exposure therapy”	04
PEdro	“phantom limb pain”	48
Oasis https://oasisbr.ibict.br/vufind/	(All fields:"realidade virtual" OR "realidades virtuais" OR "terapia com exposição à realidade virtual" OR "virtual reality" OR "virtual reality exposure therapy" AND "dor fantasma" OR "phantom limb pain" AND NOT "child" AND NOT "children" AND NOT "pediatric" AND NOT "pediatrics")	Zero
Oasis	“(All fields:”realidade virtual” AND “membro fantasma”)”	02
RCAAP https://www.rcaap.pt/	“realidade virtual” and “dor fantasma”	02

Source: The authors.

The titles and abstracts of all the articles shown in the search were analyzed to define the selection of those to be read in full. The articles were selected based on the following inclusion criteria: (1) complete primary articles, (2) no time restrictions, (3) no language or country restrictions, (4) that answered the research question, (5) conducted in adults, and (6) freely available (open access). The publication period for the articles was not specified, with the aim of attempting to identify a pattern of evolution in the intervention and to observe whether any older gaps remained that would still be relevant for future research. The choice to include open-access articles was made because the research did not receive any funding and we faced difficulties accessing paid articles.

Articles that did not meet the inclusion criteria were excluded: (1) secondary studies, letters to the editor, editorials, preprints, and books; (2) studies that did not evaluate the use of VR for the treatment of phantom limb pain and its results or outcomes. The Rayyan Review Manager® was used to manage the selection process, remove duplicate articles, and screen the articles to be included in this scoping review.

The selection was conducted by two independent reviewers (CSG and BCF). Divergences in the selection process were solved by consulting a third reviewer (RMEMC). The results obtained in this phase of the research were qualitatively analyzed regarding the variable of outcome of interest – pain – and presented descriptively and in tables and graphs.

RESULTS

The search identified a total of 318 articles: 82 articles in the PubMed database, 71 articles in LILACS, 23 articles in SciELO, 86 articles in WOS, 52 articles in PEDro, and 4 articles from sources of unpublished studies and gray literature, including 2 articles in Oasis and 2 articles in RCAAP. The article screening process is presented in the flowchart in Figure 1.

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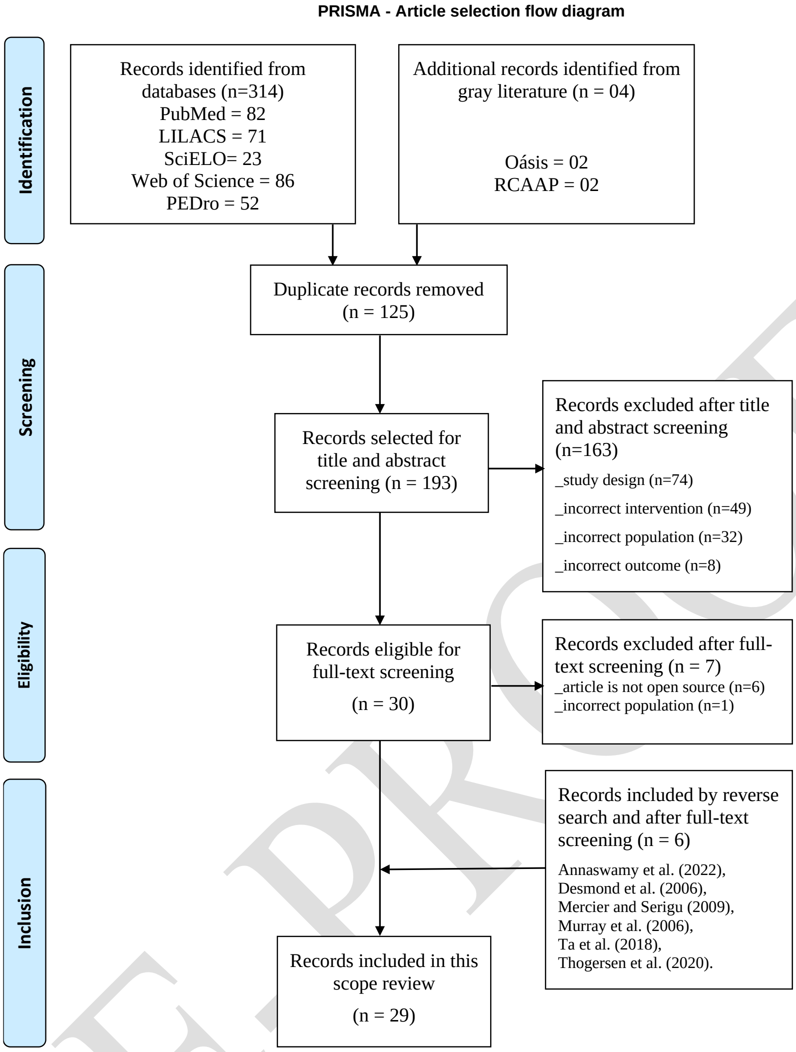

