Virtual reality-based rehabilitation in neurological physiotherapy: current evidence and clinical outcomes

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Abstract:
Virtual reality (VR)-based rehabilitation is an emerging technology-assisted approach in neurological physiotherapy that provides interactive, engaging, and progressively challenging environments for individuals with neurological disorders. Stroke, Parkinson's disease, multiple sclerosis, cerebral palsy, traumatic brain injury, and other neurological conditions commonly cause impairments in strength, balance, gait, coordination, motor control, cognition, and activities of daily living. Although conventional physiotherapy remains fundamental to neurological rehabilitation, maintaining intensive and repetitive practice over prolonged periods can be challenging because of fatigue, limited motivation, and restricted access to specialized services. VR can complement conventional rehabilitation by providing task-specific exercises, immediate visual and auditory feedback, adjustable difficulty, multisensory stimulation, and objective performance monitoring. Its applications include upper-limb rehabilitation, balance training, gait retraining, cognitive-motor exercises, postural control, and functional activity practice. VR may also improve patient engagement and support home-based and remotely supervised rehabilitation. However, clinical effectiveness can vary according to neurological condition, patient characteristics, intervention duration, technology type, immersion level, and treatment intensity. Safety, accessibility, cost, cybersickness, digital literacy, and appropriate patient selection must also be considered. Overall, VR represents a promising adjunct to neurological physiotherapy that can enhance repetitive, meaningful, and patient-centered rehabilitation while preserving the essential role of physiotherapists in assessment, clinical reasoning, treatment planning, supervision, progression, and functional recovery.

Keywords:
Virtual Reality, Neurological Physiotherapy, Neurorehabilitation, Stroke, Parkinson's Disease, Multiple Sclerosis, Cerebral Palsy, Balance, Gait Rehabilitation, Motor Recovery, Cognitive-Motor Training, Telerehabilitation.

1. Introduction:

Neurological disorders represent a major cause of long-term disability and frequently result in complex impairments involving the motor, sensory, cognitive, perceptual and psychosocial domains, making rehabilitation a prolonged and multidimensional process. Stroke may produce hemiparesis, abnormal muscle tone, impaired selective movement, sensory loss, balance dysfunction and gait abnormalities, Parkinson's disease is commonly characterized by bradykinesia, rigidity, postural instability, freezing of gait and impaired movement amplitude, multiple sclerosis may involve weakness, fatigue, ataxia, sensory disturbances, balance impairment and cognitive changes, cerebral

palsy produces lifelong abnormalities of movement and posture beginning during early development, and traumatic brain injury may combine physical disability with deficits in attention, executive function, memory and behavior. Neurological physiotherapy traditionally addresses these problems through therapeutic exercise, task-specific practice, balance and gait training, strengthening, motor relearning, sensory strategies and functional activities, but rehabilitation frequently requires large numbers of repetitions and sustained patient engagement. VR provides an opportunity to transform repetitive therapeutic activities into interactive and meaningful tasks while maintaining the fundamental principles of neurological rehabilitation. VR systems range from non-immersive screen-based environments to fully immersive head-mounted displays, and they may incorporate motion sensors, cameras, force platforms, controllers or wearable technologies to detect movement and provide immediate feedback. The therapeutic rationale is closely associated with motor-learning principles because VR allows repeated goal-directed movement, augmented feedback, adjustable difficulty and task variability within a controlled environment. Recent evidence has strengthened the clinical interest in VR while simultaneously emphasizing that it should not be regarded as universally superior to conventional physiotherapy. An umbrella review involving 78 systematic reviews of stroke rehabilitation found that most reviews reported favorable effects of VR for upper-extremity motor function, activity, balance, functional mobility, walking speed and functional independence, but the methodological quality of many underlying reviews was low or critically low (Hao et al., 2024). A separate meta-review similarly concluded that VR is promising in stroke rehabilitation but that differences in protocols and study quality make it difficult to establish a single optimal VR prescription (Khan et al., 2024). Thus, the central clinical question has shifted from whether VR can be used in neurological physiotherapy to determining which patients, therapeutic goals, technologies and treatment doses are most likely to benefit from it. Figure 1 illustrates the Integrated framework of VR-based neurological physiotherapy. The proposed framework begins with comprehensive neurological and functional assessment, followed by individualized goal setting, selection of an appropriate VR system, therapist-supervised task-specific training, real-time feedback, progressive adjustment of difficulty, functional reassessment and transfer of acquired skills into everyday activities. This model emphasizes that VR should remain embedded within evidence-based physiotherapy rather than being considered an independent treatment pathway.

