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Virtual reality in upper extremity rehabilitation of Multiple Sclerosis patients

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Abstract

Background: Virtual reality (VR) has emerged as a promising approach in the field of healthcare, particularly in the context of multiple sclerosis (MS), offering new possibilities for rehabilitation and improving the quality of life for individuals affected by this chronic neurological condition.

Methods: The electronic databases PubMed, Google Scholar, and PEDro were thoroughly searched using medical subject headings and free text related to multiple sclerosis, virtual reality, upper limb, and rehabilitation. The review followed the PRISMA guidelines.

Results: A total of 4 articles were included in the review. These articles examined the effects of VR in upper limb rehabilitation on patients with MS. The majority (n=2) of the studies compared VR with usual care, while one examined tele-VR and one with non-serious games.

Conclusion: VR interventions have shown promise in enhancing manual dexterity, upper limb rehabilitation, and arm function in MS patients. The use of serious games for arm rehabilitation has also demonstrated potential benefits in improving functional outcomes in MS patients.

Keywords: Multiple sclerosis; MS; Virtual reality; VR; Fatigue; Quality of life; Balance; Gait

1. Introduction

Multiple sclerosis (MS) is a prevalent chronic inflammatory, demyelinating, and neurodegenerative disease affecting the central nervous system primarily in young adults (Filippi et al., 2018). The characteristic feature of MS is the development of demyelinating lesions in the brain and spinal cord, often accompanied by neuro-axonal damage. These focal lesions arise from the infiltration of immune cells, such as T cells, B cells, and myeloid cells, into the central nervous system parenchyma, leading to tissue injury (Filippi et al., 2018). The disease is characterized by chronic inflammation, which persists even behind the blood-brain barrier, involving the activation of microglia and ongoing participation of T cells and B cells. This sustained inflammation can contribute to mitochondrial damage in neurons, resulting in an energy deficit and further compromising axonal health (Faissner et al., 2019).

Common symptoms commonly observed in individuals with MS include fatigue, balance disturbances, visual impairments, coordination problems, cognitive and emotional disorders, spasticity, and speech impairments (Winter et al., 2021). Among the challenges faced by MS patients, the limitation of dexterity, coordination, and functionality in the upper limb significantly impacts their ability to perform daily activities (Cuesta-Gomez et al., 2020), leading to a reduction in their independence (Corealle et al., 2017). The prodrome, an early set of signs or symptoms preceding the typical manifestations of the disease, has been identified in MS cases (Makhani et al., 2021). The risk of developing MS is influenced by interactions between genetic and environmental factors, as well as lifestyle factors (Ward et al., 2022).

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MS can be categorized into different phenotypes, including relapsing-remitting MS, primary progressive MS, secondary progressive MS, and a subgroup characterized by rapid accumulation of physical and cognitive deficits (Diaz et al., 2019). The clinical course of the disease is also influenced by the age of onset, with younger patients predominantly exhibiting relapsing-remitting MS, while those with later onset experiencing a faster progression of permanent disability (Graves et al., 2023).

The diagnosis of MS is established based on clinicopathological criteria that demonstrate the dissemination of the disease in both time and space within the nervous system (Travers et al., 2022). Unfortunately, there is a lack of imaging and biological markers that can accurately predict disease progression in individual patients (Klineova et al., 2018). However, ongoing research shows promise in identifying more reliable biomarkers for disease categorization and prognosis, enabling timely and personalized treatment approaches (Oh et al., 2018). While MRI has improved the diagnostic process for MS, misinterpretation of images and the application of MRI diagnostic criteria can contribute to misdiagnoses (Filippiet al., 2019).

The course of the disease has become milder, especially in the past 25 years since the introduction of the first disease-modifying therapies. Proper management of patients requires an understanding of the factors influencing the development and progression of the disease (Henriksen et al., 2021). Additionally, the increased longevity of the general population in the modern era has led to an increased prevalence of the disease (Doshi et al., 2016). Its occurrence in older age due to pre-existing comorbidities presents new challenges (Vaughn et al., 2019). In contrast to its higher frequency in older age groups, the frequency of pediatric-onset MS is relatively low (Deiva, 2020). It is estimated that pediatric MS (>18 years) represents 3-5% of the overall population of MS patients. Pediatric MS has a milder progression compared to adults; however, significant disability can occur at a young age (Brola et al., 2020). The life expectancy is typically normal or nearly normal, with about 74% of patients living 25 years after disease onset (Casselman et al., 2021).