Figure 1 – Article selection flowchart

Source: Adapted from PRISMA-ScR

The articles were imported into the Rayyan® review management software, where duplicate articles were removed (n=125). A total of 193 articles were then selected for title and abstract screening. Some of these articles identified by the literature search evaluated AR systems and were included in this review due to the relevance of this technology and its close connection to VR technology. Thus, 30 articles were selected according to the eligibility criteria for full-text reading. After the exclusion of 7 articles and the inclusion of 6 articles identified through reverse searching, 29 studies that use VR/AR were included in this scoping review. The characteristics of the studies included in this scoping review are presented in Table 2.

Table 2 – Characteristics of the studies included in the review

Author	Country	Study design	N, Age and Gender	Amputated limb	Time of amputation	VR 2D and VR 3D	Study objective
Ambron et al, 2018	USA and Germany	Case Series	N=2*	LL=2	7 to 11 months	3D	To assess the usability of a user-friendly VR system in the treatment of PLP
Ambron et al, 2021	USA	Single-Group Clinical Trial	N=7 Age=51 M=4 F=3	LL =7 abaixo do joelho	6 months to 11 years	3D	To investigate whether immersive VR games can reduce PLP
Annaswamy et al, 2022	USA	Pilot Study	N=4 Age= 64 M=4	LL =4	10 months to 12,8 years	3D	To assess the clinical viability for home use of the VR system developed for PLP
Chau et al, 2017	USA and United Kingdom	Case Report	N=1 Age=49 M=1	UL=1	5 months	3D	To report a case of PLP treated with RV
Cole et al, 2009	United Kingdom	Single-Group Clinical Trial	N=14 Age=56/49 M=10 F=4	UL =7 LL =7	5 months to 10 years	2D	To present the results of the VR intervention in PLP using a method that captures stump movement
Desmond et al, 2006	Ireland	Case Series	N=3 Age=38 M=2 F=1	UL =3	3 to 12 years	2D	To assess an AR system in PLP
Ichinose et al, 2017	Japan	Crossover Clinical Trial	N=9 Age=54 M=8 F=1	UL =9	6 to 36 years	3D	To investigate the analgesic effect of tactile stimulation of the cheek during VR therapy for PLP
Kulkarni et al, 2020	United Kingdom	Pilot Study	N=9 Age=46-80 M=7 F=2	UL =9	> 3 years: 8 participants < 2 years: 1	3D	To assess the effects of VR on PLP and help identify the best target group for its use
Lendaro et al, 2020	Sweden	Case Series	N=4 Age=58 M=3 F=1	UL =2 LL =2	9 years to 50+ years	2D	To investigate the benefits and challenges of in-home use of VR/AR on PLP