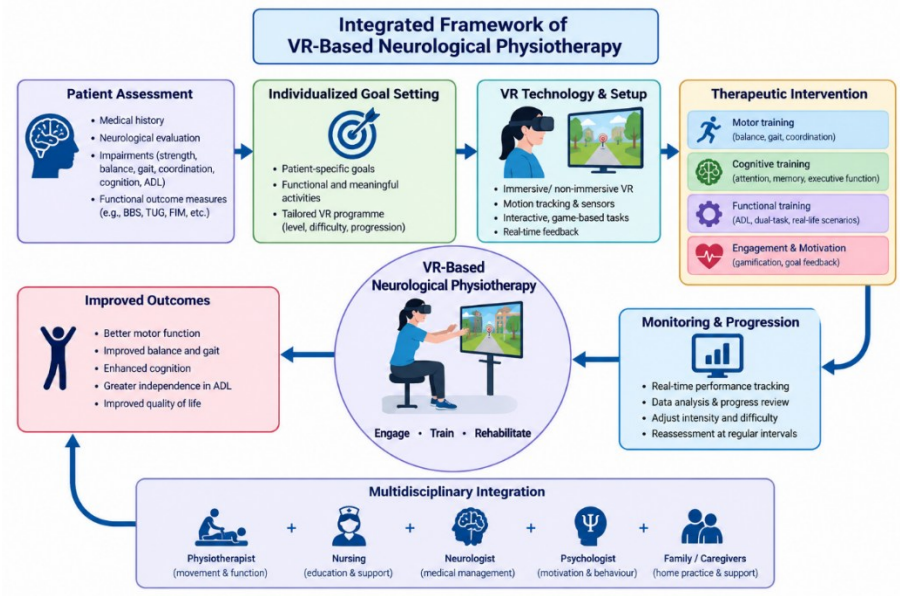


Figure 1. Integrated framework of VR-based neurological physiotherapy

2. Virtual Reality in Neurological Physiotherapy: Concepts and Therapeutic Mechanisms:

VR-based rehabilitation can be classified broadly into non-immersive, semi-immersive and fully immersive approaches, with the level of immersion referring to the degree to which the patient perceives the simulated environment as surrounding and interactive. Non-immersive systems

commonly use televisions, computer monitors or projection screens and may incorporate cameras or motion sensors to detect movement, whereas immersive systems typically use head-mounted displays that provide a three-dimensional virtual environment. From a physiotherapy perspective, immersion should not automatically be equated with clinical superiority because the therapeutic value depends on whether the technology supports the patient's specific rehabilitation objective. The principal mechanisms through which VR may influence neurological recovery include intensive repetition, task specificity, augmented sensory feedback, error-based learning, attention, motivation, environmental enrichment and progressive challenge. VR can provide visual information about movement trajectory and task accuracy while simultaneously delivering auditory signals or haptic feedback, thereby creating a multisensory learning environment. The patient can immediately recognize whether a virtual target has been reached, whether a step was correctly positioned or whether a balance task was completed within the desired range. Such feedback may facilitate error detection and encourage repeated correction, which are central components of motor learning. VR may also enhance salience because activities can be embedded within meaningful simulated environments rather than presented as isolated exercises. A patient with stroke may practice reaching for virtual objects, a person with Parkinson's disease may negotiate virtual obstacles, and an individual with multiple sclerosis may perform balance activities while responding to cognitive cues. Neural plasticity represents another proposed mechanism. A systematic review examining VR and neural plasticity after stroke identified evidence suggesting changes in neural activity and connectivity associated with VR interventions, although substantial methodological differences prevented definitive conclusions regarding the precise neural mechanisms involved (Hao et al., 2022). The combination of repetitive practice, multisensory feedback and active attention may provide an enriched environment capable of supporting experience-dependent neural adaptation. VR can also introduce variability, which is important because patients must eventually adapt learned movements to unpredictable real-world environments. The figure 2 illustrate the sequence of goal-directed movement, multisensory stimulation, visual and auditory feedback, error detection, repeated correction, motor-learning consolidation, neural adaptation and functional transfer. Importantly, the therapeutic effect of VR should not be attributed to the virtual environment alone, rather, VR creates conditions that may increase the intensity, quality and salience of practice. Therefore, the physiotherapist remains essential for selecting appropriate tasks, controlling compensatory movement, determining progression and ensuring that virtual performance reflects meaningful improvement in real-world function.

