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Virtual reality systems in occupational therapy after stroke

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Abstract: Stroke is a leading cause of long-term disability, often impairing motor, cognitive, and functional abilities, which reduces quality of life. Virtual reality (VR) has emerged as a promising tool in stroke rehabilitation, providing immersive and interactive environments that support recovery. This review examines the effects of VR-based occupational therapy (OT) on occupational performance, motor function, and cognitive outcomes in individuals following a stroke. VR enables repetitive, task-specific practice in safe, controlled settings and has been shown to enhance daily living skills, especially during chronic recovery. VR-based mirror therapy may further improve motor function and dexterity, complementing conventional OT. Additionally, VR can support cognitive and emotional rehabilitation by enhancing attention, memory, and motivation while reducing depressive symptoms. Integrating VR into OT for stroke rehabilitation promotes physical and cognitive engagement and may increase therapy adherence. However, challenges remain, such as skill transfer to real-world contexts, protocol variability, accessibility, and cost. Further research is needed to refine VR applications, improve ecological validity, and assess long-term effectiveness to support its broader integration into standard OT practice for stroke rehabilitation.

Keywords: Embedded computer control systems, stroke, occupational therapy, virtual reality, rehabilitation

1. INTRODUCTION

Stroke is the second leading cause of death and long-term disability worldwide, often resulting in enduring physical and cognitive challenges that significantly diminish the quality of life for individuals post-stroke. Each year, approximately 12.2 million new stroke cases are reported globally, with the incidence rising due to aging populations and improved survival rates following acute medical interventions (World Health Organization, 2023; Kwakell et al., 2024).

Stroke often leads to motor, sensory, cognitive, and social impairments that limit daily functioning and occupational performance. Post-stroke recovery integrates neuroplasticity principles, rehabilitation, and pharmacological methods to restore function (Braun & Wittenberg, 2021). Early rehabilitation also includes OT, which supports functional independence and quality of life. In stroke recovery, OT focuses on enhancing occupational performance - enabling participation in meaningful ADL (Landim et al., 2024). Research indicates that the most frequently utilized OT approaches for stroke recovery include task-oriented training, constraint-induced movement therapy, and VR-based interventions. These methods are specifically designed to promote functional gains and increase engagement of individuals post-stroke during rehabilitation. VR interventions can provide immersive, interactive environments to enhance motivation and recovery outcomes. (Helmold, 2023; Khan et al., 2024; Rodríguez-Hernández et al., 2021). This review examines the effects of VR-based occupational therapy on motor, cognitive, and functional outcomes in individuals post-stroke, with a focus on identifying strengths and limitations across stroke recovery phases and outlining implications for clinical practice

1.1 *Classification of Virtual Reality*

VR offers a dynamic and interactive environment where an individual can practice real-life tasks and movements in a safe and controlled space. This technology promotes motor skill recovery through repetitive practice, while also enhancing motivation and engagement, which are crucial factors in the rehabilitation process. VR systems used in stroke rehabilitation are commonly classified by their level of immersion: non-immersive, semi-immersive, and fully immersive. Each type offers unique advantages and limitations in the context of OT.

Non-immersive VR, which utilizes conventional screens combined with motion-sensing technology, provides a cost-effective and accessible rehabilitation option, as seen in systems like GestureTek IREX, Nintendo Wii, and Xbox Kinect, though its limited sensory engagement may reduce therapeutic effectiveness (Kim et al., 2020; Levac et al., 2016). Semi-immersive VR enhances user interaction by incorporating large-screen projections or multi-sensory elements, with platforms such as CAVE and SaeboVR bridging the gap between non-immersive and fully immersive environments, making therapy sessions more engaging and adaptable (Šlosar et al., 2022; Kim et al., 2016). Fully immersive VR, which includes head-mounted displays like Oculus Rift, HTC Vive, and PlayStation VR, provides a high level of presence and engagement in rehabilitation, offering real-time feedback and interactive training scenarios that promote motor learning and neuroplasticity. In addition,

