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Integrating Virtual Reality with Cognitive Behavioral Therapy to Reduce Phantom Limb Pain: Approach in Orthopedic Rehabilitation

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ABSTRACT

Phantom limb pain (PLP) remains a persistent and multifaceted challenge in orthopedic rehabilitation, often resistant to conventional treatments such as pharmacotherapy and mirror therapy. This study explores the integration of Virtual Reality (VR) and Cognitive Behavioral Therapy (CBT) into a unified VR-CBT intervention as a promising and patient-centered approach to PLP management. Through a systematic literature review and bibliometric analysis of studies published between 2015 and 2025, this research evaluates both the clinical effectiveness and the evolving thematic landscape of VR-CBT applications. Findings indicate that VR-CBT can reduce pain intensity by approximately 30–50%, improve rehabilitation adherence, and address psychological factors associated with chronic pain. Bibliometric mapping further reveals a growing research trend toward interactive, immersive, and psychosocially integrated interventions, with recent emphasis on terms like “augmented reality,” “video game,” and “quality of life.” Despite these promising developments, gaps remain in protocol standardization and large-scale clinical validation. This review underscores the urgent need for rigorous, high-quality studies to establish VR-CBT as a viable and scalable solution within modern orthopedic rehabilitation.

KEYWORDS
Phantom limb pain; VR-CBT; Orthopedic rehabilitation; Bibliometric analysis

INTRODUCTION

Phantom limb pain (PLP) is a common and distressing condition affecting amputees, leading to both physical discomfort and psychological challenges such as anxiety, depression, and reduced quality of life (Lendaro, 2025; Limakatso, 2025; Zernitz, 2024). Traditional treatments, including pharmacological interventions and mirror therapy, have shown limited success in providing sustained relief, particularly for chronic phantom limb pain (PLP) cases (Limakatso., et al, 2025). This situation underscores the need for innovative and evidence-based solutions.

In recent years, Virtual Reality (VR) has emerged as a promising tool for modulating pain perception through immersive sensory feedback (Elgendy, 2024). At the same time, Cognitive Behavioral Therapy (CBT) has been proven effective in addressing maladaptive thou ghts, emotions, and behaviors associated with pain (Zernitz, 2024; Elgendy, 2024). However, the integration of VR and CBT within orthopedic rehabilitation is still underexplored.

Phantom limb pain (PLP) is a prevalent and distressing phenomenon experienced by 60–87% of amputees, characterized by painful sensations seemingly emanating from the absent limb (Lendaro, 2025; Limakatso, 2025; Zernitz, 2024). Its pathophysiology is multifactorial, involving maladaptive cortical reorganization, disrupted body schema, and neuromatrix-level alterations (Mareboina, 2024). Despite the availability of pharmacological treatments, many patients report limited relief, prompting growing interest in non-pharmacological interventions such as mirror therapy, cognitive multisensory rehabilitation, and graded motor imagery (Limakatso., et al, 2025). However, challenges remain, including low adherence, protocol variability, and limited generalizability across patients, emphasizing the need for innovative, accessible, and evidence- based approaches (Hanyu-Deutmeyer, 2025).

Virtual Reality (VR) has emerged as a promising non-invasive intervention for PLP, leveraging immersive visual and sensory feedback to simulate limb presence and movement, which appears to reduce pain via neuroplastic modulation (Lendaro, 2025; Elgendy, 2024; Eldaly,2024). Systematic reviews and clinical trials have demonstrated VR's potential to significantly alleviate pain and enhance function, with interventions ranging from simple visual feedback to myoelectric- controlled virtual limbs.[5] Importantly, VR applications have expanded beyond clinical settings into home-based and early rehabilitation use, addressing accessibility and improving engagement (El-Gabalawy, 2025; Steckel, 2024). Both active phantom limb execution and motor imagery show comparable pain reduction (up to 68%), protocol heterogeneity and small sample sizes remain barriers to conclusive evidence (Lendaro, 2025; Gan, 2025).

Cognitive Behavioral Therapy (VR-CBT) offers a compelling psychotherapeutic approach to PLP by targeting maladaptive beliefs, emotional distress, and dysfunctional pain behaviors within an embodied virtual experience (Gan., et al, 2025). VR-CBT combines graded exposure, guided imagery, and interactive biofeedback to enhance body awareness, agency, and pain coping strategies. Preliminary studies suggest that VR-CBT may outperform standalone psychological or sensory modalities by enhancing patient motivation and facilitating adaptive neuroplasticity (Gan., et al, 2025). Nonetheless, robust clinical trials are still needed to establish VR-CBT's comparative effectiveness and to develop standardized protocols for broader clinical implementation.

