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REVIEW ARTICLE

EVALUATE THE EFFECTS OF MOTOR CONTROL IN SPINAL CORD INJURY PATIENTS THROUGH VIRTUAL REALITY EXERCISES

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ABSTRACT

Background: Spinal cord injuries (SCI) often result in significant motor impairments, limiting patients ability to perform daily activities independently. Traditional rehabilitation approaches have shown effectiveness but often lack engagement and specificity in targeting motor control deficits. Emerging technologies, such as virtual reality (VR), offer promising avenues for enhancing motor rehabilitation in SCI patients. **Objective**: The aim of this study was to assess the impact of a virtual reality-based exercise program on motor control in SCI patients, focusing on improvements in upper extremity function, trunk control, balance, and spasticity. **Methods**: This pre-post experimental study was conducted at the Neuro Physiotherapy Department of Dr. APJ Abdul Kalam College of Physiotherapy, Pravara Institute of Medical Sciences, Loni, Ahmednagar. A total of 15 participants with incomplete SCI, aged 20-65 years, were selected using convenient sampling. Participants underwent VR training for 30 minutes daily along with 3 hours of daily therapeutic exercises for four weeks. Pre- and post-intervention assessments were conducted using the Voluntary Motor Control Grading Scale (VMCGS), Fugl-Meyer Assessment Scale (FMA), Modified Functional Reach Test (mFRT), and Modified Ashworth Scale (MAS). **Results**: The results demonstrated significant improvements in all outcome measures post-intervention. The mean score for VMCGS increased from 2.066 ± 0.7988 to 4.066 ± 0.7988 ($p < 0.0001$), indicating enhanced upper extremity motor control. The mean score for FMA improved from 14.733 ± 3.01 to 23.333 ± 3.754 ($p < 0.0001$), reflecting better motor function. The mean score for mFRT increased from 17.133 ± 1.187 to 23.266 ± 1.751 ($p < 0.0001$), indicating significant gains in balance and trunk stability. The mean score for MAS decreased from 2.933 ± 0.7988 to 1.933 ± 0.7988 ($p = 0.0019$), showing a reduction in spasticity. **Conclusion**: This study concludes that VR-based exercise programs can significantly enhance motor control, balance, and spasticity in SCI patients. The interactive and engaging nature of VR therapy provides an effective and motivating approach to rehabilitation, complementing conventional techniques. These findings suggest that integrating VR technology into clinical practice can improve the quality of care and outcomes for SCI patients.

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INTRODUCTION

Trauma or illnesses to the spinal nerve tissue. can result in spinal cord injuries. Survey done in 2015 found that trauma (89.4%) from events such traffic accidents, falls, plunges, and industrial accidents was the primary cause of spinal cord damage. The most caudal part of the spinal cord that remains undamaged after an injury is referred to as the neurological level of injury. The severity of the injury is often called "the completeness" and is classified as either of the following:

Complete. If there is no preservation of sensory or motor component below the neurological level is called complete spinal cord injury.

Incomplete: If there is preservation in some motor or sensory function below the affected area, injury is called incomplete spinal cord injury. There are varying degrees of incomplete injury. Additionally, paralysis from a spinal cord injury can be referred to as:

Tetraplegia: Also known as quadriplegia, this means that arms, hands, trunk, legs and pelvic organs are all affected by spinal cord injury.

Paraplegia: . This paralysis affects all or part of the trunk, legs and pelvic organs are affected. 39.5% of quadriplegic patients with cervical spinal cord injuries reported having incomplete paralysis, and 16.3% reported having complete paralysis. In