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advanced VR systems integrate motion tracking, haptic feedback, and real-time adaptive task engagement, using wearable sensors or depth-sensing cameras to monitor individuals' movements and enhance rehabilitation through personalized, interactive therapy (Kim et al., 2016; Levac et al., 2016). Beyond traditional VR applications, extended reality technologies, including augmented reality and mixed reality, expand the scope of rehabilitation by blending virtual and real-world elements, further increasing adaptability and engagement in therapeutic interventions (Levac et al., 2016; Šlosar et al., 2022). By simulating everyday scenarios, VR-based OT enables individuals post-stroke with the opportunity to rebuild their confidence and independence, improving their quality of life. Although VR is being used in OT intervention, its effects on long-term recovery outcomes are still being studied and initial findings suggest that it can lead to improved motor function and cognitive abilities, enhancing the overall quality of life for individuals post-stroke. Current VR systems address the level of impairment, with insufficient emphasis on occupational performance which indicates that current VR interventions may not adequately simulate the functional challenges of everyday occupations, emphasizing the need for greater ecological validity (Aderinto et al., 2023; Fisk et al., 2024; Khan et al., 2024).
In addition, the optimal use and effectiveness of VR in various stages of stroke recovery still need to be explored to identify the best practices for integrating VR into OT protocols and determine which populations may benefit most from this approach (Aderinto et al., 2023; Khan et al., 2024; Landim et al., 2024).

2. LITERATURE REVIEW

To better understand the application of VR as an OT intervention aimed at improving occupational performance in individuals after stroke, we conducted a literature review in two databases: PubMed and Web of Science. This narrative review follows PRISMA guidelines in its search, screening, and selection of studies. The search was conducted in December 2024. We created keyword combinations relevant to the chosen topic: "Virtual Reality" AND "Occupational Therapy" AND "Stroke*" AND ("Occupational Performance*")** for PubMed, and "Virtual Reality" AND "Occupational Therapy" AND "Stroke*" AND ("Rehabilitation*" OR "Functional recovery*")** for Web of Science. The literature search was limited to studies published in the last five years, written in English, and with full-text access available. The search strategy is presented in Table 1.

Table 1: The search strategy for each database

Database	Search Terms	Filters Applied
PubMed	"Virtual Reality*" AND "Occupational Therapy*" AND "Stroke*" AND ("Occupational Performance*")	English language, Last 5 years, RCTs, Clinical study, Clinical trial, Case study, Excluding meta-analyses and systematic reviews
Web of Science	"Virtual Reality*" AND "Occupational Therapy*" AND "Stroke*" AND ("Rehabilitation*" OR "Functional recovery*")	

The literature search was conducted based on predefined inclusion and exclusion criteria, that is presented in Table 2.

Table 2: Inclusion and exclusion criteria

	Inclusion criteria	Exclusion criteria
Populations	People after stroke Adults, 18 +	People with other conditions as stroke Children, adolescents
Intervention	Virtual reality systems	Conventional rehabilitation techniques
Focus	Occupational therapy	Other health professions
Study design	Quantitative study	Qualitative study

In total we retrieved 51 articles. After removing duplicates, inclusion and exclusion criteria and additional filters applied, we finally analysed 12 articles. The search strategy is presented in Prisma diagram in Figure 1.