The primary aim of this literature review is to evaluate existing evidence on the effectiveness of VR-CBT in reducing PLP among post-amputation patients. Despite growing interest in both VR and CBT as individual interventions, research specifically examining their integrated application remains limited and methodologically inconsistent. To address this gap, this study not only assesses clinical outcomes related to VR-CBT but also explores the broader research landscape through a bibliometric analysis. This bibliometric component maps the evolution of the field by visualizing keyword co-occurrence, thematic clusters, and emerging publication trends. By doing so, it enhances our

understanding of the intellectual structure of VR-CBT research and highlights underexplored topics and shifting priorities. In addition to offering insight into the trajectory of current research, this study supports future investigations by identifying strategic directions for development. Given the lack of standardized protocols and the limited number of high-quality clinical trials, advancing research on VR-CBT remains a critical priority to validate its clinical utility and promote its integration into rehabilitation practice

METHODS

This literature review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to ensure transparency and reproducibility. A systematic search was performed from the Scopus database published between 2015 and 2025. The search strategy used Boolean operators and combinations of the following keywords: “phantom limb pain,” “Virtual Reality,” “Cognitive Behavioral Therapy,” and “VR-CBT.”

Inclusion criteria: The search was limited to English-language, open-access, peer-reviewed journal articles within subject areas such as Medicine, Computer Science, Neuroscience, Psychology, and Health Professions. Excluding notes, editorials, books, and short surveys. Studies lacking empirical data, unrelated to PLP, or not reporting pain or rehabilitation outcomes were excluded.

The final synthesis compared VR-only and VR-CBT interventions, with a focus on evaluating treatment effectiveness, psychological engagement, accessibility, and evidence quality. Trends, limitations, and research gaps were also identified to guide future investigation in this emerging field.

Following full-text screening, a total of 70 studies were extracted for cluster and trend analysis through bibliometric mapping, while 15 studies met the inclusion criteria and were included in the final qualitative synthesis. These selected studies were analyzed to compare the outcomes of VR- only interventions with those of integrated VR-CBT approaches. The synthesis focused on evaluating the effectiveness of pain reduction, psychological impact, patient engagement, and accessibility of interventions. Additionally, the review assessed the methodological rigor of each study, including design quality, sample size, and reporting consistency, to determine the overall strength of evidence and identify critical research gaps. Special attention was given to novel contributions, recurring limitations, and strategic directions for future research.

RESULT

Research Trend

To complement the systematic review, a bibliometric analysis was conducted using VOSviewer to visualize the intellectual structure and thematic evolution of each keyword. This approach enabled the identification of keyword co-occurrence patterns, thematic clusters, and temporal trends across the literature. The results are presented through a network visualization and an overlay visualization.

The network visualization reveals five distinct thematic clusters within the literature on phantom limb pain (PLP), Virtual Reality (VR), and Cognitive Behavioral Therapy (CBT). For example, the red cluster represents core clinical and physiological themes such as “pain,” “nerve cell plasticity,” “pathophysiology,” and “sensory feedback”—suggesting a strong research foundation in neurobiological mechanisms and pain modulation.

The green cluster emphasizes VR and technological interventions, including terms like “virtual reality,” “augmented reality,” “visual feedback,” and “motor performance,” underscoring the increasing relevance of immersive rehabilitation approaches. The blue and yellow clusters include terms such as “mirror therapy,” “exercise therapy,” “review,” and “randomized controlled trial,” highlighting traditional therapies and research design approaches.

