Exploring Parkinson's Disease Rehabilitation: Virtual Reality-based Action Observation Therapy in Focus

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Abstract. *Parkinson's disease (PD) is a chronic and progressive neurological disorder that affects motor and cognitive function. Although pharmacological and surgical treatments can help manage symptoms, non-pharmacological interventions such as rehabilitation have gained attention as a means to improve motor function and quality of life for PD patients. Virtual Reality (VR) based Action Observation Training (AOT) is an innovative rehabilitation approach that combines VR technology and the observation of movements to enhance motor learning and cognitive function. This paper provides a focused review of the literature on VR-AOT in PD rehabilitation. The article discusses the rationale and potential benefits of VR-AOT, including its ability to improve gait, balance, and upper limb function, as well as cognitive domains such as attention and executive function. Additionally, the challenges and limitations of VR-AOT are highlighted. The paper concludes by emphasizing the potential of VR-AOT as a promising and complementary therapy for PD rehabilitation, but also highlighting the need for continuing-research to establish its effectiveness and broader applicability.*

Keywords. Parkinson's disease, rehabilitation, virtual reality, action observation training, motor function, cognitive function

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1 Introduction

Parkinson's disease (PD) is a chronic and progressive neurological disorder characterised by the progressive loss of neurons in the brain [1]. This leads to a variety of motor and non-motor symptoms; the most common motor symptoms of PD [2] include tremors, rigidity, bradykinesia, and postural instability, while non-motor symptoms can include depression, anxiety, cognitive impairment, and sleep disorders [3]. Although the exact causes of PD are still unknown, it is believed that a combination of genetic and environmental factors may contribute to its development. PD affects approximately 1-2% of the population worldwide and is the second most common neurodegenerative disorder after Alzheimer's disease [4].

Over years, non-pharmacological interventions such as rehabilitation have gained attention as an important component of PD management. Rehabilitation interventions for PD can include physical therapy, occupational therapy, speech therapy, and cognitive rehabilitation [5]. Rehabilitation goals in PD include improving motor function, stabilizing mobility and balance, reducing falls, and enhancing quality of life. However, PD rehabilitation is often challenging due to the progressive nature of the disease, the presence of multiple symptoms, and the high degree of individual variability.

Virtual reality-assisted action observation training (VR-AOT) is a promising rehabilitation approach for PD that combines immersive virtual reality environments with action observation tasks. This approach is based on the concept of activation of mirror neurons system, which are specialized neurons in the brain that fire both when an individual performs a specific movement or action, as well as when that individual observes someone else performing the same movement or action [6]. By engaging mirror neuron systems, VR-AOT may help improve motor function and reduce symptoms in individuals with PD [7]. Furthermore, VR-AOT has the potential to provide a safe, engaging, and customisable rehabilitation experience that can be customised to individual needs and preferences.

Overall, the use of VR-AOT as a rehabilitation approach for PD is an exciting area of research that has the potential to improve outcomes for individuals with PD. In this short paper, we will review the current evidence on the effectiveness of VR-AOT for PD and discuss its potential benefits and limitations as a rehabilitation approach.

2 VR-AOT rehabilitation

2.1 VR-AOT framework

The framework of a VR-AOT system typically involves the following components:

- VR Environment: A simulated environment is created using computer graphics designed to provide an immersive experience for the user.
- Motion Tracking: The user's movements are tracked using motion sensors, such as inertial measurement units (IMU), Electromyography (EMG) sensors and Motion capture sensors.
- AOT: The user observes a virtual character performing a specific action, such as lifting weights or moving objects.

- Progress Tracking: The user's progress is tracked over time during the experiments to monitor improvements in performance using quantitative and qualitative assessments.

The purpose of a VR-AOT is to provide a safe and controlled environment for users to practice and improve their physical skills. By observing and mimicking the movements of virtual characters, patients can develop their own motor skills, and the system can provide feedback and adapt to their progress.

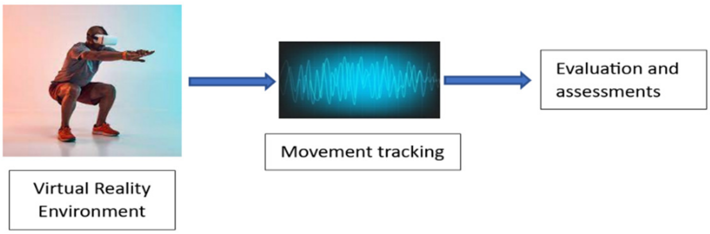

Figure 1. General framework of VR-AOT for rehabilitation experiments

2.2 Evaluation of PD rehabilitation intervention

Different assessments are used to measure improvements in PD rehabilitation[8][9]. These assessments analyse functional changes in all stages of the disease. Some commonly used evaluation measures for PD rehabilitation improvements are:

- Unified Parkinson's Disease Rating Scale (UPDRS): is a validated scale that provides an objective perspective and allows the classification of individuals with Parkinson's disease. It is used to assess various aspects of the disease, including motor symptoms, activities of daily living (ADL), and complications of therapy.
- Berg Balance Scale: is used to assess balance and stability in individuals with Parkinson's disease. It measures the ability to maintain balance during various tasks, such as sitting, standing, and transferring.
- Activities-Specific Balance Confidence (ABC) Scale is a patient-reported outcome measure that assesses an individual's confidence in maintaining balance while performing various activities.
- Six-Minute Walk Test (6MWT): measures the distance an individual can walk in six minutes. It assesses endurance and cardiovascular fitness.
- Jebsen-Taylor Hand Function Test (JTHFT): is a standardized and objective measure of fine and total motor hand function using simulated ADL.
- Functional Gait Assessment (FGA): This assessment is used to evaluate postural stability during walking and an individual's ability to perform multiple motor tasks while walking.
- 9-Hole Peg Test (9HPT) is a quantitative assessment used to measure finger dexterity.