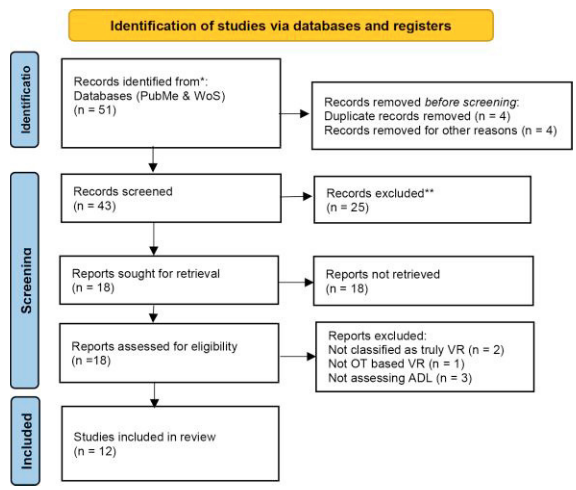

Figure 1: Prisma flow diagram

The review included nine randomized controlled trials (RCT), two clinical trials, and one experimental study. Our analysis revealed three separate groups, each related to a different stage of stroke: acute, subacute, and chronic stroke. The included studies are presented in Table 3a and Table 3b.

2.1. Studies examining the use of VR in the acute phase

Rehabilitation in the acute phase of stroke presents several challenges, including limited physical endurance, emotional distress, and cognitive impairments. VR has gained attention as a potential rehabilitation tool because it offers a structured and controlled environment that reduces physical strain while promoting engagement and neuroplasticity. Researchers are exploring VR's potential to support cognitive and motor recovery, as well as its role in enhancing ADL. By integrating VR-based interventions into acute stroke rehabilitation, individuals post-stroke can practice ADL in a controlled setting, which may contribute to improved recovery outcomes. VR environments (VIRTUE) can simulate real-life scenarios such as grocery shopping or using public transportation, enabling individuals post-stroke to engage in essential tasks safely and without real-world risks (Chatterjee et al., 2022; Cho & Lee, 2019; Wei et al., 2024).

Table 3a: Literature review

Author (Year), Study design	Study aim	Results
Aramaki et al. (2019) Clinical trial	To explore the viability of a client-centered VR rehabilitation program designed to enhance occupational performance and promote social participation.	VR is recognised as a feasible and effective tool for enhancing functional recovery.
Chatterjee et al. (2022) RCT	To explore the feasibility, safety and acceptability of a VR VIRTUE application for cognitive rehabilitation.	VR VIRTUE enhances cognitive rehabilitation in stroke, enables practice of ADLs, promotes neuroplasticity, and reduces hospital stay.
Cho & Lee (2019) Experimental study	To investigate the effects of VR combined with computerized cognitive training on cognitive function and ADL.	VR + computerized cognitive training improves cognitive function and ADL performance.
Cho et al. (2021) RCT	To evaluate the effectiveness of VRTE compared to traditional OT.	VRTE and OT groups showed significant improvements in upper limb function.
Dąbrowská et al. (2023) RCT	To evaluate the impact of VR therapy combined with traditional rehabilitation on self-sufficiency and health-related quality of life.	VR enhances rehabilitation, but did not yield significantly different outcomes compared to traditional OT.
Hsu et al. (2022) RCT	To investigate the effects of VR MT compared to traditional OT and MT on sensorimotor function of the upper limb.	Task-oriented approaches using VRMT can be used for better outcomes in upper limb motor function.
Long et al. (2020) RCT	To investigate the effects of VR training on occupational performance and self-efficacy	Integrating VR into traditional rehabilitation may enhance self-efficacy and ADL. Better alignment of VR activities with daily life tasks can enhance therapeutic outcomes and patient motivation.
Mekbib et al. (2021) RCT	To introduce the MNVR-Rehab system for upper extremity stroke rehabilitation and compare its effects with traditional OT on motor recovery and cortical reorganization.	MNVR-Rehab: a tool, to enhance upper extremity recovery in subacute stroke patients with moderate-to-severe impairments and promotes functional reorganization of the motor system.
Oh et al. (2019) RCT	To investigate the efficacy of VR combined with real instrument training on upper extremity and cognitive function.	VR with real object training improves stroke recovery and fine motor function more than traditional OT, while boosting patient motivation.