Meanwhile, purple and turquoise nodes such as “clinical article,” “article,” and “priority journal” suggest publication-level metadata was also significant in the network. The presence of

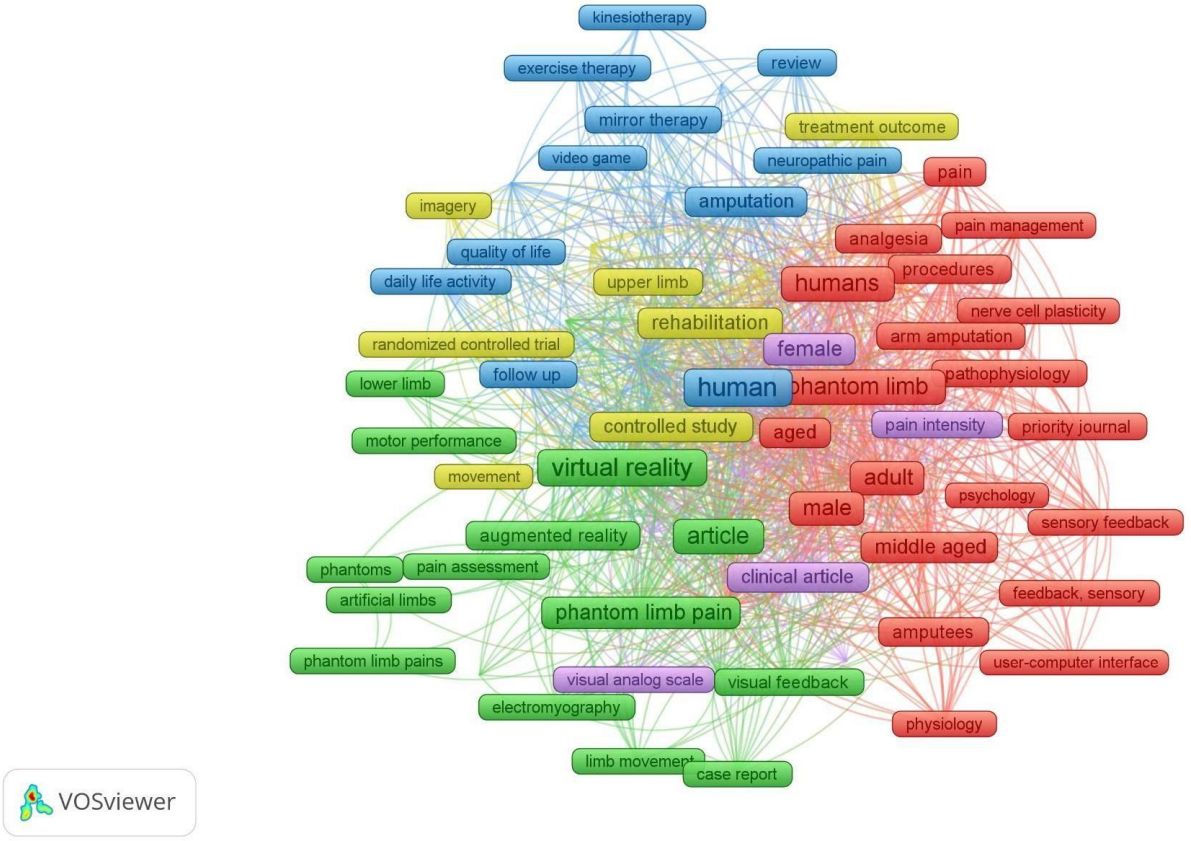

Figure 1. Network Visualization

terms like “psychology” and “rehabilitation” across clusters confirms the interdisciplinary nature of PLP research, integrating neurorehabilitation, behavioral therapy, and digital health technologies.

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The overlay visualization provides a temporal perspective of keyword usage across the literature, with color gradients representing the average year of publication for each term. Newer keywords appear in lighter shades (yellow to green), indicating recent research focus, while older, more established topics are shown in darker tones. This allows for a visual understanding of how research themes have evolved over time.

Table 1. The green cluster emphasizes VR and technological interventions

Cluster	Representative Keywords
Red: Clinical and Neurophysiological Core	phantom limb pain, pain intensity, amputation, nerve plasticity, somatosensory cortex
Green: Technological Interventions	virtual reality, augmented reality, immersive environment, visual feedback, motion capture
Blue: Psychological and Rehabilitation Approaches	cognitive behavioral therapy, biofeedback, anxiety, quality of life, coping strategies
Yellow: Research Methodology and Evidence	review, randomized controlled trial, feasibility study, clinical outcome, pilot study
Purple: Other, Publication, and Metadata	article, clinical article, priority journal, case study