contrast, 21.7% of paraplegic patients with spinal cord injuries at the T2 nerve or below reported having incomplete paralysis, and 22.1% reported having complete paralysis [1]. The acute management and rehabilitation of SCI depend on the level and type of injury to the spinal cord. Individuals with an SCI often require initial treatment in an intensive care unit with the rehabilitation process typically starting in the acute care setting, followed by extended treatment in a specialized Spinal Injury Unit. Inpatient management can last from 8 to 24 weeks, with follow up outpatient rehabilitation from 3-12 months, generally followed by yearly medical and functional reviews.
The management of an individual with SCI is complex and lifelong requiring a multidisciplinary approach. A functional, goal-oriented, interdisciplinary, rehabilitation programme should enable the individual with a spinal cord injury to live as full and independent a life as possible. Physiotherapy, occupational therapy, speech and language therapy, rehabilitation nurses, social workers, psychologists and other health and social care professionals work as a team under the coordination of a Rehabilitation Physician to decide on goals with the individual and develop a plan of discharge that is appropriate for the individuals' level of injury and circumstances. Physiotherapy for spinal cord injury rehabilitation can be an extremely effective way to optimize individual skills. Licensed professionals guide patients through exercises and effective environment to recover as much function as possible after SC1.[6.7.8]

Spinal cord injury (SCI) often results in significant motor impairments, limiting patients' ability to perform daily activities independently [2]. Traditional rehabilitation approaches have shown effectiveness but often lack engagement and specificity in targeting motor control deficits. However, emerging technologies, such as virtual reality (VR), offer promising avenues for enhancing motor rehabilitation in SCI patients [2]. Virtual reality exercises provide an immersive and interactive environment that can simulate real-world tasks while offering customizable challenges and feedback mechanisms[3]. By leveraging VR technology, rehabilitation programs can tailor exercises to individual patients' needs, promoting engagement and motivation throughout the recovery process[9]. Research has demonstrated the potential of VR-based interventions in improving motor control, balance, and functional outcomes among individuals with SCI[4]. These interventions capitalize on neuroplasticity principles, engaging patients in repetitive, task-specific exercises to promote neural reorganization and motor learning[10].

In this study we explore the potential benefits of VR-based motor rehabilitation for SCI patients, examining its efficacy, feasibility, and potential mechanisms of action[5]. By synthesizing evidence from recent studies, we aim to elucidate the role of VR in enhancing motor control and functional recovery following spinal cord injury [5]. VR [virtual reality] is defined as a "computer-based technology that allows users to interact with a multisensory simulated environment and receive 'real-time' feedback on performance" to enhance his skills to the faster level. The idea of virtual reality is attributed to Jaron Lanier in the late 1980s who created a computer model that allows user to interact with virtual environment. The interactive games are designed to provide the patient with real-life scenarios and activities relevant to daily living. The software is able to provide key concepts required for motor learning including frequency, intensity, repetition and task-oriented training while enabling the user to feel involved in their rehabilitation. These systems have many settings that allow accommodation for patient needs, abilities and goals through the manipulation of the degree of difficulty, focus on the extremity of choice as well as options for game tasks. Spinal cord injury affects approximately 15 million people worldwide every year and among those, between 55% and 75% of these survivors continue with motor deficits and reduced quality of life. These motor deficits include motor control, fine motor skills and dual-task coordination abilities, which all have the potential for significant effects on an individual's independence and quality of life. In an effort to assist these individuals with motor recovery, functional independence, performing ADLs virtual reality (VR) systems is developed. VE provides incongruent visual information forcing increased reliance on the somatosensory and vestibular systems to maintain balance, which is the foundation for VR-based perturbation training using anticipating postural response (AP) and compensatory participation response (CPR). Virtual Reality (VR) has emerged as a powerful tool in the field of rehabilitation, offering a unique and immersive environment for patients to undergo therapy. One area where VR has shown significant promise is in the treatment of Spinal Cord Injury (SCI) in healthcare to have its feet's tight to represent its multiple pros and use it in improving different case scenarios. VR-based rehabilitation approaches aim to address this issue by creating engaging and interactive environments that keep patients motivated and actively involved in their recovery process.[9,10] The integration of VR technology into rehabilitation programs holds several advantages. First and foremost, it offers a cost-effective solution by reducing the need for specialized equipment and dedicated therapy spaces. Additionally, VR environments can be easily customized and adapted to cater to individual patient needs, providing a personalized and tailored approach to rehabilitation. Moreover, VR-based therapy can be conducted in a controlled and safe environment, minimizing the risk of falls or injuries during the rehabilitation process. This is particularly beneficial for patients with mobility impairments or those in the early stages of recovery. The immersive nature of VR also facilitates the incorporation of gamification elements, which can enhance patient engagement, motivation, and adherence to the therapy regimen. By transforming repetitive exercises into interactive and engaging activities, patients are more likely to actively participate in their rehabilitation, leading to improved outcomes. Furthermore, VR technology allows for the collection of precise and objective data on patient performance, enabling therapists to monitor progress and make informed decisions regarding treatment adjustments or modifications. While the initial investment in VR systems may be higher, the long-term cost savings associated with improved patient outcomes, reduced therapy durations, and decreased reliance on specialized equipment make VR-based rehabilitation an attractive and financially viable options. As technology continues to advance and become more accessible, the integration of VR into rehabilitation programs has the potential to revolutionize the way we approach and deliver effective and engaging therapy for individuals with SCI and other neurological conditions.