Mercier and Sirigu, 2009	Canada France	Single-Group Clinical Trial	N=8 Age=37 M=8	UL =8	1 to 16 years	2D	To assess differences in individual responses to VR training and explore factors that influence the response to this approach
Murray et al, 2006	United Kingdom	Pilot Study	N=5 Age=61 M=3 F=2	UL =3 LL =2	1 year to 39 years	3D	To demonstrate the viability of VR in PLP and analyze the qualitative interview data
Murray et al, 2007	United Kingdom	Case Series	N=3 Age=63 M=2 F=1	UL =2 LL =1	1 year to 12 years	3D	To analyze preliminary qualitative data in order to evaluate the proof of concept of an RV device
Ortiz-Catalan, 2014	Sweden	Case Report	N=1 Age=72 M=1	UL =1	48 years	2D	To assess the response of the PLP to RA treatment guided by myoelectric activity in the residual limb
Ortiz-Catalan, 2016	Sweden	Single-Group Clinical Trial	N=14 Age=50 Gender=NI	UL =14	2 to 36 years	2D	To assess the effectiveness of a VR/AR system using EMF in PLP
Osumi et al, 2017	Japan	Single-Group Clinical Trial	N=8 Age=52 M=7 F=1	UL =8	6 to 36 years	3D	To investigate the use of VR in neurorehabilitation for the restoration of voluntary movement representations and the relief of PLP
Osumi et al, 2019	Japan	Single-Group Clinical Trial	N=19 Age=48 M=14 F=5	UL =19	2 to 38 years**	3D	To assess whether the characteristics of PLP influence the analgesic effects of VR
Perry et al, 2018	USA	Single-Group Clinical Trial	N=8 Age=20-30 M=8	UL =8	6 to 18 months	2D	To assess the use of a VR platform in patients with PLP
Rothgangel et al, 2018	Netherlands Germany	Randomized Controlled Clinical Trial	N=62 Age=61 M=52 F=23	LL =62	18 months to 18 years	2D	To compare MT using RA with the control groups (MT alone and sensorimotor exercises) PLP

Rutledge et al, 2019	USA	Pilot Study	N=14 Age=63 M=13 e F=1	UL =01 LL =13	1 year to 10+ years	3D	To assess the viability and acceptability of a VR device and the benefits of the treatment
Sano et al, 2015	Japan	Pilot Study	N=6 Age=55 M=6	UL =6	6 to 36 years	3D	To implement a multimodal VR system and demonstrate its effectiveness in PLP relief
Sano et al, 2016	Japan	Pilot Study	N=7 Age= 54 M=7	UL =7	6 to 36 years	3D	To apply a multimodal VR system to validate the effectiveness of tactile feedback in providing immediate PLP relief
Snow et al, 2017	United Kingdom	Case series from an on-going clinical pilot study	N=3 Age=50 M=3	UL =3	1 to 30 years	3D	To describe and evaluate a VR system with haptic interaction in PLP
Snow et al, 2022	United Kingdom	Case Report	N=1 Age=52 M=1	UL =1	2 years ***	3D	To assess whether VR therapy combined with haptic feedback reduces pain perception
Steckel et al, 2024	Brazil	Randomized Controlled Clinical Trial	N=21****	LL -21	NR*****	3D	To investigate the effects of a VR protocol on individuals with lower limb amputations
Ta et al, 2018	USA	Case Report	N=1 Age=31 F=1	LL =1	5 days	3D	To treat PLP in the immediate post-op period
Thogersen et al, 2020	Germany and Denmark	Proof-of-concept Study	N=7 Age=48 M=5 F=2	UL =7	4 to 42 years	3D	To assess the efficacy of an AR-based intervention in patients with PLP and the telescoping phenomenon
Tong et al, 2020	Canada, China, Australia	Case Series	N=5 Age=50 M=5	UL =5	1 to 30 years	3D	To explore VR therapy in multiple sessions for the treatment of PLP

Wake et al, 2015	Japan	Pilot Study	N=5 Age=58 M=4 F=1	UL =5	more than 8 years	3D	To assess the immediate clinical effect of a multimodal VR system with haptic feedback in 3 conditions
Yoshimura et al, 2023	Japan	Case Report	N=1 Age=40 F=1	UL =1	9 years	3D	To describe the effect of VR therapy on PLP

