Summary of Findings - How effective is Virtual Reality as a tool for cognitive and motor rehabilitation in patients with traumatic brain injuries?

Jet Chang, Trinity Edl, Harini Mohan, Minsoo Park, Shreya Perumal

Introduction

The use of virtual reality (VR) in the medical rehabilitation field has gained significant attention in recent years due to its unlimited potential to enhance cognitive and motor functions with the unique, immersive, and interactive experience it provides. Meanwhile, Traumatic Brain Injuries (TBI) have been one of the main causes of neurological conditions with commonly acquired symptoms including cognitive, motor, and behavioral impairment. This document explores the effectiveness of VR as a tool for rehabilitation of TBI patients through an in-depth analysis of 15 systematic reviews. The analysis was carried out starting with the data extraction of VR uses in TBI patients, then synthesizing through prominent themes, patterns, and differences across data to arrive at our conclusion. The objective of this summary is to evaluate current evidence on the impact of VR-based interventions compared to traditional approaches through extracted data from each paper. We will also identify the benefits and limitations of VR, and furthermore provide integration recommendations for future rehabilitation programs, specifically for TBI patients.

Summary of search and screening results

Initially starting with 99 papers that met our search queries, 50 of them were selected for search and screening. 26 irrelevant studies were then excluded according to the inclusion criteria in the title and abstract screening, primarily due to failure to meet the study condition/domain of mainly focusing on TBI patients and VR. 24 full-text studies were reviewed where 9 of them were excluded through group discussion, as they failed to meet the scope of the inclusion criteria for the final synthesis stage. Specific exclusion criteria during the search and screening process can be found in Figures 1 and 2. Consequently, 15 studies were included in the data extraction process, becoming the basis of the summary of findings report.

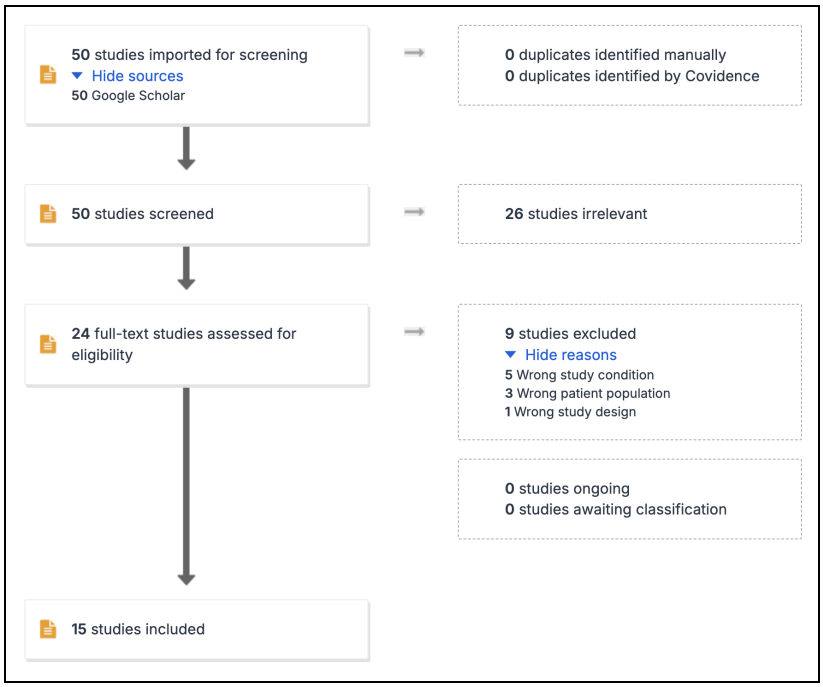

Figure 1: PRISMA Flow Diagram.

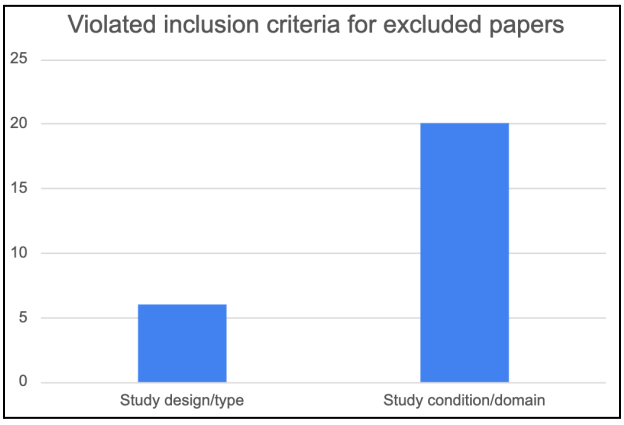

Figure 2. Violated inclusion criteria for excluded papers: Title and Abstract Screening