Table 3b: Continuation of literature review

Park et al. (2019) RCT	To assess the clinical feasibility of a VR-based planar motion exercise apparatus, VR SB, for stroke rehabilitation.	VR SB is a viable tool for enhancing upper limb function and health related quality of life- potential integration for rehabilitation. VR SB is a safe and feasible option for stroke rehabilitation.
Rodríguez-Hernández et al. (2021) RCT	To evaluate VR-based therapy's effectiveness combined with traditional rehabilitation in improving upper limb motor function and autonomy in ADL.	Combining VR with traditional rehabilitation significantly improves upper limb motor function, reduces muscle tone, and enhances autonomy in ADL.
Wei et al. (2024) Non-RCT Clinical trial	To introduce immersive VR and compare occupational performance in real-world shopping versus immersive VR	Occupational performance in shopping tasks, including memory, is comparable between Immersive VR and real-world settings, while movement duration varies, possibly due to reduced somatosensory input in virtual environments.

VR improves motor function in self-care activities like dressing and personal hygiene through its repetitive, task-oriented design, though it has not consistently shown superiority over traditional OT (Aramaki et al., 2019; Chatterjee et al., 2022). Similarly, Cho et al. (2021) found that although both VR-based therapeutic activities and traditional OT improved upper limb function and ADL in acute stroke, VR showed no added benefit. Severe impairments and the need for adaptations, such as strapped controllers, may have limited natural movement and reduced VR effectiveness. Rodríguez-Hernández et al. (2021) reported that combining VR with traditional OT led to greater improvements in motor function, reduced muscle tone, and increased ADL independence, supporting VR as a valuable complement to standard OT intervention. VR also enhances cognition by stimulating brain regions involved in attention, memory, and executive function, which may contribute to better rehabilitation outcomes. The use of head-mounted displays in VR therapy can further support cognitive recovery by minimizing external distractions, thereby enhancing focus and motivation. Additionally, studies suggest that VR interventions may be particularly beneficial for individuals with severe cognitive impairments and may even reduce hospital stays (Cho & Lee, 2019; Chatterjee et al., 2022). Another key advantage of VR is its ability to make rehabilitation more engaging and enjoyable, which is essential for maintaining motivation in the early stages of stroke recovery. In the acute phase, sustained participation in therapy is crucial, and VR's interactive design can help facilitate this. Features such as single-action controllers and adjustable task difficulty levels make VR accessible to older adults and individuals with limited experience using technology (Wei et al., 2024). Also, gamification elements, such as scoring systems and achievement levels, provide real-time feedback and reinforce a sense of accomplishment, further encouraging active participation in rehabilitation (Aramaki et al., 2019; Chatterjee et al., 2022; Dąbrowská et al., 2023; Wei et al., 2024).

2.2. Studies examining the use of VR in the subacute phase

The subacute phase (weeks to six months post-stroke) is critical for recovery, requiring targeted motor, cognitive, and emotional interventions (Aramaki et al., 2019; Mekbib et al., 2020). VR enhances occupational performance and satisfaction in subacute stroke rehabilitation. Tailored VR interventions can support upper limb function recovery. For example, the use of VR-based systems, such as the Rapael Smart Board, has been associated with improvements in active range of motion and overall health-related quality of life. Research also suggests that VR facilitates motor learning and neural plasticity, which are essential for recovery during this phase. Immersive VR encourages repetitive task engagement, activating mirror neurons critical for motor recovery. (Aramaki et al., 2019; Mekbib et al., 2020; Oh et al., 2021; Park et al., 2019). VR-based tasks, particularly those using the Mirroring Neuron VR-Rehab system (MNVR), support motor recovery through neuroscience-based, gamified, and task-oriented activities that enhance upper limb function and engagement (Mekbib et al., 2020; Wei et al., 2024). Although VR interventions in subacute stroke rehabilitation show potential, some studies indicate that their effectiveness may not be significantly greater than traditional OT. Long et al. (2020) conducted a RCT investigating the effects of VR training on occupational performance and self-efficacy in post-stroke rehabilitation. VR training significantly improved self-efficacy and ADL but was not superior to traditional OT in upper limb function or satisfaction, aligning with other studies indicating that increased motivation does not consistently lead to better functional outcomes (Long et al., 2020). Dabrowska et al. (2023) reported no statistically significant differences in self-sufficiency and balance scores between individuals receiving VR-based OT and those undergoing traditional OT, although both groups demonstrated improvements. Combining VR with traditional OT may have additional benefits, as the interactive and engaging nature of VR can increase motivation and adherence, leading to potentially better rehabilitation outcomes (Aramaki et al., 2019; Dabrowska et al., 2023). Furthermore, VR-based interventions have been linked to cognitive improvements in attention and memory, both of which are commonly affected after a stroke. By providing a stimulating environment for cognitive tasks, VR can support cognitive rehabilitation (Cho & Lee, 2019; Park et al., 2019). Emotional benefits, such as reduced depression and increased motivation, have also been observed, as the enjoyable and rewarding elements of VR-based therapy encourage participation and engagement (Park et al., 2019). Overall, VR seems to be a valuable tool to complement traditional OT in subacute stroke rehabilitation, though further research is needed to determine optimal implementation strategies, including timing and intervention selection (Wei et al., 2024).