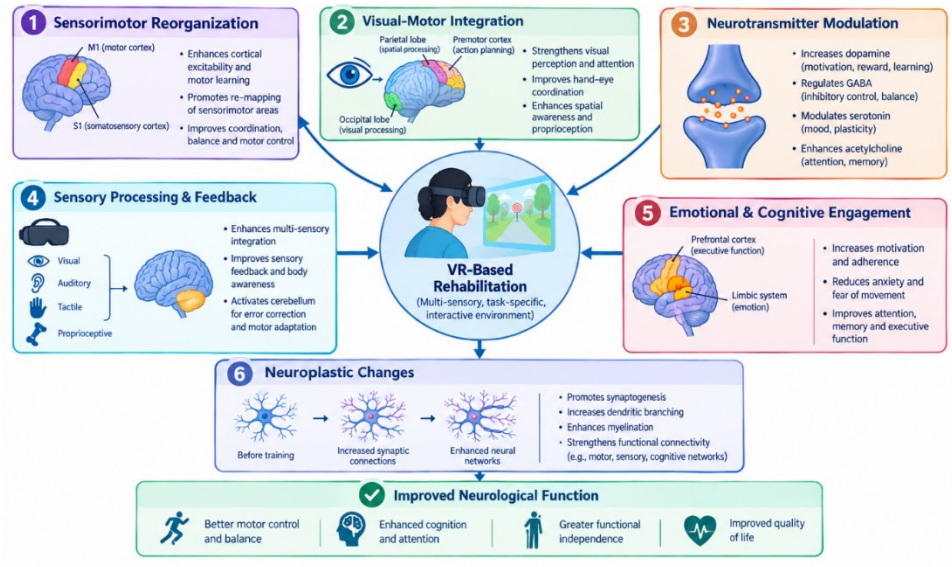


Figure 2. Proposed neurophysiological mechanisms of VR-based rehabilitation

3. Current Evidence in Stroke Rehabilitation:

Stroke rehabilitation currently represents the largest and most developed clinical evidence base for VR in neurological physiotherapy, with interventions targeting upper-limb recovery, balance, gait, mobility, activities of daily living and cognitive function. Upper-limb rehabilitation is particularly suitable for VR because recovery frequently requires repetitive reaching, grasping, pointing, manipulation and coordinated movement, which can become monotonous during conventional therapy. VR can convert these repetitions into goal-oriented tasks involving virtual objects, targets and interactive environments, while difficulty can be modified by changing target size, distance, speed or movement complexity. A meta-analysis of immersive VR for upper-extremity stroke rehabilitation involving 10 studies and 324 participants reported significant improvements in activities of daily living and Fugl-Meyer upper-extremity outcomes compared with conventional rehabilitation, suggesting that immersive environments may provide additional therapeutic value when appropriately integrated into rehabilitation programs (Alashram et al., 2024). Similarly, broader meta-analyses have reported beneficial effects of VR on upper- and lower-limb motor function, balance, gait and daily activities, although effect sizes and certainty vary between outcomes (Zhang et al., 2021, Prajjwal et al., 2024). The evidence for gait rehabilitation is also encouraging. A systematic review and meta-analysis of 32 studies involving 809 individuals found that VR-based interventions produced significant improvements in cadence, stride length and gait speed after stroke, with additional benefits when VR was combined with robotic gait training (Ghai et al., 2020). More recent evidence in chronic stroke involving 43 randomized controlled trials and 1,136 participants demonstrated moderate effects on walking and larger effects on balance when VR was incorporated into therapeutic exercise (Huang et al., 2025). Balance is another important target because post-stroke balance impairment is strongly associated with falls, reduced community mobility and decreased confidence. Previous meta-analyses have demonstrated improvements in Berg Balance Scale and Timed Up and Go performance when VR was combined with conventional treatment (Mohammadi et al., 2019), while newer evidence continues to support potential improvements in dynamic balance, although heterogeneity and risk of bias remain important limitations. The figure 3 demonstrate how a stroke survivor progresses from neurological assessment and impairment identification to upper-limb VR practice, balance training, gait simulation, functional task practice, objective reassessment and real-world activity transfer.