Legend: VR: virtual reality; N: number of patients; M: male; F: female; NR: not reported; UL: upper limb; LL: lower limb; AR: augmented reality; PLP: phantom limb pain; PME: phantom motor execution; MT: mirror therapy.
* the study did not report the participants' age and gender.
** the study reported time of disease (PLP) in place of time of amputation, which may differ from one another.
*** estimated time – the study reports the year of the amputation, and the time was calculated based on the year reported in the study and the publication date.
**** the study shows discrepancies in the information regarding the sample size.
***** it was not possible to draw conclusions about the time of amputation based on the reported data.
Source: The authors.

The 29 identified articles exploring VR visualization techniques for the treatment of PLP studied a total of 252 patients and were published between 2006 and 2024 (Figure 2) by research groups from 12 countries: the United States, Germany, the United Kingdom, Ireland, Denmark, Japan, Sweden, Canada, France, Brazil, the Netherlands, and China.

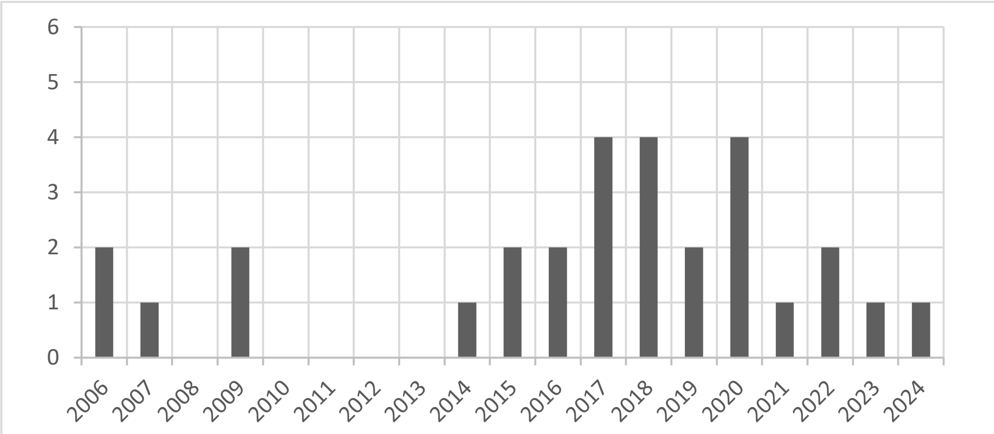

Figure 2 – Number of articles published per year.
Source: Prepared by the authors.

The largest sample studied was in a clinical trial[10] in which 62 participants completed the established protocol. Among the studies analyzed, the youngest participant was 27 years old[11] and the oldest participant was 80 years old[12]. The reported number of male participants was significantly higher (male = 178 and female = 50). The number of upper limb amputees was n=130, and the number of lower limb amputees was n=122. There was a wide variability in the time of amputation, ranging from a participant who had been amputated more than 50 years prior[13] to a participant whose amputation had occurred 5 days prior[14]. Most studies used 3D VR technology.

Table 3 summarizes the data regarding the VR systems used in the studies analyzed.