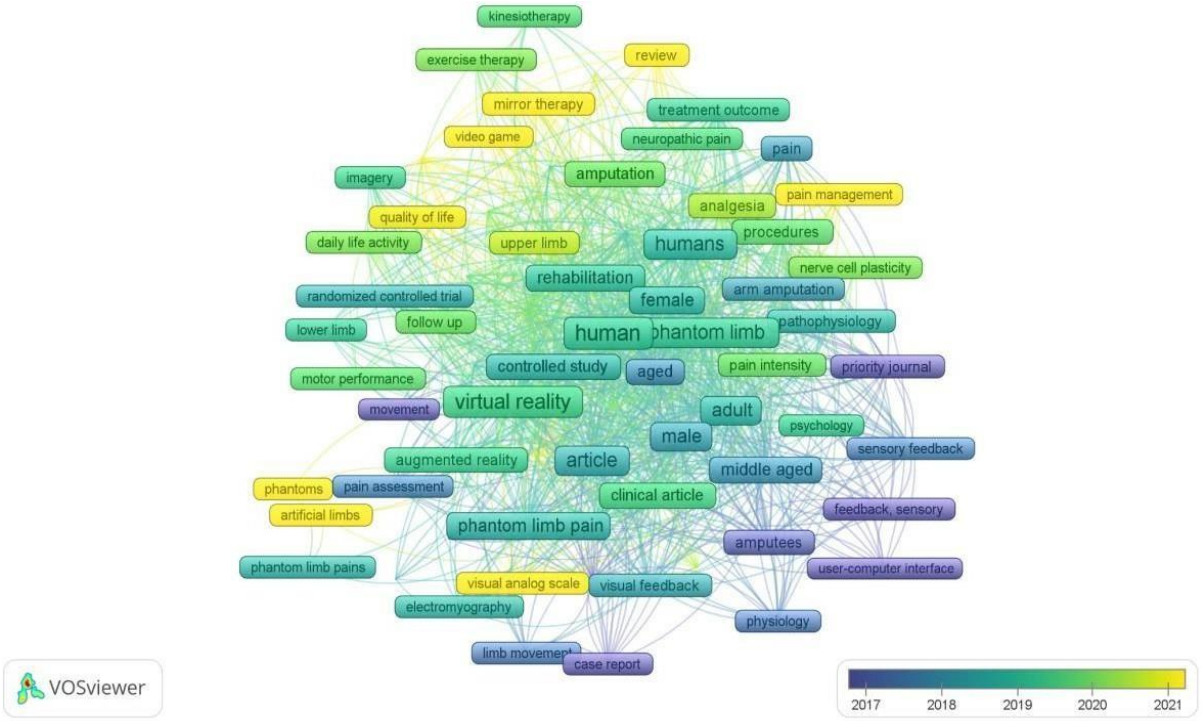

Figure 2. Overlay Visualization

Keywords highlighted in yellow and green—such as “augmented reality,” “video game,” “exercise therapy,” and “quality of life”—have become more prominent in publications from 2020 onward, signaling an increased interest in interactive, patient-centered solutions. These trends suggest a broadening of research scope beyond purely clinical approaches toward interventions that incorporate immersive technologies and psychosocial support. This growing focus reflects a greater recognition of the importance of patient engagement, emotional well-being, and usability in pain management strategies.

In contrast, foundational terms like “phantom limb pain,” “amputation,” “pain intensity,” and “rehabilitation” appear in darker hues, indicating their dominance in earlier years of the review period (2017–2019). The temporal progression from traditional topics to more integrated and technology-enhanced therapies illustrates a paradigm shift in the field—one that increasingly values multidisciplinary frameworks such as VR-CBT. This evolution aligns with global trends in digital health and remote rehabilitation, particularly in response to accessibility challenges highlighted during the

COVID-19 pandemic. As research momentum continues to build around immersive, scalable, and patient-tailored interventions, it becomes evident that VR-CBT is positioned at the intersection of innovation and clinical relevance in PLP care.

Recent Studies

Recent advancements in the treatment of PLP have highlighted the therapeutic potential of VR and its integration with CBT. Among the most influential works is Ortiz-Catalan et al. (2016), which introduced Phantom Motor Execution (PME) using augmented reality and myoelectric pattern recognition, demonstrating significant PLP reduction through cortical reorganization and restoration of disrupted body schema (Ortiz-Catalan, 2016). These findings align with immersive VR studies showing improved pain outcomes and sensorimotor function when patients engage with simulations of limb movement (Murray, 2007; Osumi, 2018). Platforms such as the Mr. MAPP systems extend these benefits into home environments, enabling gamified therapy and remote engagement, and offer promising scalability without sacrificing clinical effectiveness (Annapureddy., et al, 2023).