Physical therapy has shown positive results in improving muscle function, physical fitness, and upper limb function in patients with MS (Centonze et al., 2020). In the last decade, there has been increased interest in the use of virtual reality (VR) for rehabilitation, both in clinical and home settings (Truijen et al., 2022). VR-based rehabilitation is rapidly evolving and has several benefits for the rehabilitation of neurological patients, especially when combined with conventional therapy (Porras et al., 2018).

Due to the long duration of treatments, patients gradually lose their motivation and compliance with therapy programs. Technology-based systems, such as virtual reality (VR), hold great promise as a complementary therapeutic tool. These approaches enhance patients' motivation, facilitate motor learning, and promote neuroplasticity through increased exercise intensity (Cuesta-Gomez et al., 2020). VR has been successfully used to support therapeutic approaches for various conditions, making it a highly promising method (Hollywood et al., 2022). The popularity of research on VR-based motor rehabilitation for patients with multiple sclerosis is rapidly increasing. However, few studies have focused on upper limb rehabilitation (Webster et al., 2021).

Upper limb rehabilitation requires special attention (Grange et al., 2022). This arises from the need to regain fine motor skills, and achieving smooth and precise fine motor control requires more time and dedication (Cuesta-Gomez et al., 2020). Upper limb disability leads to increased dependence on caregivers (Kanzler et al., 2022). Dysfunction of the upper limbs is one of the most significant impairments observed in individuals with MS (Krause et al., 2022). Studies reveal that this dysfunction can even occur in the early stages of the disease, with over 50% of patients experiencing such impairments (Lamers et al., 2016). Nerve entrapments of the upper limbs are quite common in patients with multiple sclerosis. In the later stages of the disease, patients use mobility aids, which contribute to such problems. These neuropathies should be considered in treatment and prevention. Patients report sensory and motor symptoms in their upper limbs (Yin et al., 2020).

It is important within the context of therapy to approach the patient holistically (Yamout et al., 2018). For example, occupational therapy in combination with virtual reality has shown significant improvement in terms of the accuracy and effectiveness of certain movements (Paniagua et al., 2019).

This review serves to explore the efficacy and potential of VR technology as a novel approach for rehabilitating upper limb impairments in individuals diagnosed with MS. By investigating the utilization of immersive VR environments in rehabilitation settings, the article aims to shed light on the advantages and limitations of this innovative therapeutic intervention. Through a comprehensive examination of existing studies, the article endeavors to provide a critical analysis of the impact of VR-based interventions on motor function, coordination, and overall quality of life for MS patients. Ultimately, the article strives to contribute valuable insights into the integration of VR technology as a promising adjunctive tool in upper limb rehabilitation for individuals living with Multiple Sclerosis.

2. Methodology

2.1. Review strategy

The review was conducted following the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) reporting guideline, which provides a checklist and diagram to ensure comprehensive and transparent reporting of the review process (Moher d et al., 2009).

2.2. Data sources

The electronic databases PubMed, Google Scholar, and PEDro were thoroughly searched using medical subject headings, and free text related to multiple sclerosis, virtual reality, upper limb, and rehabilitation.

2.3. Inclusion criteria

To ensure the inclusion of all relevant studies, the following criteria were applied:(a) studies reporting original research data on individuals diagnosed with multiple sclerosis;(b) studies evaluating outcomes related to upper limb rehabilitation;(c) studies with full-text availability; and(d) studies published in either English or other languages but with an English version.

2.4. Study selection

The eligibility screening process for the included studies was performed by two independent reviewers, Ev.T. and C.T., using a standardized and blinded approach. Initially, titles and abstracts were screened to identify relevant articles, and any duplicate publications were removed. Subsequently, full paper copies were obtained for further screening. The full-text screening was also conducted in a blinded manner by the same reviewers (Ev.T. and C.T.). In the event of any disagreements between the two reviewers, a third reviewer (Em.T.) was consulted to facilitate a consensus decision.

