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Innovations in Sports: A Key to Enhancing Rehabilitation Outcomes

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ABSTRACT:

Introduction and purpose: Traditional rehabilitation methods often have limitations in improving motor function and cognitive abilities. This review aims to provide an updated overview of innovative methods in rehabilitation, focusing on the role of immersive and interactive technologies in enhancing rehabilitation outcomes. The literature suggests that these technologies can improve upper limb mobility, grip strength, and manual dexterity, as well as cognitive function, attention, and spatial awareness. Additionally, innovative balance and gait rehabilitation programs have been shown to improve functional mobility and reduce the risk of falls. The use of these technologies in combination with other rehabilitation modalities, such as electrostimulation and robotic assistance, may lead to even greater improvements in motor function and cognitive abilities. While more research is needed to fully understand the benefits and limitations of these innovative approaches, the existing evidence suggests that they have the potential to revolutionize rehabilitation and improve quality of life for patients.

Materials and Methods: A literature review was conducted using PubMed with search phrases immersive and interactive technologies and rehabilitation.

Description of the state of knowledge: Traditional rehabilitation methods often have limitations in improving motor function and cognitive abilities.Upper extremity impairment is a common and debilitating consequence of stroke.

Summary: mmersive and interactive technologies have the potential to improve upper limb mobility, grip strength, and manual dexterity, as well as cognitive function, attention, and spatial awareness. Innovative balance and gait rehabilitation programs have been shown to improve functional mobility and reduce the risk of falls. The use of these technologies in combination with other rehabilitation modalities may lead to even greater improvements in motor function and cognitive abilities.

INTRODUCTION

Statistically, one person in the world suffers a stroke once every two seconds [1] . According to Global Burden of Disease 2019, stroke ranks second in terms of deaths worldwide and is the third most common cause of death and disability combined. Since 1990, there has been an increasing incidence of stroke of around 70% and the resulting disability is a major public health problem [2] . Statistics indicate that the global lifetime risk of stroke, starting at the age of 25, is 24.9% [3].

Stroke is a neurological condition that significantly impacts patients' quality of life, often hindering their ability to perform daily activities [4] . Upper extremity impairment is the most common disability affecting stroke survivors' inability to perform activities of daily living [5] . The recovery of hand motor function has a major impact on daily living activities. Many stroke patients suffer from functional impairment and are unable to move their hands due to insufficient rehabilitation. Hand impairments caused by stroke often present challenges in motor rehabilitation, requiring creative therapy for successful recovery [6,7]. One of the most serious and common sequelae of stroke is impaired balance, which significantly increases the risk of falls [8] . ‘Silent’ cerebrovascular pathology also plays a crucial role in the development of cognitive impairment in older adults[1].

AIM

The primary aim of this review is to provide clinicians with an updated overview of stroke rehabilitation options with using virtual reality. By summarizing current evidence and identifying gaps in knowledge, this review aims to inform about innovative methods of disability management after stroke.

MATERIAL AND METHODS

Database such as Pubmed was used for the literature review with the keywords: Eighty-four articles were considered for inclusion, with keywords immersive and interactive technologies and rehabilitation, with publication dates between 2019 and 2024 to ensure relevance to contemporary understanding and practice.

DESCRIPTION OF THE STATE OF KNOWLEDGE:

Over the past twenty years, the treatment of stroke has changed dramatically with new, effective methods of prevention, treatment in the acute phase and rehabilitation in the chronic phase [1] . The efficacy of conventional exercises in improving stroke patients' concentration may be limited due to the prolonged duration of therapy sessions[9]. A breakthrough appears to be the concept of mirror neurons, which is the foundation of mirror therapy (MT), an intervention used in upper limb rehabilitation in post-stroke patients[10]. The neuronal illusion is created by placing a mirror between two arms in such a way that the reflecting side faces odd[11]. The patient then makes arm movements on both sides and observes the reflection of the arm movements. This is a preparatory technique to induce neuroplasticity[12]. Brain preparation leads to modulation of cortical excitability, which can create a favorable environment for neurons to reorganize [13] . More recently, virtual reality also has been widely used in rehabilitation to promote user involvement, which has been proven to induce brain plasticity[6]. Games enriched with visual and audio feedback use neurophysiological reward mechanisms, such as by engaging dopaminergic reward systems, which can increase brain plasticity[14].

Virtual Reality in post-stroke upper limb rehabilitation

In the literature special attention has been given to the use of VR in upper limb rehabilitation in both the acute and chronic phases of stroke. According to many authors, this aspect is particularly important because the return of upper limb function is a major challenge for rehabilitation teams. Traditional therapy has several limitations in the reduction of motor impairments and the improvement of the general functional capacity of the upper limb[15].

