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The Impact of Virtual Reality Training on Sport Injury Rehabilitation – a Literature Review

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Abstract

Introduction and Purpose:

Virtual reality (VR) technology is being studied more and more as an effective tool in sports injury rehabilitation. This review addresses current evidence concerning the application of VR in recovery from musculoskeletal and neurological injuries, control of pain, and psychological assistance, and potential roles in rehabilitation.

State of Knowledge:

Evidence indicates that rehabilitation with VR enhances patient engagement with immersive and interactive therapy, which can improve motor function, balance, and functional outcomes overall. VR is used in recovery rehabilitation of ligament injuries, orthopedic surgery, stroke, spinal cord injury, and traumatic brain injury. VR also proves effective as a non-pharmacological method of pain control, with a potential reduction in analgesic needs, such as opioids. Importantly, it was also shown that VR improves mental health by decreasing symptoms of anxiety, depression, and posttraumatic stress disorder, thereby convincing the audience about the overall benefits of VR-based rehabilitation.

Methods

The present paper searched the literature on electronic databases, including PubMed and ResearchGate, using the keywords "VR," "virtual reality injury," "virtual reality rehabilitation," "virtual reality pain," "virtual reality psychology," and "virtual reality cognitive function" Articles include randomized controlled trials, meta-analyses, and systematic reviews between 1999 to the present year, preferring the sources that were published from 2020 and onwards.

Conclusions

While VR offers a global, patient-centered approach that complements traditional rehabilitation methods, the scientific research in the field is meager. More studies are clearly warranted to establish VR's long-term effects and full potential in rehabilitation. This review highlights the current shortcomings and future promise of VR-based rehabilitation in sports injury rehabilitation.

Keywords

VR, virtual reality injury, virtual reality rehabilitation, virtual reality pain, virtual reality psychology, virtual reality cognitive function.

Introduction

Virtual reality (VR) technology has transformed numerous fields, including healthcare, by offering innovative solutions for rehabilitation (1). Injuries are common consequences of physical activities, affecting both professional and recreational athletes. Traditional recovery programs often require extensive physical therapy and patient engagement (2). However, recently, there has been a growing interest in integrating new technologies into rehabilitation processes, such as VR. Virtual reality-based rehabilitation offers an engaging, interactive, and customizable approach to therapy, that increases patient motivation and improves functional outcomes (1,3). This review explores the impact of VR training on sports injury rehabilitation, focusing on musculoskeletal recovery, neurological rehabilitation, pain management, mental health, and future advancements in the field (4,5).

Effectiveness of VR in Physical Rehabilitation

Musculoskeletal injuries, such as fractures, ligament tears, and joint dysfunctions, often require prolonged rehabilitation to restore strength, flexibility, and coordination. VR-based rehabilitation has gained attention as an effective method of enhancing recovery through immersive exercises encouraging movement in a controlled, engaging setting (6,7). Studies have shown that VR-assisted physical therapy helps athletes regain the motor control needed for specific movements. This method enables the creation of a wholly standardized and precisely controlled laboratory environment through predetermined geometric movement patterns and their intensity, which create more effective and transferable sensory-motor adaptations than those achieved through conventional exercise protocols (8). A recently published systemic review highlighted the effectiveness of VR-based therapy in recovering anterior cruciate ligament injury. Patients who recently underwent surgery due to injury were divided into two groups; 159 were rehabilitated using various VR-based methods, including

non-immersive VR (NIVR), semi-immersive VR, and immersive VR (IVR). At the same time, the remaining 171 participants formed the control group and received conventional treatment. Results showed improved pain reduction, knee function, strength, flexion range of motion, and dynamic balance among patients with VR-based therapy (9). Another application of VR in rehabilitation is its use in upper limb motor impairments in patients with stroke. The analysis considered the classification of patients according to their stage of recovery, applied rehabilitation approaches, duration of intervention, form of VR interaction, and the variety of games used. The results demonstrated the significant impact of virtual reality in enhancing motor function and refining manual dexterity (10). The findings suggest that VR-based rehabilitation serves as a valuable supplement to traditional methods rather than a replacement, potentially alleviating pain and improving functionality. This innovative approach shows promise in enhancing recovery outcomes following orthopedic surgery and offers a hopeful future for rehabilitation. Overall, VR-based rehabilitation offers a promising pathway to enhancing postoperative recovery in orthopedic patients (11,12).

Neurological Rehabilitation and VR

VR has shown remarkable potential in the rehabilitation of neurological conditions, including stroke recovery, traumatic brain injury (TBI), and spinal cord injury (SCI). Traditional neurological rehabilitation focuses on repetitive motor tasks to retrain the brain and restore lost functions (13). However, these exercises can become monotonous, reducing motivation and inconsistent progress (14). VR addresses this issue by creating immersive environments that enhance patient engagement and facilitate neuroplasticity. The meta-analysis examined 27 studies researching sensorimotor rehabilitation, which differed in the types of VR systems utilized and addressed both upper and lower limb function and balance training. Neural plasticity was assessed using functional magnetic resonance imaging (fMRI), electroencephalography (EEG), and transcranial magnetic stimulation (TMS), revealing a positive correlation between neuroplastic changes and improvements in functional recovery (15). An interactive, task-specific virtual reality system known as MNVR-Rehab was implemented in the rehabilitation of stroke patients presenting with moderate to severe functional impairments. Clinical trials which were examined in meta-analysis have demonstrated that the repetitive execution of functional tasks enhances neural activation, with an increase in the activity of mirror neurons (MNs), which plays a key role in supporting the