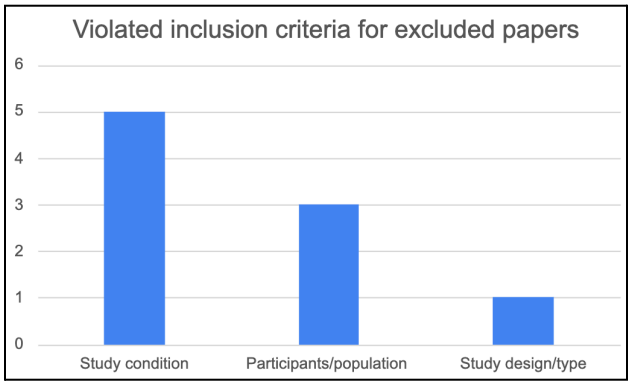

Figure 3. Violated inclusion criteria for excluded papers: Full Text Review

Data Extraction

The three tables given below showcase the information extracted from the articles reviewed in the full-text screening. Given that the data extraction table was too large the data was divided amongst three tables. Table 1 contains basic information (Title, Citation, Authors, Country, Year and Objectives), Table 2 contains key features of each study (Study Type, Number of Participants, Demographic, VR usage, Other methods included) and Table 3 contains observations and findings of each study (Testing Measures, Improvement, Setting/Context and Major Findings). The selected articles are highlighted in green below. During the data extraction, articles were selected based on the findings of each of the systematic reviews detailed in the tables. Most studies focused on either the potential for use of VR in cognitive rehabilitation or how it can improve or test cognitive abilities. Reviews were included if they presented sufficient rationale or evidence demonstrating how the use of VR technology could impact cognition through repetitive use. The systematic reviews included after the data extract were systematic reviews [1], [3], [4], [5], [6], [7], [9], [10], [11], [12], [13], [14], [15] and the reviews excluded were [2] & [8]. Reviews [2] & [8] were excluded as a result of the studies lacking relevant findings and/or substantial justification.

Table 1: Basic Information of Each Study Reviewed in Full - Text Screening

Paper title and citation details	Author(s)	Country of Origin	Year	Objectives
Cognitive rehabilitation post traumatic brain injury: A systematic review for emerging use of virtual reality technology [1] Reviewer: Minsoo Park	Alashram, Anas R; Annino, Giuseppe; Padua, Elvira; Romagnoli, Cristian; Mercuri, Nicola Biagio	Italy	2019	Examine the effects of virtual reality (VR) training interventions on cognitive function in patients with traumatic brain injury (TBI). Identify effective VR treatment protocols for cognitive rehabilitation on patients.
Effects of physical therapy interventions on balance ability in people with traumatic brain injury: A systematic review [2] Reviewer: Minsoo Park	Alashram, Anas R; Annino, Giuseppe; Raju, Manikandan; Padua, Elvira	Italy	2020	Access the effectiveness of different therapy interventions such as VR or VRT (vestibular rehabilitation therapy), or other traditional physical therapy

Vision-based serious games and virtual reality systems for motor rehabilitation: A review geared toward a research methodology [3] Reviewer: Minsoo Park	Ayed, Ines; Ghazel, Adel; Jaume-i-Capo, Antoni; Moya-Alcover, Gabriel; Varona, Javier; Martínez-Bueso, Pau	Spain, Tunisia	2019	Review the use of vision-based serious games and virtual reality systems in motor rehabilitation programs
Available Virtual Reality-Based Tools for Executive Functions: A Systematic Review [4] Reviewer: Jett Chang	Francesca Borgnis; Francesca Baglio; Elisa Pedroli; Federica Rossetto; Lidia Uccellatore; Jorge Alexandre; Gaspar Oliveira; Giuseppe Riva; Pietro Cipresso	Italy	2022	Examine the effects of virtual reality (VR) training interventions on cognitive function in patients with traumatic brain injury (TBI). Identify effective VR treatment protocols for cognitive rehabilitation on patients.
Design and assessment of amblyopia, strabismus, and myopia treatment and vision training using virtual reality [5] Reviewer: Jett Chang	Hoi Sze Chan; Yuk Ming Tang; Chi Wai Do; Horace Ho Yin Wong; Lily YL Chan; Suet To;	China	2023	Review the use of virtual reality-related interventions in amblyopia, strabismus, and myopia research. Focus on strabismus (TBI related) and relation to research question
Efficacy of Virtual Reality Rehabilitation after Spinal Cord Injury: A Systematic Review [6] Reviewer: Jett Chang	Amanda Vitória Lacerda de Araújo; Jaqueline Freitas de Oliveira Neiva; Carlos Bandeira de Mello Monteiro; Fernando Henrique Magalhães	Brazil	2019	VR-Based rehabilitation efficacy after spinal cord injury VR rehabilitation after traumatic brain injury, balance control, gait recovery after stroke and other TBI