Table 3 - Characteristics of VR systems and study results

Author	Technique	Controls the virtual limb	Devices	Game objective (software)	Home use	Results
Ambron et al, 2018	PME	Stump	HMD Oculus Rift, simple inertial sensors, laptop, hearing feedback	4 games: Search for Fire, Web Browser, Chess, and Checkers	No	Pain reduction immediately after the session
Ambron et al, 2021	DISTRACTION+ PME	PME: Stump	HMD headset, sensors on the limbs with Velcro straps, electromagnetic tracker, the public game "Cool!" and a customized game	To move blocks with the virtual limbs, feed the dog, use a web browser, and play chess	No	Pain reduction after the sessions and throughout the study, with no significant difference between the distraction treatment and the movement treatment
Annaswamy et al, 2022	MT	Intact	Camera, HMD Oculus Rift, software Mr.MAPP, laptop	To pop bubbles, pedal game, and piano game	Yes	Pain showed signs of improvement
Chau et al, 2017	PME	Stump	HMD HTC Vive VR, portable controls, position-tracking sensors, myoelectric control armband, customized game software, commercial game software, PC.	To handle objects in an interactive kitchen	No	Pain and pain area reduction
Cole et al, 2009	PME	Stump	Image displayed on a PC, motion capture device, electromagnetic sensors on the arm or leg	To grab an apple, play the drums	No	Pain reduction
Desmond et al, 2006	MT	Intact	Wireless data gloves, computer monitor, graphic computing software	To perform movements with the fingers and palms	No	Discomfort and pain perception reduction
Ichinose et al, 2017	MT	Intact	HMD Oculus Rift, Kinect sensor on the unaffected limb, vibrating device	To touch the objects	No	Evidence of analgesic effects resulting from tactile stimulation applied to the cheek on the side of the affected limb during VR
Kulkarni et al, 2020	MT	Intact	HMD Oculus Rift and motion tracking	3D Ball Game	No	The study lacked evidence of the effectiveness of RV in PLP
Lendaro et al, 2020	PME	Stump	Myoelectric pattern recognition device, electrodes, laptop, and VR/AR game	4 game options: VR virtual limb control; AR	Yes	Participants used VR/AR as a supplement treatment to

				environment; racing game; target-reaching control test		medication, with a reduction in dosage
Mercier and Sirigu, 2009	MT and PME	Intact	Mirrored video displayed on a computer screen	To mimic the movement in the video	No	Pain reduction at the end of the study and at the end of the follow-up
Murray et al, 2006	MT	Intact	HMD, glove, sensors, and electromagnetic tracker	To put hand/foot on pieces that light up, hit or kick a ball, aim the ball at a target, perform lifting/bending movements	No	All participants reported PLP pain reduction while immersed in the virtual environment
Murray et al, 2007	MT	Intact	HMD V6VR Headset, glove, and sensors	To put hand/foot on pieces that light up, hit or kick a ball, aim the ball at a target, perform lifting/bending movements	No	Pain relief in at least one of the sessions
Ortiz-Catalan, 2014	PME	Stump	BioPatRec movement prediction technology, webcam, electrodes, EMG sensors, AR and VR environments, computer screen	To perform movements in a VR and AR environment, and a racing game	No	Positive effect of the intervention on pain reduction
Ortiz-Catalan, 2016	PME	Stump	BioPatRec movement prediction technology, webcam, electrodes, EMG sensors, AR and VR environments, computer screen	Car racing games and random target positions using phantom motions	No	Pain intensity reduction throughout the treatment. The improvement remained after 6 months
Osumi et al, 2017	MT	Intact	HMD Oculus Rift, video camera with an infrared sensor, 3D computer graphics software	To reach a target object	No	Short-term VR rehabilitation program reduced PLP
Osumi et al, 2019	MT	Intact	HMD Oculus Rift, sensor, 3D computer graphics software	To move the ball, carry blocks, draw an 8	No	VR technique was more effective for pain associated with distorted movements of the phantom limb and fixed posture
Perry et al, 2018	PME	Stump	EMG capture of residual limb movements, laptop, virtual reality platform	Wrist flexion, extension, pronation, and supination + opening and closing the hand to form a fist	No	Symptom relief in 7 of the 8 patients