recovery of motor skills (16). Patients experienced more significant improvements in upper limb function and motor control than after the conventional therapy alone (17,18). A clinical trial on TBI demonstrated that semi-immersive VR can lead to better rehabilitation outcomes, achieving improved cognitive and behavioral results. Individuals were allocated into two groups: 50 received traditional cognitive rehabilitation, while 50 underwent virtual reality therapy (VRT). Both groups of patients showed improvements in cognitive function; however, those undergoing virtual reality therapy (VRT) demonstrated superior results and exhibited more significant enhancements in specific cognitive areas, such as cognitive flexibility, attentional shifting, visual search, and executive and visuospatial functions, which play a crucial role in the ability to organize and manage everyday tasks (19). Other studies have examined the impact of VR technology on gait using diverse devices. The meta-analysis included essential components of walking, such as lower limb strength, balance, and coordination, which are important elements of many activities. VR has demonstrated the potential to improve gait and balance in individuals with SCI (20).

Pain Management and VR

Pain is a significant barrier to effective rehabilitation, as it can limit movement, decrease motivation, and prolong recovery. Many athletes endure both acute and chronic pain because of injuries they have sustained in the past. Studies suggest that virtual reality is an effective non-pharmacological tool in pain management (21–23). VR has become a helpful tool by providing immersive distractions that alter the brain's pain perception. The analgesic effect is achieved by altering the activity of the body's intricate pain modulation system. Interaction with virtual reality delivers simultaneous visual, auditory, and haptic stimulation. This multisensory input is thought to occupy cognitive resources, thereby limiting pain processing and reducing the subjective experience of pain (24–26). For individuals recovering from orthopedic injuries or post-surgical procedures, such as knee surgery, common among athletes, VR can be integrated into therapy sessions to encourage movement while minimizing pain perception (27). A randomized, within-subjects, crossover clinical trial was performed to assess the effect of immersive VR. The study reported a positive analgesic effect in patients with traumatic injuries, attributed to increased activation of the parasympathetic nervous system and a sense of beneficial engagement (28). Numerous studies have investigated the use of VR as a non-pharmacological supplement to minimize the reliance on analgesics. VR demonstrates potential

as a practical therapeutic modality and complementary approach to pharmacological treatment; however, its integration into routine clinical practice requires additional high-quality empirical evidence (29,30). The study conducted by McSherry et al. showed that incorporating VR into painful wound care procedures significantly decreased the amount of opioid medication administered compared to procedures without VR (31). Another valuable application of VR is in rehabilitating burn patients, which helps reduce the duration of painful procedures. Additionally, it promotes faster injury epithelization and shortens hospitalization time (32–35).

Cognitive and Psychological Benefits of VR Rehabilitation

The psychological impact of sports injuries is often underrated but plays an important role in recovery. Athletes may experience stress, anxiety, and depression during their rehabilitation process, especially when they are unable to engage in their sport due to medical conditions. Sometimes, trauma can lead to disability, which can result in psychological problems (36). For example, patients after lower limb amputation may suffer from phantom limb pain, which increases the risk of depression (37). In a randomized trial, the experimental group, which received virtual reality training and standard rehabilitation, demonstrated a marked improvement in mental health outcomes. Studies show that adding VR to traditional rehabilitation reduces pain and is beneficial in depression treatment (38,39). Patients with spinal cord injuries also responded positively to virtual reality sessions, experiencing significant improvements in their mental well-being (40). Another practical application of VR is in the treatment of anxiety disorders, such as phobias and posttraumatic stress disorder (41). It enables personalized stimulation through safe and controlled exposure and exceeds the constraints of conventional talk therapy, which primarily focuses on the verbal processing of trauma-related memories (42). VR therapy has the potential to evoke deeper emotional and physiological responses by placing patients in immersive environments that replicate the sensory and emotional dimensions of their trauma (43,44). Combining various aspects of motor training with psychological and cognitive elements can be particularly effective among athletes. This

method may improve mood, strengthen motivation for active participation in the rehabilitation process, and improve visuospatial orientation and cognitive stimulation (45,46).

Challenges and Limitations of VR in Rehabilitation

Despite the great potential of VR in the rehabilitation of sports injuries, one cannot overlook its several disadvantages. The need to purchase expensive equipment and possess specialized expertise to operate it remains a serious obstacle. In addition, not every athlete will perform at its best in VR, which will discourage its practical use in recuperation. There is also the risk of motion sickness in patients, especially in a highly immersive environment. VR motion sickness triggers symptoms like nausea, dizziness, and fatigue, reducing the comfort of the users and hindering recovery (47,48). We found very little literature that reports long-term evidence of the efficacy of VR for sports rehabilitation. The majority of studies address short-term durations of rehabilitation. Additional studies must assess the long-term consequences of VR training, the impact on re-injury, and the contribution to the restoration of overall sports performance.

Conclusions

This review aimed to evaluate the impact of virtual reality training on sports injury rehabilitation in physical, neurological, psychological therapy, and pain management. VR has been demonstrated to have great potential as an adjunctive method in sports injury rehabilitation. Evidence exists that the interactive nature of VR increases patient engagement in therapy and supports functional recovery through task-specific, immersive training paradigms. In addition, evidence indicates the effectiveness of VR in pain reduction, thereby outlining its use to reduce pharmacologic dependence, specifically in injured and surgically treated patients suffering from chronic pain. Despite the growing number of studies on VR in rehabilitation, long-term randomized controlled trials must be carried out to determine more solid and sound conclusions. Further research is required to establish standardized protocols, assess long-term therapeutic gain maintenance, and integrate VR into multimodal rehabilitation systems.

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