METHODOLOGY

The data for this study was sourced from Dr. VitthalraoVikhe Patil Pravara Rural Hospital and collected as primary data by the principal investigator. The study was conducted at Dr. APJ Abdul Kalam College of Physiotherapy over a duration of six

months. It was designed as a pre-post experimental study, which is an interventional study type. Participants were selected through convenient sampling, with a sample size of 15 according to Open EPI. The participants included those admitted with spinal cord injuries at Pravara Rural Hospital. The inclusion criteria for the study were patients diagnosed with incomplete spinal cord injury of varying severity, aged between 18 and 65 years, with neurological levels at cervical and thoracic levels. Participants needed to demonstrate willingness and ability to participate in virtual reality exercises, irrespective of gender, and be able to understand and follow instructions in their chosen language. Additionally, they required a stable medical condition to engage in physical activity and had to consent to participate in the research study.
The exclusion criteria were as patients with other neurological conditions aside from SCI, those with unstable medical conditions preventing physical activity, individuals with severe cognitive impairments, those with a history of severe motion sickness or adverse reactions to virtual reality, and those unable to understand the study requirements.

Pre informed consent form had been taken from the participants and pre assessment was done, using Voluntary Motor Control Grading Scale , Modified Functional Reach Test, Fugl-Meyer Assessment Scale and Modified Ashworth Scale. The participants have been explained about the virtual reality exercise procedure to be performed for the four consecutive weeks. All the 15 participants were induced to the general environment to settle to the environment with Virtual Reality device (Meta-Quest 2) with the comfortable Assisstance. The participants were trained with virtual reality for 30 minutes with daily therapeutic exercises training for 3 hours (exercise training). After the adaptation with VR, the participants were given various VR games and task-oriented games. The progression was done from easy to difficult level which were sub categories as, exploration and task-oriented games in a daily session of 30 minutes. The intervention started with fallowing:

1 SESSION FOR 2 WEEKS	2ND SESSION FOR NEXT 2 WEEKS
Fruit ninja Alcove	Bait Beat Saber

For Ist andIInd week we start participant with giving the Virtual Reality games i:e (fruit ninja and Alcove) to enhance the motor control of the upper extremity by giving Virtual Reality exercises like grasping , and manipulating virtual objects for 30 minutes along with daily (exercise training). By IIIrdandVIth week we start participant with giving an others types of Virtual Reality games i:e (The Climb and Beat saber) to enhance the trunk control for static balance of the patients by giving Virtual Reality exercises like reaching for virtual objects and performing co-ordinating movements for 30 minutes along with daily (exercise training). Along with the Virtual Reality based intervention, the daily exercise training programme are as follows :A] Range of Motion Exercises :-It can help to maintain flexibility and prevent muscle contracture with gently moving joints through full ROM. B] Strength Training :- To strengthen muscles around trunk and arm by giving resistance training using bands, weights, etc. C] Functional Training :- It helps patients to regain independence in daily lives by transferring from bed to wheelchair and reaching for objects. D] Core strengthening :- It helps to improve posture, stability and overall trunk control by giving pelvic bridging and static abdominalis. By the End of VIth week where we recorded the final results of participants. Post interventional data collection and assessment was done to check the impact of study design. Then the Pre and Post data of the paticipants was recorded and the data was drawn for the data analysis and results.