Rothgangel et al, 2018	MT	Intact	Telerehabilitation platform, camera integrated into a tablet with software (platform) installed	Exercises with the intact limb	Yes	MT with AR did not show better results than traditional MT and sensormotor therapy
Rutledge et al, 2019	PME	Stump with prosthesis	Earphones, Oculus Rift, built-in camera, foot pedal, motion sensor, VR game, laptop (replaced by a smartphone at the end of the study)	To ride a bicycle	Yes	Pain intensity and phantom sensations reduction
Sano et al, 2015	MT	Intact	Kinect motion sensor, HMD Oculus Rift, earphones, glove and sensors, vibration device	To move the intact arm to reach the target object with the affected hand in the virtual environment	No	Pain intensity reduction and feasibility of the tested system
Sano et al, 2016	MT	Intact	Kinect movement sensor, HMD Oculus Rift, gloves, vibration devices, Unity game platform	To reach a target object	No	Pain-relieving effect of a few minutes
Snow et al, 2017	PME	Stump	HMD Oculus Rift, Unreal Engine 4, Nimble camera, 6-DOF HapticMaster, electrodes	Exercises featuring daily activity scenes to reach, pick up, and place objects	No	Association between an augmented sense of embodiment of the virtual limb and pain levels reduction
Snow et al, 2022	PME	Stump	Oculus Rift headset, vibration device, movement sensors, customized game	To move and stack blocks, tactile stimulation of the stump	No	Reduction in pain levels and improvement in movement range
Steckel et al, 2024	AO	Avatar	GEAR VR headset and Galaxy smartphone	Lower-body exercises, such as knee extensions with weighted pads	No	No improvement in PLP
Ta et al, 2018	MT	Intact	Headset VR + smartphone with app	Mirror therapy exercises using the Mirror Therapy VR mobile app	No	Pain level reduction
Thogersen et al, 2020	PME and RMf	Stump	HTC Vive headset, cameras, position tracker, myoelectric control armband, computer, Blender 3D modeling software (open source)	To choose and place an object in its proper spot game, imitation game, and sorting game	Yes	Pain reduction and reversal of cortical reorganization
Tong et al, 2020	MT	Intact	HMD Oculus Rift, HTC Vive, VR controller held by intact hand, Unity3D	To push the ball off the table and make a basketball shot	No	Pain reduction

Wake et al, 2015	MT	Intact	Kinect movement sensor, HMD Oculus Rift, gloves for finger movement detection, vibration devices, Unity game platform	To move the intact arm to reach the target object with the affected hand in the virtual environment	No	Pain scores decreased in 4 of the 5 patients
Yoshimura et al, 2023	PME	Stump	HMD HTC Vive, VR controller on the amputation stump, Unity software	To catch a ball with the virtual hand	No	Reduced pain intensity

Legend: PME: phantom motor execution; MT: mirror therapy; HMD: head-mounted display; AR: augmented reality; AO: action observation; fMRI: functional magnetic resonance imaging; RIFT, HTC VIVE VR, and GEAR VR are models of VR headsets. MR MApp is the name of the software used in the study. Source: The authors.

Unlike other pain syndromes in which VR therapy has been studied and administered through distraction techniques, the synthesis of this review showed that the design of VR systems for the treatment of PLP was based not only on distraction but also on three other techniques: mirror therapy (MT), phantom motor execution (PME), and action observation (AO). Only Ambron et al.[15] used the distraction technique, but in combination with PME. In interventions that applied MT as the conceptual basis for the system architecture[10,12,14,16–28], the intact limb was used to control the illusions and generate the mirror image for the opposite (amputated) limb as an image of an intact limb in the virtual environment.

Although the VR mirroring technique is possible for unilateral amputees, its applicability to bilateral amputees is limited due to the need for an intact limb as a reference. PME does not have this restriction, allowing its use by patients with bilateral amputations. This approach uses the stump of the amputated limb to generate the illusion of a complete limb in VR and has also been explored in studies[2–3,11,13,15,29–36]. However, only Ortiz-Catalan et al.[32] and Perry et al.[2] included participants with bilateral amputations. In the intervention by Steckel et al.[37], participants observed the avatar performing the exercises (OA) and remained seated without performing any movements.

With the exception of the study by Ambron et al.[15] – which used distraction through immersive video in one phase of its intervention – and the study by Steckel et al.[37] – which displayed an app featuring an avatar performing physical exercises – all other research was conducted using gamification or repetitive exercises in the implementation of VR exposure therapy. Despite the diversity in thematic content (Table 3), the game and exercise software programs were designed with the objective of performing a task that required the participant to move their limbs.