2.3. Studies examining the use of VR in the chronic phase

In chronic stroke rehabilitation, enhancing occupational performance, particularly in basic and instrumental ADL is a key objective. VR-based OT interventions have been found to significantly improve individuals' perceived performance and satisfaction in these tasks. By enabling task-specific training, VR offers an innovative approach that may surpass the effectiveness of traditional OT in certain areas. For example, VR allows for the replication of complex real-world scenarios, such as shopping, providing a structured and controlled setting for skill development. Additionally, the person-centered design of VR emphasizes individualized, task-oriented training, which has been shown to enhance both occupational performance and satisfaction. VR-based mirror therapy (VRMT) strengthens motor recovery by incorporating multisensory feedback, facilitating targeted, task-specific exercises that may be difficult to replicate with traditional OT interventions (Aramaki et al., 2019; Hsu et al., 2022; Wei et al., 2024). While VR has demonstrated effectiveness in improving occupational performance, a major challenge is in ensuring that the skills learned in virtual environments transfer to real-world situations. Wei et al. (2024) and Aramaki et al. (2019) point out the need for long-term studies to determine whether skills gained through VR are maintained over time and useful in everyday life. Such research would provide valuable insights into the long-term effectiveness of VR interventions in promoting independence and functionality.

Motor recovery is also an important aspect of rehabilitation for individuals with chronic stroke. Studies have shown that VRMT can lead to notable improvements in wrist motor function and dexterity, even outperforming traditional OT and traditional mirror therapy. These advancements are largely attributed to VR's ability to provide enhanced multisensory feedback and activate motor-related brain regions, fostering neuroplasticity. However, overall progress in primary motor functions, as assessed through standardized measures, has been moderate. This indicates that VR has the most effects as a supplement to traditional OT rather than an independent intervention in OT for individuals post-stroke. (Aramaki et al., 2019; Hsu et al., 2022). VR interventions also integrate cognitive and physical tasks, offering a more comprehensive approach to stroke rehabilitation. Wei et al. (2024) highlighted how virtual activities, such as simulated shopping, engage memory and executive function, reinforcing cognitive-motor integration, that is essential component of functional independence. This multidimensional capacity makes VR suited for addressing the complex challenges associated with chronic stroke recovery. Motivation and engagement of individuals post-stroke have emerged as critical factors in the success of VR rehabilitation programs. Aramaki et al. (2019) reported full adherence to a 12-week VR intervention, with participants frequently citing the enjoyable and stimulating nature of the tasks as a primary source of motivation. Similarly, Hsu et al. (2022) and Wei et al. (2024) found high levels of patient participation in VR sessions, attributing this to the interactive and gamified nature of the technology. Maintaining long-term engagement is particularly vital in chronic stroke rehabilitation, where individuals may experience frustration or fatigue that could otherwise hinder participation. Despite its advantages, several challenges remain in integrating VR into rehabilitation, including variability in intervention protocols, limitations in sensory feedback, and financial constraints. Many VR systems lack haptic feedback, reducing their ability to fully replicate real-world sensory experiences, which may impact skill transfer. To maximize VR's potential, future research should focus on developing cost-effective systems that incorporate advanced sensory feedback mechanisms. Additionally, hybrid rehabilitation models that combine VR with traditional OT could offer a more balanced approach. Longitudinal studies are also needed to examine the long-term sustainability of VR-acquired skills and their overall impact on quality of life (Aramaki et al., 2019; Hsu et al., 2022; Wei et al., 2024).