Figure 3. VR-assisted stroke rehabilitation pathway

Table 1. Major clinical applications of VR in neurological physiotherapy

Neurological condition	Main VR applications	Common therapeutic targets	Representative outcomes
Stroke	Reaching, balance, gait, obstacle negotiation	Motor recovery, balance, mobility	FMA, BBS, TUG, 10MWT, ADL
Parkinson's disease	Stepping, gait, obstacles, balance	Postural control, mobility	BBS, TUG, UPDRS, gait measures
Multiple sclerosis	Balance, cognitive-motor training, exercise	Balance, fatigue, cognition	BBS, TUG, fatigue and QoL scales

Cerebral palsy	Interactive games, reaching, balance	Gross motor function, coordination	GMFM, PBS, WeeFIM
Traumatic brain injury	Cognitive-motor simulation, mobility	Balance, cognition, community skills	Mobility and cognitive measures

The evidence therefore supports VR as a useful adjunct to stroke rehabilitation, particularly when it increases practice intensity and provides task-specific feedback. However, the current literature does not justify replacing conventional physiotherapy with VR, and recent reviews emphasize that the quality of evidence remains inconsistent (Hao et al., 2024). VR should instead be selected according to the patient's impairment profile, rehabilitation goals and tolerance, with the physiotherapist ensuring that improvements in virtual performance translate into meaningful functional outcomes.

4. Applications in Parkinson's disease, Multiple Sclerosis, Cerebral Palsy and Traumatic Brain Injury:

The application of VR has expanded considerably beyond stroke, particularly in Parkinson's disease, multiple sclerosis, cerebral palsy and acquired brain injury, although the quantity and certainty of evidence differ between conditions. Parkinson's disease is particularly suitable for VR because rehabilitation frequently requires repetitive practice of balance, gait initiation, stepping, obstacle negotiation, movement amplitude and postural responses. Virtual environments can provide visual targets and obstacles while requiring patients to modify stepping strategies in response to changing environmental information. A meta-analysis of 22 randomized controlled trials involving 836 individuals with Parkinson's disease reported improvements in balance, activities of daily living, quality of life and depressive symptoms following VR-based rehabilitation, although the certainty of evidence ranged from very low to low (Li et al., 2021). More recent evidence involving 28 studies and 1,151 participants has demonstrated potential benefits for balance and mobility while also identifying substantial methodological heterogeneity (recent evidence: 2025). A 2025 systematic review and meta-analysis focusing on fully immersive VR reported improvements in dynamic balance, motor function and quality of life compared with conventional treatment, although static balance outcomes were less consistently affected (Fernandes et al., 2025). Multiple sclerosis presents different rehabilitation challenges because patients may experience fatigue, weakness, ataxia, sensory impairment, balance dysfunction and cognitive difficulties, making individualized dosing particularly important. A systematic review and meta-analysis of VR-based rehabilitation for cognitive function and mood in multiple sclerosis found improvements in global cognition, immediate and delayed recall and visuospatial abilities, suggesting that VR may support combined cognitive-motor rehabilitation (Zhang et al., 2024). Earlier randomized trials have also indicated that VR-based balance training can improve selected balance and cognitive-motor outcomes, although conventional exercise may remain equally or more effective for certain domains. In cerebral palsy, VR may improve motivation while facilitating repetitive practice of balance, reaching, coordination and gross motor activities. Meta-analyses have reported improvements in balance, motor function, activities of daily living and upper-limb function among children with cerebral palsy (Komariah et al., 2024), while more recent evidence suggests that VR can improve gross motor function, balance and functional independence, although the certainty of evidence remains variable (Li et al., 2025). The figure 4 depict stroke-related reaching and gait training, Parkinson's disease obstacle negotiation and balance training, multiple sclerosis cognitive-motor exercise, cerebral palsy interactive motor activities and traumatic brain injury community-based cognitive-motor simulation. In traumatic brain injury and acquired brain injury, VR is particularly attractive because physical rehabilitation can be integrated with cognitive tasks such as navigation, environmental scanning, decision making and dual-task performance. A systematic review of VR implementation for acquired brain injury emphasized the importance of designing virtual environments around the complex and diverse impairments associated with brain injury (Brassel et al., 2021).