Some of the studies used VR in a home setting, administered by the participants themselves.[10,13,16,33,36] The remaining studies were conducted in laboratory and hospital settings.

Among the studies that were analyzed, the pilot study by Kulkarni[12] and the randomized controlled clinical trial by Steckel et al.[37] were unable to demonstrate the efficacy of VR in treating this type of pain. The study by Rothgangel[10], a randomized controlled clinical trial, was unable to demonstrate the superiority of TE with AR compared to traditional TE and sensorimotor treatment in relation to the outcome pain. All other studies presented positive results in reducing PLP and signaled their potential use in the therapeutic treatment of these patients.

DISCUSSION

The first studies exploring VR for the treatment of PLP date back to 2006[17,20]. Over the past 18 years, most of the research provided an immersive experience that required users to perform active physical movements and was conducted in laboratories using complex, high-cost, difficult-to-transport equipment and required customized software programs, limiting their replication in clinical settings. VR headsets and their integrated accessories, currently available on the market, are capable of providing the necessary interaction between the user and the immersive environment. Because they are lightweight and portable, these devices make this modality more accessible and user-friendly. Rutledge et al.[33] advocate for the concept that VR-based treatment for patients with PLP should be portable and equipped with a system that is easy to initiate to manage pain in real time.

Within the 29 studies analyzed, only 5 proposed VR systems that were used in a home setting and administered by the patients themselves[10,13,16,33,36]. However, the complexity of the equipment's architecture[13,33,36] and the use of customized software[10,16] require resources and specific infrastructure, making their application in household environments impractical. The study by Ta et al.[14], although conducted on a hospitalized patient, presented a VR system with potential for home use, utilizing an HMD with a smartphone and a commercially available app. All of these studies were published from 2018 onward, showing a tendency to seek a solution that can be administered autonomously and used continuously.

The study by Annaswamy et al.[16] demonstrated the importance of home technical support in helping patients with the configuration of the complex VR systems used in the research. Patients received home visits and weekly remote support, and one of them received support via Skype. However, a protocol that includes home visits is difficult to implement, given that most healthcare systems do not offer home care support for outpatients. On the other hand, it is possible to use digital technologies to provide teleassistance and telemonitoring to these patients.

Given the interest in making VR therapy available for home use, the low adherence to home treatment among study participants was a significant finding highlighted by Rothgangel[38] and Lendaro[13]. The factors attributed to the low adherence included difficulty in adapting to the routine; the complexity of the protocols; and usability issues with the devices. In contrast, the patient's intrinsic motivation is considered a factor in the effectiveness of VR[39]. Thus, engagement strategies are essential to the success of home therapy and should be considered.

The accelerated pace of technological development poses a significant challenge for VR research. As noted by Rutledge et al.[33], equipment becomes outdated very quickly, which can compromise the ecological validity of studies. Rutledge's team faced this situation throughout their research, needing to replace the equipment under study due to its obsolescence. This experience illustrates the difficulty of conducting research in a field in which technology becomes obsolete in a short period of time. The constant updating of devices requires researchers to adopt procedures to ensure that their studies remain relevant and that the results can be applied in care practice.

However, the lack of robust clinical studies with control groups, statistically significant samples, and well-designed protocols limits our understanding of the effectiveness of this technology. It is important to note that most studies present methodological limitations, such as single-case reports and case series[13–14, 17, 21, 26, 28–31; 34–35], single-group trials[2, 11, 15, 18–19, 22–23, 32], and pilot studies[12,16,20,24-25,27,33,36]. Although the reviewed literature indicates a general consensus regarding the efficacy of VR in managing pain associated with PLP, the pilot study by Kulkarni et al.[12], as well as the two randomized controlled trials conducted by Rothgangel[10] and Steckel et al.[37], did not provide sufficient evidence of the effect of VR on PLP. The results of Ambron et al.[15], in turn, showed no difference between the distraction and PME movements phases, raising questions about the best VR approach for PLP. The heterogeneity of the methods used and the protocols of use adopted in the different studies makes it difficult to compare results and identify the factors that influence the efficacy of VR. These findings highlight the need for further research to clarify these gaps and identify the most effective VR modality for PLP.