3. KNOWLEDGE GAPS

The reviewed studies highlight the potential of VR-based OT in stroke rehabilitation; however, several consistent limitations reveal important gaps that require further investigation.

3.1. Ecological validity and skill transfer

While some studies simulate real-life activities (Wei et al., 2024), most focus on impairment-level tasks rather than meaningful occupations. Few interventions are explicitly designed for improving ADL, limiting their ecological validity. As a result, the transfer of skills from virtual to real environment remains unclear, especially in the chronic phase (Aramaki et al., 2019; Wei et al., 2024)

3.2. Lack of standardized protocols

The reviewed studies show wide variability in intervention duration, frequency, and content. Some focus on upper motor function (Rodríguez-Hernández et al., 2021; Mekbib et al., 2021) while others emphasize cognitive training (Cho & Lee, 2019) or ADL (Long et al., 2020). This heterogeneity hinders comparability and the development of evidence-based guidelines for clinical use.

3.3. Accessibility and usability

Several studies report practical challenges in applying VR with individuals post-stroke, particularly in the acute phase. Cho et al. (2021) indicate that individuals with severe impairments require controller adaptations, potentially reducing engagement and natural movement. The complexity and cost of immersive systems remain barriers to widespread adoption, especially in resource-limited settings (Mekbib et al., 2020; Park et al., 2019).

3.4. Adaptation for severe impairments

Few OT interventions are tailored for individuals with severe motor or cognitive impairments. Most systems rely on handheld devices or hand-mounted displays, which may not be suitable for individuals with limited mobility or low cognitive endurance. This is particularly evident in the acute stroke phase (Cho et al., 2021; Chatterjee et al., 2022), where engagement was dependent on physical adaptability.

3.5. Limited long-term evidence

Most studies assess short-term effects on motor and cognitive function but lack follow-up on long-term occupational performance. Aramaki et al. (2019) and Wei et al. (2024) highlight the need for longitudinal studies to verify the lasting impact of VR on functional outcomes.

4. CONCLUSIONS

VR has emerged as a promising tool in OT for stroke rehabilitation, offering immersive and interactive training environments that enhance motor, cognitive, and emotional recovery. The findings from this review indicate that VR-based OT interventions can significantly improve ADL, self-efficacy, and engagement in rehabilitation. Studies show that VR enhances motivation, facilitates neuroplasticity, and provides a structured setting for repetitive task practice, supporting motor and cognitive rehabilitation across acute, subacute, and chronic stroke phases. Despite its advantages, VR is not consistently superior to traditional OT in improving upper limb function or overall occupational performance. Some studies suggest that while VR enhances engagement and adherence, its direct impact on functional recovery remains comparable to conventional rehabilitation approaches. Challenges such as cost, accessibility, and the need for standardized protocols still hinder the widespread adoption of VR in clinical settings. Ensuring that VR-based training can be transformed into real-world functional gains remains a critical area for future exploration. Future research should focus on developing evidence-based guidelines, improving ecological validity, and incorporating advanced feedback mechanisms to enhance skill transfer.