3. Results

Additionally, an interesting study examined virtual reality, which included only serious games specifically for rehabilitation, to improve upper limb muscle strength, fine dexterity, mobility, patient compliance, coordination, fatigue, and quality of life. The Leap Motion Controller (LMC) was used in these games. The patients were divided into the experimental group, where they underwent this virtual reality intervention for 15 minutes, and conventional physical therapy, and the control group, where patients received the same conventional physical therapy. Both groups followed a 60-minute/week program for 10 weeks. Specifically, in the experimental group, the patients had their elbows flexed at 90 degrees, any manual assistance from the physical therapists was present, and fatigue was taken into account. In this specific virtual reality, the Unity3D Game Engine and a USB LMC were used, which act as motion sensors for joint positions and movements, etc. In this particular study, 6 video games mimickedconventional physical therapy/exercises performed in both the experimental and control groups. These exercises included flexion, extension, finger extension, palmar extension, etc. The program progressively started with the execution of one limb and later involved both limbs. The following figure depicts the 6 games: piano game (PI), reach and grasp game (RG), sequence game (SG), grasp game (GG), pinch game (PG), and flipping game (FG). The results showed that the combination of virtual reality and conventional exercises can complementarily lead to significant improvements in speed, strength, coordination, fine/gross dexterity-mobility, quality of life, and treatment compliance. Moreover, significant improvements were noted on the more affected side of the patient (Cuesta-Gómez et al., 2020).

Furthermore, virtual reality was studied in tele-rehabilitation compared to conventional rehabilitation. Twenty-four patients with multiple sclerosis were included and underwent 16 training sessions over a total duration of 8 weeks. The patients were divided into the experimental group, where they had access to a private/portable computer, and the conventional group, where patients performed tasks in a sitting position. Specifically, this virtual reality program was provided by Unity Technology Inc. It is a game engine with capabilities of 3D/2D/augmented reality and simulations. Specifically, here, virtual reality is applied in three areas: self-care, dressing, and meal preparation, in a realistic space where the patient is required to interact with objects, etc. The movement trajectory, speed, upper limb coordinates of the patient, movement smoothness, and accuracy of object placement in the target are continuously recorded. This data is sent to the specialist for analysis. The parameters of the game are personalized to each patient. The results of this study indicate tremendous potential for functional upper limb activities. Patients must consult with healthcare professionals specializing in rehabilitation before undergoing such interventions to receive proper guidance. During the implementation of these games, any comparable results should be recorded separately, and the patient should use the best available option. These exercises, therefore, reduce the risk of falls, disability, and increase independence. It is worth noting that the cost of the platform is low, and the software is provided for free (Kalronet al., 2020).

A study compared the use of serious virtual reality games to non-serious games for rehabilitation. Sixteen patients were included and divided into the following groups: In the experimental group, 10 patients received therapy using serious games, Rehab@Home (Kinect), while in the control group, 6 patients received therapy using non-serious games, Nintendo Wii (exergame). Both groups underwent a 4-week program, 40 minutes per session, totaling 12 sessions, with 4 sessions per week. The program for the experimental group involved the use of 6 serious games that the patients performed in an upright or seated position. The results of this study showed a significant improvement in upper limb function (by 20% or more) in the experimental group, with minimal or no improvement in the control group. The perception of the patient regarding their health improved in both groups, but a noticeable improvement was observed in the experimental group. Motivation and experience were positive in the experimental group. Given that neurological conditions require the repetition of exercises several times, this specific method provides motivation and compliance for the patient. However, Nintendo improves the patient's perception without significant clinical improvement in upper limb function. This indicates that it also provides motivation but lacks sufficiently recognized worldwide beneficial components (Jonsdottir et al., 2018).