Image 1 and 2. Patient performing Virtual Reality Training

STATISTICAL ANAYLSIS

The results were analyzed on basis of data obtained pre and post intervention using Graph Pad Instat application. Descriptive statistics for all outcome measures were expressed as mean, standard deviations and test of significance such as paired ttest . whereas the level of significance ($P<0.005$). The age distribution of the participants were categorized into two age groups: 20-40 years and 41-60 years. Out of the 15 participants, 09 (60%) participants are in the category of 20-40 years of ages, while 06 (40%) participants are in the category of 41-60 years. The gender distribution of the participants

included total 15 participants in which 11 (73.3%) participants are male and 04 (26.7%) participants are female.

RESULTS

INTERPRETATION:-In table 1, Virtual Reality intervention was given to patients, the mean value of Voluntary Motor Control Grading Scale of PRE is 2.066±0.7988 and POST is 4.066±0.7988.Mean value of Modified Ashworth Scale of PRE is 2.933±0.7988 and POST is 1.933±0.7988. hence, the intervention shows extremely significant improvement in post outcome measure as compared to pre measures (p=<0.0001) and (p=0.0019) i:e very significant.

Table 1. Comparison between the mean of pre and post values of vmcgs and mas

OUTCOME MEASURE	ASSESSMENT	MEAN ± SD	T VALUE	P VALUE	SIGNIFICANT
VOLUNTARY MOTOR CONTROL GRADING SCALE	PRE	2.066±0.7988	6.857	<0.0001	EXTREAMLY SIGNIFICANT
	POST	4.066±0.7988			
MODIFIED ASHWORTH SCALE	PRE	2.933±0.7988	3.428	0.0019	VERY SIGNIFICANT
	POST	1.933±0.7988			

Table 2. Comparison Between The Mean Of Pre And Post Values Of Fma And Mfrt

OUTCOME MEASURE	ASSESSMENT	MEAN ± SD	T VALUE	P VALUE	SIGNIFICANT
FUGL MEYER ASSESSMENT SCALE	PRE	14.733±3.01	6.921	<0.0001	EXTREAMLY SIGNIFICANT
	POST	23.333±3.754			
MODIFIED FUNCTIONAL REACH SCALE	PRE	17.133±1.187	11.228	<0.0001	EXTREAMLY SIGNIFICANT
	POST	23.266±1.751			

INTERPRETATION:-In table 2, Virtual Reality intervention was given to patients, the mean value of Fugl Meyer Assessment Scale for PRE is 14.733±3.01 and POST is 23.333±3.754**.**Mean value of Modified Functional Reach Test of PRE is 17.133±1.187 and POST is 23.266±1.751 hence, the intervention shows extremely significant improvement in post outcome measure as compared to pre measures (p=<0.0001).

DISSCUSION

The study was carried out to assess the impact of a virtual reality-based program on motor control in patients with spinal cord injuries. The results demonstrated a significant impact on motor control, trunk control, balance, and spasticity using the voluntary motor control grading scale, fugl-meyer assessment scale, modified functional reach test, and modified Ashworth scale before and after the virtual reality-based training. The improvement in upper extremity function was one of the study's primary outcome measures. The participants' capacity to regulate their upper limb motions was evaluated using the Voluntary Motor Control Grading Scale. After the intervention, the mean score increased from 2.066 to 4.066. This notable increase implies that virtual reality training can help patients with spinal cord injuries improve their upper extremity motor skills.