- **Potential of computer games as a tool to support motor rehabilitation**

Numerous studies focus on the effectiveness and safety of implementing rehabilitation programs based on the use of gaming systems. The authors argue that such engaging and easily accessible solutions can be a valuable and effective complement to traditional rehabilitation[16]. Aguilera Rubio et al. studied the effectiveness of an inexpensive VR system based on the Leap Motion Controller®. It has included specially designed games that focused on different aspects of upper limb mobility, from shoulder joint movements and stabilization through pronation and supination of the forearm to hand movements, coupled with elements of traditional therapy. According to the authors, the system in combination with conventional physiotherapy benefits better grip strength, manual dexterity, and overall upper limb mobility compared to traditional exercises alone. In addition to the impact on upper limb function, the inclusion of VR had a positive effect on patients' satisfaction and tolerance of the therapy which was also reflected in the 100% attendance of participants[17].

Similar results were achieved when commercial gaming systems Jintronix and HTC Vive were attached[16,18]. Traditional ambulatory therapy augmented with an additional 4-week session with the Jintronix system resulted in statistically significant improvements in mobility, physical performance, and activities of daily living (ADLs) compared to the group without VR implementation. In terms of safety, no serious adverse events (falls, dizziness or pain) have been reported [18] . Also independly implemented the HTC Vive system, based head-mounted display has achieved similar results, contributing to increases self-agency among chronic stroke patients [16] . A study by Fen-Ling Kuo et al. found that also the use of the wearable sensor-based PABLO virtual gaming system resulted in greater improvements in the function of the upper limb, particularly in the hand dexterity and shoulders and elbows movements compared to traditional treatments. In addition, study participants also expressed greater satisfaction with the therapy[19].

Amin et al. showed that addictive computer games that engage cognitive functions and provide visual feedback can be an effective tool for improving hand motor function in post-stroke patients in the subacute phase of recovery. In the cognitive engagement paradigm, visual feedback in patients involves attentional processes, such as focusing on visual cues to select the colour of an object, and decision-making processes, such as selecting the right object of the right colour after the random appearance of the same objects of different colors. The six-week intervention, which included a set of four fully immersive games designed for hand rehabilitation, was a valuable addition to traditional therapy and an engaging rehabilitation environment[9].

On the other hand, Hung et al. showed that the Kinect2Scratch system, which uses a motion sensor to control games, provide similar benefits to therapist-led training in improving upper limb function in chronic stroke patients. According to the authors, while it may not completely replace traditional therapy, it could be a valuable adjunct to it, potentially reducing the burden on therapists[20].

- **Electrostimulation as a complementary rehabilitation tool using virtual reality**

Several authors have studied the impact of innovative interventions involving the addition of elements of electrostimulation combined with virtual reality to rehabilitation. Norouzi-Gheidari et al. evaluated the effectiveness of a rehabilitation program combining robotics, VR, and neuromuscular electrostimulation (NMES). In a stroke rehabilitation study, participants underwent a 4-week intervention, with sessions three times a week, tailored to their individual functional abilities. The researchers used a specialized algorithm, Predict Recovery Potential, to evaluate the integrity of the corticospinal tract, which involved measuring muscle responses to electrical stimulation and manual muscle testing. Based on the results, participants were divided into two groups: those with limited potential for hand recovery, who received robotic therapy focused on elbow and shoulder movements, and those with a higher potential for hand recovery, who received electromyography-triggered NMES in addition to robot-assisted therapy. The authors suggest that a personalized approach combining different rehabilitation modalities may be more beneficial in improving upper limb function in people with moderate to severe post-stroke impairment than using individual modalities[21].

Llorens et al, Lee et al, and Yao et al. conducted the studies to test whether combining transcranial direct current stimulation (tDCS) with VR therapy could effectively improve motor function in post-stroke patients[22–24]. Llorens et al suggest that the combination of tDCS and VR results in significant improvements in motor function, similar sensory effects, and improved cognitive function compared to traditional physical therapy[22]. Research conducted by Lee et al. indicates that anodal tDCS when applied to the same-side primary motor cortex (M1) during VR training, can significantly improve upper limb function, cognitive abilities, and executive function in individuals who have experienced a stroke [23] . Also Yao et al. suggests that combining cathodal tDCS with VR therapy may lead to greater improvements in upper limb motor function, overall functionality, and quality of life for individuals who have suffered an ischemic stroke, compared to using VR therapy alone [24]. In addition, Chen et al. studied efficacy of intermittent theta burst stimulation (iTBS) on the virtual reality-based cycling training for upper limb function in patients with stroke. This non-invasive brain stimulation technique has been shown to enhance the responsiveness of the brain's motor areas on the same side as the affected limb. As a result, effectiveness of VR cycling training may increase, leading to reduced spasticity, increased upper extremity use, and improved participation in daily activities[25].