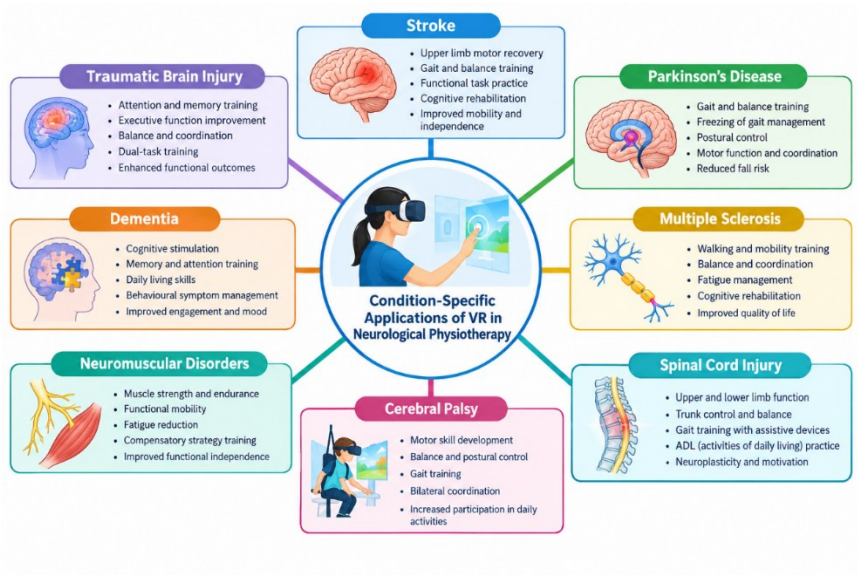


Figure 4. Condition-specific applications of VR in neurological physiotherapy

5. Effects on Balance, Gait, Upper-Limb Function and Cognitive-Motor Performance:

The clinical outcomes associated with VR-based neurological physiotherapy can be broadly organized into motor impairment, balance, gait, upper-limb function, activities of daily living, cognition, psychological outcomes and quality of life. Balance represents one of the most consistently investigated outcomes because VR can create controlled challenges involving weight shifting, reaching outside the base of support, stepping, visual manipulation and obstacle negotiation. In stroke populations, evidence suggests that VR can improve both static and dynamic postural control, particularly when incorporated into conventional rehabilitation, although differences between immersive and non-immersive approaches are not always consistent (Garay-Sánchez et al., 2021). Recent evidence involving 36 randomized controlled trials and more than 1,100 stroke participants has reported improvements in dynamic balance measured by the Berg Balance Scale and Timed Up and Go, while also emphasizing substantial heterogeneity and risk of bias. Gait is another major outcome, with VR allowing patients to practice stepping, cadence regulation, obstacle crossing and environmental adaptation. The meta-analysis by Ghai et al. (2020) demonstrated improvements in cadence, stride length and gait speed, supporting the use of VR as an adjunct to gait rehabilitation. Upper-limb function is similarly responsive to task-specific VR because reaching and manipulation can be repeated at high volume while feedback is delivered continuously. A systematic review and meta-analysis of immersive VR after stroke reported improvements in Fugl-Meyer scores and activities of daily living compared with conventional rehabilitation, although clinical interpretation should consider differences in intervention dosage and patient characteristics (Alashram et al., 2024). Cognitive-motor function is an increasingly important target because real-world mobility requires patients to combine movement with attention, planning, visual scanning and decision making. VR can simulate road crossing, shopping, navigation, obstacle avoidance and other community activities while adding cognitive demands. This approach may be particularly relevant to people with Parkinson's disease, multiple sclerosis and acquired brain injury. Psychological outcomes should also be considered because prolonged neurological disability is frequently associated with reduced confidence, anxiety, depression and social isolation. A recent systematic review and meta-analysis found that VR-based rehabilitation may improve mental health and quality of life in stroke survivors, although the magnitude of benefit varied among outcomes (Wang et al., 2025).

Table 2. Common outcome measures for VR-based neurological physiotherapy

Outcome domain	Common measures	Clinical relevance
Motor recovery	Fugl-Meyer Assessment	Quantifies post-stroke motor impairment

Upper-limb function	Action Research Arm Test, Box and Block Test	Measures functional arm and hand performance
Balance	Berg Balance Scale, Mini-BESTest	Measures static and dynamic postural control
Mobility	Timed Up and Go	Measures functional mobility and fall risk
Gait	10-Meter Walk Test, 6-Minute Walk Test	Measures speed and walking endurance
ADL	Barthel Index, Functional Independence Measure	Measures independence
Cognition	MoCA and executive-function tests	Evaluates cognitive contribution to mobility
Quality of life	SF-36 and disease-specific scales	Evaluates patient-centered benefit
Fatigue	Fatigue Severity Scale, Modified Fatigue Impact Scale	Important in multiple sclerosis and other conditions

These outcomes emphasize that VR performance should never be evaluated exclusively through game scores. A patient may become more efficient within a virtual environment without demonstrating meaningful improvement in real-world function. Consequently, validated clinical measures and functional activities must remain central to treatment evaluation.