A recent systematic review examined the effects of virtual reality on upper limb rehabilitation in patients with multiple sclerosis. The review included 10 articles, 6 randomized controlled trials, 3 cohort studies, and 1 pilot study. About 73.4% of the participants had relapsing-remitting MS. The included studies utilized different types of virtual reality games, both commercial (Nintendo) and rehabilitation-specific (Microsoft Kinect). However, all types included similar exercises involving grasping and reaching. There were also other types of movements such as touching and twisting, performed with the help of a robot. For example, Rehab@Home consisted of exercises such as organizing the kitchen, object relocation, and flower picking/gathering. The duration per session varied from 20 minutes to 1 hour, and the overall program duration ranged from 1 day to 6 months. The results of this review showed that virtual reality can significantly improve upper limb motor function, and its effectiveness is greater than that of conventional exercises. Additionally, combining virtual reality with conventional exercises appears to further enhance the outcomes compared to using virtual reality alone. However, this study does not determine the clear relationship between effectiveness and the type of virtual reality or the required duration or intensity of the exercises (Webster et al., 2021).

Table 1 Studies included in the review

Author	Method	Results
Webster et al., 2021	VR (serious and non-serious games) vs conventional therapy	-VR > -VR + conventional therapy > enhanced results compared to VR alone -Lack of specification regarding appropriate intensity, duration, etc.
Cuesta-Gomez et al., 2020	VR (serious games) vs conventional therapy	-VR + conventional therapy > increased speed/strength/coordination/fine and gross motor skills/dexterity/compliance
Karlon et al., 2020	Tele + VR	-Promising method -Reduction in falls, improvement in independence -Lower cost, free software
Jonsdottir et al., 2018	VR (serious games) vs VR (non-serious games)	-Serious games > -Statistically significant results in upper limb improvement with serious games -Significant improvement in perception for both types -Serious games > in terms of experience and motivation

4. Discussion

The evaluation of the existing literature yielded a total of 4 articles that were included in the review. These articles examined the effects of VR in upper limb rehabilitation on patients with MS. The majority (n=2) of the studies compared VR with usual care, while one examined tele-VR and one with non-serious games.

The studies conducted by Webster et al. and Cuesta-Gomez et al. agree that serious VR games, in combination with conventional rehabilitation, have significant outcomes in various domains such as strength, coordination, gross/fine motor skills, and more. However, Webster's research indicates superiority when using serious games compared to non-serious games. Additionally, the study by Jonsdottir et al. shows that serious games yield statistically significant results compared to non-serious games regarding dexterity and upper limb mobility, among others. Finally, the research by Karlon et al. mentions that the addition of tele-rehabilitation leads to a greater degree of autonomy and level of independence, including compliance.

Despite the encouraging results presented in the studies, certain limitations need to be taken into account. Firstly, these studies may have a limited sample size, and thus generalizations to larger population groups should be made with caution. Additionally, the duration of rehabilitation and the frequency of serious VR game usage may impact the outcomes and should be further studied.

5. Conclusion

Based on the reviewed literature, it is evident that there is a growing body of research focused on various aspects of MS and its management. Studies have explored different interventions and rehabilitation approaches aimed at improving outcomes for individuals with MS. VR interventions have shown promise in enhancing manual dexterity, upper limb rehabilitation, and arm function in MS patients. Additionally, physical activity has been recognized as an essential component of managing mild MS, considering its positive impact on fatigue, energy levels, and walking speed. The use of serious games for arm rehabilitation has also demonstrated potential benefits in improving functional outcomes in MS patients. Furthermore, advances in physical rehabilitation techniques continue to evolve, offering new possibilities for addressing the challenges associated with MS. By integrating these findings into clinical practice, healthcare professionals can enhance the quality of care and overall well-being of individuals living with MS.

Future research in this field should focus on addressing the limitations identified in previous studies and further exploring the potential benefits of serious virtual reality games in combination with conventional rehabilitation. It would be valuable to conduct larger-scale studies with diverse populations to determine the generalizability of the findings. Additionally, investigating the optimal duration and frequency of serious VR game usage during rehabilitation could provide valuable insights into maximizing the effectiveness of this approach. Furthermore, examining the long-term effects and sustainability of the improvements achieved through this combined intervention would be beneficial.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflict of interest.

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