- **Robotic assistance virtual reality**

Park et al. have proposed a VR-based rehabilitation program using the RAPAEL Smart Glove, which has been shown to be more effective than traditional therapy in improving upper limb function, activities of daily living, and increasing patient participation in the acute phase of stroke. Another promising development is the combination of robotic VR with task-oriented therapies that lead to activation of the cerebral cortex. Research suggests that robotic VR game training can effectively reduce spasticity and improve upper limb motor function in people in the chronic phase of stroke[26].

- **Mirroring Therapy Enhanced by Virtual Reality**

Mekbib et al. have investigated the effectiveness of an immersive virtual reality system called "Mirroring Neuron VR Rehab" (MNVR-Rehab), which is based on the premise that stimulating mirror neurons by combining the execution of a movement with its observation can accelerate the recovery of motor function. The system offers three modes of operation that focus on grasping, moving, and releasing the ball in a virtual environment. A study of brain activity using functional magnetic resonance imaging (fMRI) showed that neural activity increased after VR therapy, particularly in areas associated with mirror neurons, such as the motor cortex. This suggests that the MNVR-Rehab system may stimulate mirror neurons, potentially leading to better rehabilitation outcomes[27].

A study by Hsu et al. also have showed that virtual reality-based mirror therapy may be more effective than conventional occupational therapy and traditional mirror therapy in restoring upper limb motor function in post-stroke patients, especially wrist function and coordination[28].

A study by Jo et al. found that a novel mirror therapy based on 360° immersive virtual reality (360MT) was more effective than traditional mirror therapy and conventional physical therapy in rehabilitating the upper limb in post-stroke patients. Patients who received 360MT therapy reported greater engagement and motivation [29]. According to Errante et al, the use of combination therapy with VR can be an effective rehabilitation approach because it has the potential for better therapeutic outcomes by using both classical exercise therapy and the immersive environment of VR[30].

- **Effects of Virtual Reality on neuroplasticity and motor function**

Confirmation of the efficacy of the technological solutions mentioned above can be sought from MR studies of the brain and of the activity of the cortex in response to the stimuli applied. Chen et al. sought to understand how VR training affects cognitive processes related to movement planning and whether improvements in these processes translate into improvements in hand function. VR training was found to be more effective than conventional therapy in improving electromyography (EMG) reaction time and contingent negative variation (CNV) latency, suggesting improvements in cognitive processes related to motor anticipation [31] . The study by Keller et al. was designed to test whether virtual reality therapy (VAI) could improve upper limb motor function in people after brain injury. Participants in the experimental group showed an increase in gray matter volume in five brain areas: the caudate of the hippocampus, the left caudate nucleus, the left cingulate cortex, the left medial sulcus, and the left visual cortex. There was also a significant increase in the amount of gray matter in the brain areas responsible for movement (motor and premotor) on the side of the injury. This suggests significant changes in the brain's ability to remodel its structure [32] . The study by Huang et al. aimed to investigate the effects of immersive virtual reality-based motor control training on inflammation, oxidative stress, and neuroplasticity. The results of the study showed a significant effect of therapy duration on the levels of interleukin-6 (IL-6), heme oxygenase 1 (HO-1), 8-hydroxy-2-deoxyguanosine (8-OHdG), and on all motor functions assessed except coordination and speed. A significant treatment group effect was observed only for elbow extension range of motion and forearm pronation. In addition, the use of positive feedback in the form of "good" messages increased dexterity, as assessed by the time interval between touching the target and the beep, and performance, as assessed by the length of movement path, touch time, and accuracy of touch with the virtual hand, compared to negative feedback in the form of "bad" messages[33].

The Potential of Virtual Reality in Post-Stroke Balance and Gait Rehabilitation

Among the problems affecting post-stroke patients are dizziness, balance and gait disturbances. These limitations are particularly dangerous as they are often the cause of falls and a reduction in the patient's sense of independence, affecting their quality of life. Dedicated approaches involving virtual reality technologies exist to improve patient functioning in this area.

Previously known for virtual games, the Nitendo Wii or Xbox consoles are now an enrichment tool for traditional rehabilitation [34–36] . According to Sana et al, VR as a complementary or alternative therapy is potentially a more engaging and motivating option for improving balance and gait [34] . According to Marques-Sule et al. the addition of virtual reality with the Nintendo Wii to conventional physiotherapy provided greater benefits in the areas of reaction time, balance and activities of daily living. Being able to visualise one's own movements using an on-screen avatar and receiving positive feedback can stimulate neuroplasticity, resulting in improved balance in patients. However, the Wii Sports package did not significantly affect the range of function of the upper limb, suggesting that the applied exercises with Wii Fit did not specifically affect this area[35]. Also, the Wii Fit software on the Xbox console proved to be effective in improving functional mobility, independence and trunk stretch coordination in post-stroke patients. However, no difference was observed in terms of balance improvement compared to traditional exercises[36].