The absence of discussions regarding the disinfection of VR equipment in the studies analyzed is concerning. Given the increasing use of VR in hospital settings, proper disinfection is essential to prevent the transmission of pathogens among patients. It is essential that future studies address this issue, considering the specific characteristics of each device and best practices for preventing hospital-acquired infections.

It was also noted that there is a need for further research exploring the integration of VR technologies with games that are accessible to the general public, as well as the use of standardized protocols for providing tele-assistance.

A limitation of this scoping review is that the search strategy considered only the term “virtual reality” and did not include the term “augmented reality.” This may have influenced the results and excluded some relevant studies using AR. The criterion of including only open-access articles for study selection may also be considered a limitation. However, it is believed that the literature reviewed adequately represents the scientific production on the topic investigated.

In summary, VR represents an innovative and promising approach to the treatment of phantom limb pain. By providing an immersive experience, VR can serve as an adjunct to conventional treatment and significantly improve patients’ quality of life. However, further studies are essential to evaluate the efficacy of VR in patients with PLP and to develop standardized treatment protocols.

CONCLUSION

This scoping review aimed to synthesize the evidence regarding the application of VR in the treatment of PLP. The data analysis shows that the VR systems employed in the treatment of PLP result from a combination of the execution technique, the VR equipment, and the 3D game software.

To conduct VR therapy, the studies analyzed applied not only the principle of distraction adopted in other pain syndromes, but also the principles of three techniques: MT, PME, and AO. Distraction and AO allow VR therapy to be performed on these patients even without active movements, eliminating the need for sophisticated equipment. It can be inferred that these two techniques can be applied using VR headsets paired with smartphones, which favors their use due to their low cost.

On the other hand, MT and PME techniques require equipment that needs to detect the patient’s movements. Although the studies reviewed used complex devices, it can be inferred that current VR headset technology allows for this application in clinical practice, provided that modifications are made to attach the equipment's accessories to the amputated stump and capture the user's movements.

Regarding the software, the mapping shows the use of customized games. However, for widespread clinical application, the software must be accessible. It is recommended that future research use publicly available games that are compatible with the VR headsets.

The results are promising; however, the synthesis of the evidence shows that the analgesic effect of VR in these patients has not been proven by the two randomized clinical trials. Future research should employ more robust methodological designs and adopt strategies that promote participant inclusion and adherence, given that the studies reviewed faced difficulties with this study population.

This review provided insight into how VR has been applied in PLP. It was important to address this knowledge gap. The synthesized data do not demonstrate whether there is a superior technique for promoting the analgesic effect or whether a combination of techniques would be more appropriate. They also show that there are no validated protocols regarding the frequency and duration of therapy. The need to explore equipment sterilization is also highlighted. These gaps should be the focus of future research in order to clarify the role of VR in the therapeutic management of these patients.

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VIRTUAL REALITY-BASED SYSTEMS AND THEIR ANALGESIC EFFECTS IN THE TREATMENT OF PHANTOM LIMB PAIN: A SCOPE REVIEW

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Authors' contributions	
Crisley da Silva Guenin:	Conceptualization; data curation; investigation; methodology; data and experiment validation; data presentation design; writing –original draft.
Beatriz Cristina Freitas:	Investigation; methodology; data and experiment validation.
Rosa Maria Esteves Moreira da Costa:	Conceptualization; project management; provision of tools; supervision; data and experiment validation; writing –review and editing.
All authors approved the final version of the manuscript.	

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Corresponding author: Crisley da Silva Guenin
Rio de Janeiro State University - UERJ
Boulevard 28 de Setembro, 77. Prédio CePeM - 3° andar. Vila Isabel.
Rio de Janeiro, RJ, Brazil - CEP: 20551-030
crisleyguenin@hotmail.com

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