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5. REFERENCES

Aderinto, N., Olatunji, G., Abdulbasit, M. O., Edun, M., Aboderin, G., & Egbunu, E. (2023). Exploring the efficacy of virtual reality-based rehabilitation in stroke: a narrative review of current evidence. In *Annals of Medicine* (Vol. 55, Issue 2). Taylor and Francis Ltd. https://doi.org/10.1080/07853890.2023.2285907

Aramaki, A. L., Sampaio, R. F., Cavalcanti, A., & Dutra, F. C. M. S. E. (2019). Use of client-centered virtual reality in rehabilitation after stroke: A feasibility study. *Arquivos de Neuro-Psiquiatria*, *77*(9), 622–631. https://doi.org/10.1590/0004-282X20190103

Braun, R., & Wittenberg, G. F. (2021). Motor Recovery: How Rehabilitation Techniques and Technologies Can Enhance Recovery and Neuroplasticity. *Seminars in Neurology*. https://doi.org/10.1055/S-0041-1725138

Chatterjee, K., Buchanan, A., Cottrell, K., Hughes, S., Day, T. W., & John, N. W. (2022). Immersive Virtual Reality for the Cognitive Rehabilitation of Stroke Survivors. *IEEE*

Transactions on Neural Systems and Rehabilitation Engineering, *30*, 719–728. https://doi.org/10.1109/TNSRE.2022.3158731

Cho, D., & Lee, S. (2019). Effects of virtual reality immersive training with computerized cognitive training on cognitive function and activities of daily living performance in patients with acute stage stroke. *Medicine, 98*(11). https://doi.org/10.1097/MD.0000000000014742

Cho, H., Song, E., Moon, J.-H., & Hahm, S.-C. (2021). Effects of virtual reality-based therapeutic exercise on upper extremity function and activities of daily living in patients with acute stroke: A pilot randomized controlled trial. *Medico-Legal Update, 21*(2), 676-682. https://doi.org/10.37506/mlu.v21i2.2761

Dąbrowská, M., Pastucha, D., Janura, M., Tomášková, H., Honzíková, L., Baníková, Š., Filip, M., & Fiedorová, I. (2023). Effect of virtual reality therapy on quality of life and self-sufficiency in post-stroke patients. *Medicina (Lithuania), 59*(9), 1669. https://doi.org/10.3390/medicina59091669

Fisk, A., Fox, S., Floyd, J., & Blustein, D. (2024). *A low-cost virtual reality stroke rehabilitation system: Development and initial feasibility assessment*. medRxiv. https://doi.org/10.1101/2024.08.23.24312233

Helmold, M. (2023). *Effects of Occupational Therapy for Persons with Stroke on Restoration of Roles, Tasks, and Activities and on Remediation of Impairments*. https://doi.org/10.1093/med/9780197630402.003.0040

Hsu, H. Y., Kuo, L. C., Lin, Y. C., Su, F. C., Yang, T. H., & Lin, C. W. (2022). Effects of a Virtual Reality–Based Mirror Therapy Program on Improving Sensorimotor Function of Hands in Chronic Stroke Patients: A Randomized Controlled Trial. *Neurorehabilitation and Neural Repair*, *36*(6), 335–345. https://doi.org/10.1177/15459683221081430

Khan, A., Imam, Y. Z., Muneer, M., et al. (2024). *Virtual reality in stroke recovery: A meta-review of systematic reviews* (Version 1) [Preprint]. Research Square. https://doi.org/10.21203/rs.3.rs-4319427/v1

Kim, W.-S., Cho, S., Ku, J., Kim, Y., Lee, K., Hwang, H.-J., & Paik, N.-J. (2020). Clinical application of virtual reality for upper limb motor rehabilitation in stroke: Review of technologies and clinical evidence. *Journal of Clinical Medicine, 9*(10), 3369. https://doi.org/10.3390/jcm9103369

Kwakkel, G., Stinear, C., Essers, B., Munoz-Novoa, M., Branscheidt, M., Cabanas-Valdés, R., ... & Verheyden, G. (2023). Motor rehabilitation after stroke: European Stroke Organisation (ESO) consensus-based definition and guiding framework. *European Stroke Journal, 8*(4), 880–894. https://doi.org/10.1177/23969873231191304