According to Kwak et al VR with a touch controller can stimulate purposeful upper limb movements in varied virtual environments, resulting in better body awareness and anticipatory movement ability. With VR, patients can practice movements in more varied and challenging environments, which translates into better postural control and body stability. Technologies using VR can vary in terms of immersivity, i.e. the degree of 'immersion' in the virtual world, which translates into providing the user with the most realistic and immersive experience possible. Immersive training compared to semi-immersive and traditional treadmill training provides an increase in gait speed and higher levels of motivation [37] . Fishbein et al. also evaluated dual-task training based on virtual reality performing cognitive and motor tasks simultaneously during training can be more effective than focusing on only one task. The authors also highlight the fact that the use of VR can make training more interesting and motivating for patients and increase confidence. There are also reports showing no significant difference between VR-based training and traditional vestibular rehabilitation therapy approaches for balance and gait [38].

Virtual Reality in Post-Stroke Cognitive Rehabilitation

Stroke, by causing brain damage, often results in impaired cognitive abilities such as memory, the ability to learn new information, plan task sequences, speech, reading with understanding and communication. However, thanks to the plasticity of the brain, post-stroke patients can re-learn the skills necessary to perform everyday activities.

In response to this challenge, Chatterjee et al. presented the Virtual Reality Environment for Therapeutic Use (VIRTUE) application, which uses immersive virtual reality technology to simulate ADLs using head-mounted displays. Key features of VIRTUE, such as ADL-based scenarios, difficulty level customization, therapist control and competitive elements in the game, aim to increase patient motivation and optimize the rehabilitation process. Pilot studies have shown promising results, indicating improvements in cognitive function especially in patients with more severe deficits, as well as reduced hospitalization times[39].

Also, Maiera et al. developed a programme called Adaptive Conjunctive Cognitive Training (ACCT). Patients performed a variety of tasks in a virtual environment that required them to use different cognitive abilities simultaneously. The programme automatically adjusted the difficulty level of the tasks to the patient's individual abilities, ensuring an optimal level of challenge. The experimental group that used ACCT showed significant improvements in attention, spatial awareness, and overall cognitive functioning. In the control group using traditional cognitive training, no significant changes were observed in any of the tested domains. A decrease in depression was also observed in patients using ACCT, suggesting a positive effect of VR training on psychological wellbeing[40].

A study by Manuli et al. investigated the impact of VR and robotic gait rehabilitation using the Lokomat, which is a robotic lower limb orthosis that allows patients with post-stroke gait disorders to perform treadmill training. Using an orthosis attached to the patient's legs, the robotic arm moves the patient's legs to stimulate a natural gait pattern. The included weight-bearing system reduces the strain on the patient's legs, allowing even people with limited muscle strength to train. The VR attached to the Lokomat acted as a virtual reality-based feedback module. This module provided patients with instructions, interaction and feedback related to their gait, displaying the results of the exercises on a screen. Exercises mainly consisted of collecting and avoiding objects randomly placed in a virtual environment. By adjusting the intensity and level of difficulty, the exercises could be adapted to the patients' motor and cognitive skills, providing personalized feedback. In this way, VR not only made the training more interesting, but also engaged patients in tasks requiring attention and decision-making, which contributed to a greater improvement in cognitive function than the use of the Lokomat alone[41].

However, not all studies agree on this point. A study by Ersoy and Iyigun aimed to compare the effects of virtual and real boxing training as an adjunct to traditional neurodevelopmental therapy. The study did not find that virtual reality boxing training was better than real training. Despite the small effect, the study suggests that boxing training, both in VR and in reality, may be a valuable adjunct to cognitive rehabilitation after stroke [42]. A study by Lee et al. investigated the effect of non-immersive virtual reality training on upper limb function and cognitive function in people with chronic hemiparesis after stroke. VR training included the use of the RAPAEL smart glove system, which facilitates task-oriented exercises in a virtual environment. Again, this study showed no clear advantage of VR training over recreational activities in improving cognitive function[43].

SUMMARY

Virtual reality has emerged as a promising tool in post-stroke upper limb rehabilitation, offering a more engaging and effective way to improve motor function, cognitive abilities, and overall quality of life for patients. Studies have shown that VR-based interventions can improve upper limb mobility, grip strength, and manual dexterity, as well as cognitive function, attention, and spatial awareness. Additionally, VR-based balance and gait rehabilitation programs have been shown to improve functional mobility and reduce the risk of falls. While more research is needed to fully understand the benefits and limitations of VR-based interventions, the existing evidence suggests that VR has the potential to revolutionize post-stroke rehabilitation and improve patient outcomes.

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