From movement to thought and back: A review on the role of cognitive factors influencing technological neurorehabilitation [7] Reviewer: Trinity Edl	De Bartolo, Daniela; Spitoni, Grazia Fernanda; Iosa, Marco; Morone, Giovanni; Ciancarelli, Irene; Paolucci, Stefano; Antonucci, Gabriella	Italy	2019	"highlight the relationship between cognition and motion and, in the light of new rehabilitation technologies, to better define how aspects of cognition can affect motor rehabilitation."
Leveraging Technology for Vestibular Assessment and Rehabilitation in the Operational Environment: A Scoping Review [8] Reviewer: Trinity Edl	Hoppes, Carrie W; Lambert, Karen H; Whitney, Susan L; Erbele, Isaac D; Esquivel, Carlos R; Yuan, Tony T	USA	2024	"This scoping review aimed to examine the literature for technologies that can be utilized for vestibular assessment and rehabilitation in operational environments."
Exploring the potential of immersive virtual reality in the treatment of unilateral spatial neglect due to stroke: a comprehensive systematic review [9] Reviewer: Trinity Edl	Martino Cinnera, Alex; Bisirri, Alessio; Chioccia, Ilaria; Leone, Enza; Ciancarelli, Irene; Iosa, Marco; Morone, Giovanni; Verna, Valeria	N/A	2022	"The present review aims to explore the use of Immersive Virtual Reality (IVR) in the treatment of visual perception in Unilateral Spatial Neglect (USN) after a stroke."
"Augmentation and Rehabilitation with Active Orthotic Devices" [10] Reviewer: Harini Mohan	Gelu Onose, Maria Veronica Morcov, Corina Sporea, Andrada Mirea, and Vlad Ciobanu	Romania	2021	To determine the effectiveness and use of active orthotic devices and exoskeletons, as well as using VR technology, in the rehabilitation of neuromotor impairments.

What is the future for immersive virtual reality in memory rehabilitation? A systematic review [11] Reviewer: Harini Mohan	Adela Plechata, Tereza Nekovarova, and Iveta Fajnerova	Czechia	2021	Determine the effectiveness of virtual reality based rehabilitation in enhancing memory functions.
A retrospective analysis and systematic review of the areas of entertainment computing and persuasive technologies for health [12] Reviewer: Shreya Perumal	Silva, Paula Alexandra; Bermúdez i Badia, Sergi; Cameirão, Mónica S	Portugal	2023	Examine the impact of entertainment computing and persuasive technologies in healthcare.
Trends on the application of serious games to neuropsychological evaluation: A scoping review [13] Reviewer: Shreya Perumal	Valladares-Rodríguez, Sonia; Pérez-Rodríguez, Roberto; Anido-Rifón, Luis; Fernández-Iglesias, Manuel	Spain	2016	To conduct a scoping review to map key concepts and developments in the use of serious games for neuropsychological evaluation.
Leveraging Emerging Technologies to Expand Accessibility and Improve Precision in Rehabilitation and Exercise for People with Disabilities [14] Reviewer: Shreya Perumal	Willingham, T Bradley; Stowell, Julie; Collier, George; Backus, Deborah	United States of America	2024	To determine the barriers in physical rehabilitation and assess how new technology can create improvements.
"IoT-driven augmented reality and virtual reality systems in neurological sciences" [15] Reviewer: Harini Mohan	Mehar Sahu, Rohan Gupta, Rashmi K. Ambasta, Pravir Kumar	India	2024	Explore the use of Internet of Things AR and VR in diagnosing and treating neurological disorders. It highlights the potential impact of these technologies on neurorehabilitation and neurosurgical practices.

Table 2: Key Features of Each Study Reviewed in Full - Text Screening

#	Type of study	Number of participants	Participant Demographic	VR Usage Frequency	Type of VR Technology	Additional Therapies
[1]	Systematic Review	131	83.52% male, 16.48% female mean average ranging from 20 ~ 40.3	90 minutes in duration ; 3 times per week ; 5 weeks	3DVisor head mounted display system (HMD)	Table Game Activities Psycho-educational vocational training
[2]	Systematic Review	259	27.41% female, 72.59% male 18+ patients 1.4 ~ 6 months post TBI patients	18 sessions of 60 minutes (3 sessions per wk for 6 wks)	N/A	Vestibular Rehabilitation Therapy Video Game Therapy Elliptical Trainer Device Mobility Training
[3]	Systematic Review	15	30.6 years old average	N/A	Microsoft Kinect	Prototype games: Virtual Teacher (VT), Virtual Challenger (VC), Courtyard, Skateboard, Boat, and Octopus
[4]	Systematic Review	N/A	N/A	3-4 days a week, 45 mins a day in the VMALL (virtual mall) trial Otherwise N/A	(used in) VR-DOT (virtual apartment environment) VAP-S (virtual supermarket environment)	N/A
[5]	Systematic Review	N/A	N/A	N/A	Cyberdome 1400 StereoGraphics crystal eyes shutter goggles Oculus Rift	N/A