Landim, S. F., López, R., Caris, A., Castro, C., Castillo, R. D., Avello, D., Magnani Branco, B. H., Valdés-Badilla, P., Carmine, F., Sandoval, C., & Vásquez, E. (2024). Effectiveness of Virtual Reality in Occupational Therapy for Post-Stroke Adults: A Systematic Review. In *Journal of Clinical Medicine* (Vol. 13, Issue 16). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/jcm13164615

Levac, D., Glegg, S. M. N., Sveistrup, H., Colquhoun, H., Miller, P. A., Finestone, H., DePaul, V., Harris, J. E., & Velikonja, D. (2016). A knowledge translation intervention to enhance clinical application of a virtual reality system in stroke rehabilitation. *BMC Health Services Research, 16*, 557. https://doi.org/10.1186/s12913-016-1807-6

Long, Y., Ouyang, R., & Zhang, J. (2020). Effects of virtual reality training on occupational performance and self-efficacy of patients with stroke: A randomized controlled trial. Journal of NeuroEngineering and Rehabilitation, 17(1), 150. https://doi.org/10.1186/s12984-020-00783-2

Mekbib, D. B., Zhao, Z., Wang, J., Xu, B., Zhang, L., Cheng, R., Fang, S., Shao, Y., Yang, W., Han, J., Jiang, H., Zhu, J., Ye, X., Zhang, J., & Xu, D. (2020). Proactive Motor Functional Recovery Following Immersive Virtual Reality–Based Limb Mirroring Therapy in Patients with Subacute Stroke. *Neurotherapeutics*, *17*(4), 1919–1930. https://doi.org/10.1007/s13311-020-00882-x

Oh, Y. Bin, Kim, G. W., Han, K. S., Won, Y. H., Park, S. H., Seo, J. H., & Ko, M. H. (2019a). Efficacy of Virtual Reality Combined With Real Instrument Training for Patients With Stroke: A Randomized Controlled Trial. *Archives of Physical Medicine and Rehabilitation*, *100*(8), 1400–1408. https://doi.org/10.1016/j.apmr.2019.03.013

Park, M., Ko, M., Kim, S., Lee, H., Lee, S., & Shin, J. (2019). Effects of virtual reality-based planar motion exercises on upper extremity function, range of motion, and health-related quality of life: A multicenter, single-blinded, randomized, controlled pilot study. *Journal of NeuroEngineering and Rehabilitation, 16*(1), Article 1. https://doi.org/10.1186/s12984-019-0581-4

Rodríguez-Hernández, M., Criado-Álvarez, J.-J., Corregidor-Sánchez, A.-I., Martín-Conty, J. L., Mohedano-Moriano, A., & Polonio-López, B. (2021). Effects of virtual reality-based therapy on quality of life of patients with subacute stroke: A three-month follow-up randomized controlled trial. *International Journal of Environmental Research and Public Health, 18*(6), 2810. https://doi.org/10.3390/ijerph18062810

Šlosar, L., Voelcker-Rehage, C., Paravlić, A. H., Abazović, E., de Bruin, E. D., & Marušič, U. (2022). Combining physical and virtual worlds for motor-cognitive training interventions: Position paper with guidelines on technology classification in movement-related research. *Frontiers in Psychology, 13*, 1009052. https://doi.org/10.3389/fpsyg.2022.1009052

Wei, X., Zhou, P., Wei, Y., Wu, D., Qin, P., Zhang, Y., Zhu, J., Ren, Z., Li, H., & Zhang, Y. (2024). Comparison of occupational performance in immersive virtual and real environments among patients with stroke: Observational randomized crossover pilot study. *JMIR Serious Games, 12*, e58388. https://doi.org/10.2196/58388

World Health Organization – WHO (2023). Stroke, cerebrovascular accident. http://www.emro.who.int/health-topics/stroke-cerebrovascular-accident/index.html