Mechanism: By offering repetitive, task-specific training, the VR workouts greatly improved the participants' upper limb control. As a result of this training, the brain developed neuroplasticity, which is the capacity to rearrange and create new neural connections. Participants' scores significantly increased as their upper limb motor control improved with regular practice and prompt feedback. Similar results were shown in earlier research, including that conducted by Faisal Amin *et al*. (2024), which showed that completely immersive virtual reality-based therapies significantly improved stroke patients' motor recovery. The potential of virtual reality as an effective aid for motor rehabilitation is further supported by these findings.[13] SCI sufferers must improve their trunk control and balance in order to restore their independence and carry out daily tasks in a safe manner. The subjects' trunk stability and balance were assessed using the Modified Functional Reach Test. Significant improvements in trunk control and balance were demonstrated by the mean pre-intervention score of 17.133, which increased to 23.266 after the intervention. Virtual reality workouts that mimic tasks demanding dynamic balance and trunk stability can be a useful tool for honing these abilities. Patients can practice movements that test their balance and coordination by playing games like Beat Saber and The Climb, which were employed in this study.

Mechanism: Participants were able to enhance their dynamic balance and trunk stability skills by participating in virtual reality exercises that replicated real-world tasks. Exercises that tested participants' balance, such as Beat Saber and The Climb, helped them develop greater trunk control. Virtual reality activities' captivating and inspiring qualities prompted active engagement, which resulted in noticeable improvements in trunk control and balance.

Similar results from earlier research by Hao Feng *et al*. (2019**)** have shown that a 12-week virtual reality training program greatly enhanced gait and balance in Parkinson disease patients. These gains are probably the result of VR's dynamic and captivating features, which encourage patients to actively engage in their recovery.[15] Patients with SCI frequently have spasticity, which is characterized by elevated muscle tone and resistance to passive movement. The subjects' levels of spasticity were measured using the Modified Ashworth Scale. Before the intervention, the mean score was 2.933; after the intervention, it improved to 1.933. This decrease in spasticity suggests that VR exercises may be useful for controlling muscle tone and enhancing motor performance in general. Patients can engage in regulated exercises that target particular muscle groups and motions in virtual reality-based therapies.

Mechanism: The regulated setting of the virtual reality exercises enabled precise motions to control muscle tone and lessen stiffness. Participants engaged in task-specific training that enhanced general motor function and got prompt feedback. The enhanced scores demonstrate how this controlled environment significantly reduced spasticity. Similar results from earlier research by Jiayin Chen *et al*. (2022) showed that exercise therapy aided by virtual reality greatly enhanced upper extremity motor function and stiffness in stroke patients. These results provide more evidence in favor of using virtual reality technology to help SCI patients manage their spasticity and improve their motor skills.[18] Virtual reality

exercises can be a useful supplement to traditional rehabilitation techniques, according to the study's findings. Combining daily therapeutic exercise training with virtual reality exercises provides a thorough approach to SCI rehabilitation that addresses both functional independence and motor control. Virtual reality's dynamic and captivating qualities boost patient engagement and motivation, all of which are essential for a successful recovery. Prior research by Meetika Khurana *et al*. (2017) shown that, in contrast to real-world task-specific training, VR game-based balancing training improved balance and functional performance in people with paraplegia.[11] Patients can hone their motor abilities in a secure setting by using virtual reality technology. More focused and efficient rehabilitation is made possible by the capacity to replicate real-world tasks and offer instant feedback. The quality of care for patients with SCI can be greatly enhanced by integrating virtual reality technology into clinical practice as it develops and becomes more widely available.

CONCLUSION

According to this study, patients with spinal cord injuries (SCI) can greatly enhance their motor control with virtual reality (VR) workouts. We saw significant gains in balance, spasticity, trunk control, and upper extremity function when using VR. By offering an interactive and inspiring environment, virtual reality (VR) enhances rehabilitation's effectiveness and engagement. According to these results, VR may be a useful supplement to conventional rehabilitation techniques, giving SCI patients a higher probability of recovery and a higher standard of living.

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