These assessments help to monitor changes in function, balance, walking, and mobility in individuals with PD. It is common for combination of multiple assessments to be used in controlled clinical trials to provide a comprehensive evaluation of PD rehabilitation improvements.

2.3 VR-AOT related works

There are several studies exploring the use of VR-AOT in rehabilitation of PD. This paper searched PubMed, BMC, ScienceDirect, and Future Medicine databases for recent randomized controlled trials on VR interventions and their effects on motor and cognitive functions in Parkinson's disease patients. Various combinations of keywords like "PD and VR-AOT", "neurodegenerative disease and VR-AOT", "PD rehabilitation with VR" and "motor and cognitive functions" were used for this purpose. In the following table the selected related works are presented with details about the main findings and the experiment assessment in form of outcome measures (Table.1).

Table 1. Selected articles on the effectiveness of VR and AOT for PD rehabilitation

Papers	Intervention	Main findings	Outcome measures
Yang et al. [10]	Home based VR balance training and conventional home balance training for a duration of 6 weeks.	Training options were equally effective in improving balance, walking, and quality of life	• Berg Balance Scale • Dynamic Gait Index • PD Questionnaire • UPDRS
Faria et al. [11]	The intervention is VR based cognitive rehabilitation through simulated activities of daily living and it lasts for 1 month.	Significant improvements within VR group in global cognitive functioning, attention, memory, visuo-spatial abilities, executive functions, emotion and overall recovery.	• Addenbrooke Cognitive Examination (Primary Outcome) • Trail Making Test a And B • Picture Arrangement From Wais Iii • Stroke Impact Scale 3.0
Edu et al. [12]	Gait training with VR with 37 participants	Gait training with a VR program is as effective as treadmill training in improving walking distance and temporal gait variables in individuals with PD.	• Walking Distance • Gait Variables • 6 Minute Walk Test (6Mwt)
Emuk et al. [13]	AOT for upper extremity-function experiment with	• Action observation training improved upper extremity functions in all groups • Observing self-actions resulted in statistically significant positive changes in more variables compared with other methods ($p < 0.001$)	• Jebsen Taylor Hand Function Test Performance With Dominant and non-Dominant Hand • 9 Hole Peg Test Performance • Serial Reaction Time Task Performance • D2 Test Of Attention Performance
Errante et al. [14]	VR-AOT rehabilitation for upper limb function in patients with stroke for 6 months.	Effectiveness of AOT combined with VR technology compared to a control treatment of observation of naturalistic scenes without any action content followed by VR training.	• Upper Limb Function

Papers	Intervention	Main findings	Outcome measures
Gandolfi et al.[15]	21 sessions of balance and gait exercises lasting 50 minutes each, either in home VR telerehabilitation or in clinic sensory integration balance training (SIBT).	• VR telerehabilitation was found to be more effective than in-clinic SIBT in improving postural stability in PD patients. • Both groups showed improvements in all outcome measures over time, except for fall frequency.	• Berg Balance Scale • Dynamic Gait Index • Fall Frequency
Kashif et al. [16]	VR and MI training techniques in addition to routine physical therapy for 12 weeks.	The study is a two-armed parallel design, single-blinded, single-centred, randomized controlled trial that investigate the effects of VR with MI techniques in addition to routine physical therapy on motor function, balance, and ADLs in patients with PD.	• UPDRS (Part III) • Berg Balance Scale (BBS) • Activities Specific Balance Confidence Scale (ABC) • UPDRS (Part II)

Several systematic reviews have been published about the application of VR-AOT in different neurological diseases along with PD. On the whole, VR technologies is showing enhancement of the reorganization of the motor neuron ways and improve motor disability as well as assess and treat medical conditions [17], [18].

3 Conclusion

Rehabilitation through a new VR-AOT instrument is shown to be a valuable training tool in improving motor and non-motor symptoms including cognitive function in PD. Research on VR-AOT targeting lower-extremity functions such as gait rehabilitation is wildly explored compared to the rehabilitation of the upper-extremity function for PD. Therefore, more research is required to evaluate the efficacy of VR-AOT technology with a focus on the upper extremities before its implementation is promoted further. The effectiveness of VR-AOT interventions in different disease stages of PD should also be studied to determine the usefulness of VR-based interventions in the prevention of physical decline during the early stages of PD and during the progression of PD in the middle to late stages. Additionally, evidence-based recommendations should be provided on the frequency, duration, and content of VR-AOT interventions for PD rehabilitation that should be provided.

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