6. Home-Based VR, Telerehabilitation and Patient-Centered Care:

The expansion of affordable head-mounted displays, motion sensors, cameras and internet-based communication has created opportunities for VR rehabilitation beyond hospitals and physiotherapy clinics. Home-based VR may increase access to rehabilitation, reduce travel requirements, extend treatment beyond conventional appointment schedules and support long-term exercise adherence. This is particularly relevant for individuals living in rural areas or those with transportation difficulties. A systematic review and meta-analysis of home-based VR training and telerehabilitation in stroke, Parkinson's disease and multiple sclerosis found that home-based interventions were feasible and could produce benefits in balance-related outcomes, although the evidence was based on a relatively small number of randomized trials (Truijen et al., 2022). Home rehabilitation also enables therapists to monitor adherence and modify exercises remotely, potentially creating a continuum between supervised clinic-based rehabilitation and independent home practice. Nevertheless, home VR should not be interpreted as an automatic replacement for professional supervision. Patients may perform exercises incorrectly, experience cybersickness, misunderstand instructions or select inappropriate levels of difficulty. Recent evidence increasingly supports the importance of remote therapist involvement, especially for individuals with complex neurological impairments. Patient-centered care is equally important because individuals differ in their preferences, technological familiarity, cognitive capacity and rehabilitation goals. Some patients may enjoy game-based environments, whereas others may find head-mounted displays uncomfortable or confusing. Rehabilitation should therefore be designed around meaningful personal goals such as walking independently, reaching household objects, returning to work, improving community mobility or participating in recreational activities. Figure 5 illustrates Home-based and digital VR rehabilitation pathway, the proposed pathway begins with clinical assessment and individualized prescription, followed by home-based VR exercise, remote physiotherapy monitoring, symptom and performance tracking, progressive modification of exercise difficulty, periodic face-to-face reassessment and multidisciplinary review. Patient safety should remain central to home-based intervention, particularly for individuals with impaired balance or a history of falls. The home environment should be assessed for physical hazards, and appropriate caregiver support should be considered when necessary. Digital literacy and access to reliable internet and suitable hardware may also determine whether home VR is feasible. Therefore, future implementation should focus not merely on

distributing VR devices but on developing structured digital rehabilitation programs that combine technology with therapist supervision, patient education and objective clinical monitoring.



Figure 5. Home-based and digital VR rehabilitation pathway

7. Clinical Implementation, Safety, Treatment Dosage and Role of the Physiotherapist:

Successful implementation of VR in neurological physiotherapy requires careful consideration of patient selection, clinical goals, treatment dosage, safety, technology usability and therapist expertise. Before beginning VR, the physiotherapist should evaluate cognition, vision, hearing, balance, vestibular function, upper- and lower-limb control, fatigue, cardiovascular tolerance and the ability to follow instructions. Patients with severe cognitive impairment, significant visual dysfunction, uncontrolled vestibular symptoms or very high fall risk may require modified or non-immersive approaches. Cybersickness is one of the most recognized adverse effects and may include dizziness, nausea, headache, visual discomfort and disorientation, particularly when visual movement does not correspond with actual body movement. Immersive head-mounted systems may also create safety concerns because patients can become visually separated from their physical surroundings. Consequently, standing and walking tasks should be conducted with appropriate guarding, assistive devices, environmental preparation or harness systems when required. Treatment dosage remains another unresolved issue because studies vary considerably in session duration, frequency, total intervention period and intensity. Rather than prescribing a universal dose, clinicians should individualize treatment according to neurological status, fatigue, task complexity and response to exercise. Shorter sessions may be appropriate during early exposure or for individuals prone to fatigue or cybersickness, whereas patients who tolerate VR well may gradually progress toward longer or more complex training. Importantly, the physiotherapist must monitor movement quality because digital systems may reward task completion even when patients use compensatory strategies. A patient may successfully reach a virtual target by excessive trunk movement rather than appropriate shoulder control, and the software may fail to recognize this distinction. The therapist therefore remains responsible for clinical interpretation, positioning, movement correction and progression. VR should ideally be integrated into a broader session rather than delivered as an isolated activity. A typical session may include neurological assessment, warm-up, conventional therapeutic exercise, VR-based task practice, gait or balance training, functional transfer and reassessment. Evidence from stroke and Parkinson's disease suggests that VR often provides its greatest value when combined with conventional rehabilitation rather than when used alone (Hao et al., 2024, Fernandes et al., 2025). The physiotherapist therefore occupies a central role in the successful clinical integration of VR, functioning as assessor, treatment designer, supervisor, safety monitor, data interpreter and progression planner rather than being replaced by technology.