The evolution of PLP interventions has also moved toward more psychologically immersive and interactive approaches. Studies have shown that low-cost VR, when paired with graded motor imagery (GMI) and extended reality (XR) modalities, not only modulates neural responses but also enhances emotional regulation, body agency, and patient adherence (Lendaro, 2025; Ambron, 2018). While formal VR-CBT protocols for PLP are still emerging, initial feasibility trials integrating CBT principles—such as guided exposure, relaxation training, and biofeedback—into VR environments report enhanced self-efficacy and engagement.[8,9] These psychologically driven interventions align with the biopsychosocial model of chronic pain and represent an important evolution from traditional motor-only therapy models.

Despite encouraging outcomes, the field still faces several methodological and practical limitations. Many studies remain small in scale, with limited control conditions, heterogeneous protocols, and short-term follow-ups (Ishigami, 2024; Makin & Flor, 2020) . Bibliometric analysis supports the growing interest in VR and CBT integration post-2020, especially in interdisciplinary publications spanning neuroscience, rehabilitation, and digital health. However, the literature is still dominated by exploratory or pilot-level studies. For VR-CBT to gain clinical adoption, future research must prioritize well-designed randomized controlled trials, protocol standardization, and implementation strategies that consider therapist training, accessibility, and usability challenges (Steckel, 2024; Ishigami, 2024).

DISCUSSION

Although the application of Virtual Reality (VR) and Cognitive Behavioral Therapy (CBT) for phantom limb pain (PLP) has gained increasing attention in recent years, the current body of literature remains fragmented and methodologically limited. Many studies are pilot-scale or case- based, often lacking standardized protocols, control groups, or long-term follow-up. Furthermore, while VR and CBT have individually shown promise in managing chronic pain, there is a notable scarcity of rigorous research investigating their integrated use (VR-CBT) specifically for PLP populations. Recent exploratory trials and system prototypes, such as home-based VR platforms and graded motor imagery within immersive environments, indicate promising outcomes in terms of pain reduction, psychological engagement, and usability—but these approaches are still underrepresented in large-scale clinical evaluation. This underscores a critical gap between experimental development and clinical application.

To better understand the intellectual landscape and evolving trends in this domain, our study incorporated a bibliometric analysis of peer-reviewed literature from 2015 to 2025. Using co- occurrence mapping and overlay visualization, we identified five major thematic clusters—ranging

from neurophysiological mechanisms and pain rehabilitation to emerging technologies such as XR and gamified therapy. Notably, more recent keywords such as “augmented reality,” “video game,” and “exercise therapy” reflect a growing focus on accessible, patient-centered VR interventions. However, the bibliometric evidence also confirms the limited presence of VR-CBT-specific studies, highlighting a research niche that remains underdeveloped. This reinforces the urgency for future research to not only validate the effectiveness of VR-CBT interventions through robust randomized controlled trials but also to develop standardized, scalable, and psychologically grounded protocols that can bridge the gap between experimental innovation and clinical practice.

CONCLUSIONS

This literature review concludes that the integration of VR and CBT into a unified VR-CBT approach offers a promising, multidimensional intervention for managing phantom limb pain. By simultaneously addressing the sensory-motor disruptions and psychological distress commonly associated with PLP, VR-CBT presents a comprehensive and patient-centered strategy that aligns with contemporary rehabilitation paradigms. While early studies suggest encouraging outcomes in terms of pain reduction, engagement, and functionality, the current evidence base remains limited by small sample sizes, heterogeneous protocols, and a lack of large-scale clinical validation. Therefore, future research must prioritize robust randomized controlled trials, protocol standardization, and implementation pathways to fully realize the clinical potential of VR-CBT in orthopedic and neurorehabilitation settings.

CONFLICT OF INTEREST

The author(s) declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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None

PATIENT CONSENT STATEMENT

None

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request

GENERATIVE AI STATEMENT

The author(s) declare that no Generative AI was used in the creation of this manuscript

LIST OF ABBREVIATIONS

CBT : Cognitive Behavioral Therapy

COVID-19: COronaVIrus Disease of 2019
GMI : Graded Motor Imagery
PLP : Phantom limb pain
PME : Phantom Motor Execution
VR : Virtual Reality
XR : Extended Reality

PUBLISHER'S NOTE

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