Table 3. Advantages, limitations and clinical considerations of VR-based neurological rehabilitation

Potential advantages	Clinical limitations	Practical considerations

High repetition	Variable evidence quality	Use validated outcome measures
Immediate feedback	Cybersickness	Screen patients before use
Increased engagement	Equipment cost	Select cost-effective platforms
Adjustable difficulty	Technology dependence	Provide therapist supervision
Objective performance data	Limited standardization	Establish individualized protocols
Simulated real-world tasks	Transfer may be incomplete	Include real-world practice
Home rehabilitation potential	Digital literacy barriers	Provide patient training
Cognitive-motor integration	Possible sensory overload	Adjust complexity gradually
Remote monitoring	Connectivity problems	Establish technical support

8. Wearable Sensors, Artificial Intelligence and Future Directions:

The next stage of VR-based neurological physiotherapy is likely to involve integration with wearable sensors, artificial intelligence, motion capture, robotics and advanced tele-rehabilitation platforms. Wearable inertial measurement units can quantify movement acceleration, joint motion, step characteristics and symmetry, while cameras and depth sensors can provide three-dimensional information about posture and movement trajectories. Force platforms can measure weight distribution and center-of-pressure changes during balance tasks, allowing VR systems to provide increasingly objective information about performance. The combination of these technologies with VR may enable physiotherapists to monitor parameters such as movement speed, smoothness, reaction time, trajectory accuracy, repetition number, weight shifting, gait symmetry and postural stability. Artificial intelligence may further enable adaptive rehabilitation by identifying movement patterns and automatically modifying task difficulty according to patient performance. For example, if a patient consistently achieves a virtual reaching task with high accuracy, the system could reduce target size, increase distance or introduce a secondary cognitive task, conversely, if performance deteriorates because of fatigue, the system could reduce task complexity or recommend a rest period. Such adaptive systems may facilitate individualized rehabilitation, but automated algorithms should remain under professional oversight because changes in performance can result from pain, fatigue, compensation, attention or technical problems rather than genuine neurological recovery. Robotics and VR may also be combined to provide intensive sensorimotor training. Evidence from network meta-analysis suggests that combinations involving robotics and VR may offer advantages for some post-stroke balance and functional outcomes, although additional trials are required to determine the optimal combinations (Zhang et al., 2023). Future VR systems may also incorporate physiological monitoring, including heart rate and exertion, allowing treatment intensity to be adjusted dynamically. Figure 6 shows Integrated VR, wearable sensor and artificial intelligence rehabilitation system. The proposed model includes patient movement capture through wearable sensors and cameras, transfer of performance data to a VR platform, AI-assisted analysis of movement quality, automated adjustment of task difficulty and therapist review of performance data and individualized progression of treatment. Another major future direction is the development of highly realistic community simulations. Instead of practicing isolated virtual movements, patients may navigate virtual homes, hospitals, supermarkets, roads, workplaces and public transportation environments, allowing rehabilitation to address complex cognitive-motor demands. Such environments may be particularly useful for acquired brain injury, Parkinson's disease and stroke survivors preparing for community reintegration. Nevertheless, future technological development must be accompanied by research

examining cost-effectiveness, data security, accessibility, patient acceptability and clinical validity. The most successful technology will not necessarily be the most immersive or technically sophisticated, rather, it will be the system that produces clinically meaningful functional improvements while remaining safe, affordable and practical for therapists and patients.

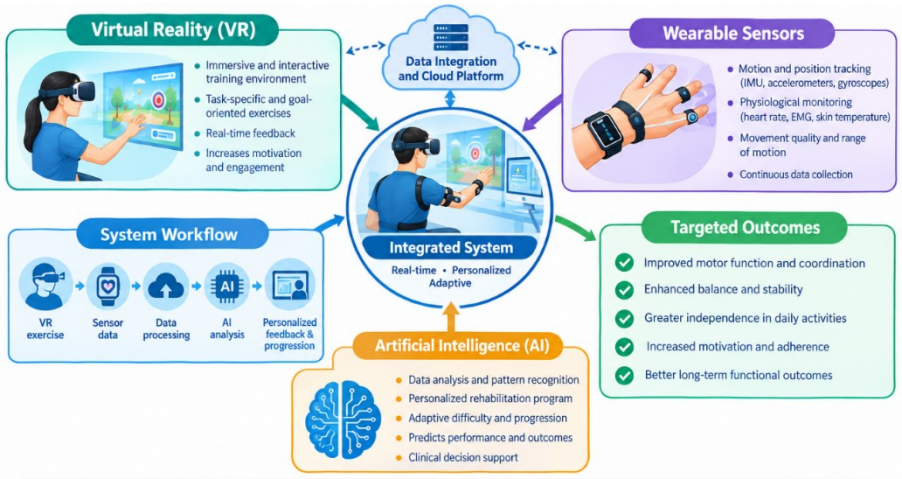


Figure 6. Integrated VR, wearable sensor and artificial intelligence rehabilitation system

9. Evidence Gaps, Clinical Challenges and Research Priorities

Despite the rapid growth of VR research, several important evidence gaps prevent the establishment of universally accepted clinical guidelines. The first challenge is substantial heterogeneity between studies. Researchers use different hardware platforms, software environments, immersion levels, treatment durations, frequencies, outcome measures and comparator interventions, making direct comparison difficult. A second issue is the methodological quality of existing systematic reviews and randomized trials. The 2024 umbrella review of stroke rehabilitation identified 78 reviews but found that many were rated as low or critically low methodological quality, demonstrating that a large quantity of literature does not necessarily equate to high certainty of evidence (Hao et al., 2024). Similar limitations have been identified in Parkinson's disease research, where recent reviews report promising improvements but emphasize variation in intervention design and risk of bias (Fernandes et al., 2025). Another major challenge is determining the optimal dose. It remains unclear whether VR produces greater benefits because of the technology itself or because it increases the total amount of therapeutic practice. Future studies should therefore compare dose-matched VR and conventional interventions and should report treatment intensity in detail. Long-term follow-up is also required because many studies assess outcomes immediately after intervention, providing limited information regarding whether improvements are maintained for six months or longer. Functional transfer represents another major research priority. Future trials should evaluate whether improvements achieved in virtual environments translate into actual community mobility, employment, social participation and independence. Research should also determine which patients are most likely to benefit from immersive versus non-immersive VR and whether specific neurological phenotypes respond differently. Cost-effectiveness should become a standard outcome because expensive rehabilitation technologies may not be sustainable in low-resource healthcare settings. Accessibility is particularly important for patients in rural or underserved communities. Another concern involves cybersickness, visual dependence and sensory overload, which require standardized safety reporting. Finally, future trials should incorporate patient-centered outcomes such as satisfaction, confidence, treatment preference, adherence and meaningful participation rather than relying solely on impairment-level measures. The proposed future model combines clinical assessment, individualized physiotherapy, VR-based task practice, wearable sensing, AI-supported analysis, remote monitoring, home exercise, periodic face-to-face reassessment and multidisciplinary decision-making, with functional participation remaining the final therapeutic goal. Future research should therefore move beyond demonstrating that VR can improve a particular test score and instead determine how VR can contribute to sustained improvements in independence, participation and quality of life. Well-

designed multicenter randomized trials with standardized treatment protocols, clinically meaningful outcomes, longer follow-up and transparent reporting of adverse events will be essential for establishing stronger evidence. VR should also be evaluated within different healthcare contexts because a system that is effective in a specialized rehabilitation center may not be practical in community physiotherapy or home care.

10. Conclusion:

Virtual reality-based rehabilitation represents a significant development in neurological physiotherapy and offers a flexible platform through which repetitive, task-specific, interactive and progressively challenging rehabilitation can be delivered. Current evidence demonstrates encouraging effects on upper-limb function, balance, gait, mobility, activities of daily living, cognitive-motor performance and selected quality-of-life outcomes across neurological populations, with particularly substantial evidence in stroke rehabilitation. Parkinson's disease research indicates potential benefits for dynamic balance, mobility, motor performance and quality of life, while evidence in multiple sclerosis supports possible improvements in cognitive function, balance and fatigue-related outcomes. In cerebral palsy, VR provides an engaging environment for repetitive motor practice and has demonstrated promising effects on gross motor function, balance and functional independence. The broader clinical value of VR lies in its ability to increase the amount and quality of meaningful practice while providing immediate feedback and objective performance information. Nevertheless, current evidence remains limited by methodological heterogeneity, variable treatment dosage, differences in technology, small sample sizes and inconsistent outcome measures. VR should therefore not be interpreted as a replacement for conventional neurological physiotherapy or professional clinical reasoning. The physiotherapist remains responsible for assessment, patient selection, treatment planning, movement correction, safety, progression and functional transfer. The most appropriate contemporary model is an integrated approach in which conventional physiotherapy provides the clinical foundation and VR enhances repetition, engagement, feedback and environmental simulation. Future rehabilitation is likely to combine VR with wearable sensors, artificial intelligence, robotics, tele-rehabilitation and home-based monitoring, potentially creating highly individualized treatment pathways. However, technological sophistication should always remain secondary to patient-centered clinical outcomes. The ultimate purpose of VR-based neurological rehabilitation is not to help patients perform better inside a virtual environment but to help them move more safely, function more independently and participate more meaningfully in real-world life. Continued high-quality research will be necessary to identify optimal treatment doses, patient-selection criteria, technology types and long-term outcomes, but the current evidence supports VR as a promising adjunct to modern neurological physiotherapy.

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