[6]	Systematic Review	N/A	N/A	N/A	Virtual reality driving simulator CyberGlove® Gait Real-time Analysis Interactive Lab (GRAIL)	None
[7]	Systematic Review	N/A	Children and adults with motor deficits	N/A	N/A	Action observation therapy, mirror therapy, real or virtual actuators, sensors, serious exergames, etc.
[8]	Systematic Review	N/A		N/A	VIRVEST wearable virtual reality-based system, head-mounted display (C-SVV® goggles), (Convergence VR Tech Labs Pvt. Ltd.)	
[9]	Systematic Review	77 with Unilateral Spatial Neglect (USN) and 134 healthy	51% male USN from a stroke	N/A	N/A	N/A
[10]	Systematic Review	N/A	Participants mainly included individuals with neuromotor impairments, paraplegia, or stroke patients.	VR technologies were mentioned as a supporting treatment but the frequency of use was not described.	N/A	VR combined with robotic-assisted therapy (Lokomat and G-EO).

[11]	Systematic Review	N/a	People with neurological and mental conditions, such as Alzheimer's disease, depression, schizophrenia, and stroke patients. People with TBI or acquired brain injuries.	VR therapy sessions range from weekly sessions to daily exercises. The specific frequency depended on the study, but many studies involved sessions multiple times per week for a duration of several weeks.	Both immersive and non-immersive VR technologies. Immersive VR involved head-mounted displays , while non-immersive VR used standard monitors and screens.	Many studies included traditional therapist-led cognitive training, conventional rehabilitation, or personalized paper-pencil exercises.
[12]	Systematic Review	N/A	Healthy Participants Patients	N/A	2D & 3D VR	Augmented Reality, Mixed Reality, Mobile Games
[13]	Systematic Review	N/A	Healthy Individuals; People with: Mild Cognitive Impairment, Alzheimers, TBI, ASD	N/A	VR Headset	N/A
[14]	Systematic Review	N/A	Various disabilities (ex. cognitive impairment, mobility issues, visual/auditory impairment, etc...)	N/A	VR Integrated Devices (such as treadmills, eyewear, etc...)	N/A
[15]	Systematic Review	N/A	N/A	N/A.	Head-mounted displays, semi-immersive setups, and mixed reality environments.	Conventional therapist-led cognitive training and physical rehabilitation alongside AR/VR applications

Table 3: Observations & Findings of Each Study Reviewed in Full - Text Screening

#	Measures of Cognitive Function	Degree of Improvement After VR Interventions	Setting/Context	Major Findings
[1]	Improvement measured in: Corsi's Supraspan Test Real-life behavioral PM test CAMPROMPT–CV total score (prospective memory performance) HKLLT (effectiveness of learning and memory) etc.	Corsi's Supraspan Test: Improvement from 1 to 3 Real-life behavioral PM test: Event-based tasks Pre 8.74 ± 3.38, Post 12.26 ± 3.03 Time-based tasks Pre 3.37 ± 2.20, Post 6.26 ± 3.26 Ongoing tasks Pre 0.96 ± 0.08, Post 0.91 ± 0.16 CAMPROMPT-CV total score: Pre 20.53 ± 4.10, Post 24.53 ± 4.34 HKLLT: Learning slope Pre 1.50 ± 1.25, Post 1.84 ± 1.33	Authors affiliated with several universities in Italy wanted to find effective measures of VR for rehabilitation after TBI.	According to study results, VR training interventions led to various cognitive function improvements such as memory, executive function and attention. Even though there is further research needed on the effects on attention, it showed that there were no apparent adverse effects of the VR approach. Limitations included small sample sizes of research as well as not enough information on long term effects of VR on TBI rehabilitation.
[2]	Berg Balance Scale (BBS) Dynamic Gait Analysis (DGI) Limits of StabilityReaction Time Backwards LOS (RT-B) Motor Control Test (MCT) Balance Error Scoring System (BBES) Community Balance and Mobility Scale (CB&M)	BBS: improvement of 0.19 points per day CB&M: Enhancement, no specific numbers	There were no systematic reviews on the impact of physical therapy intervention on TBi patients, specifically their balance impairment.	There was limited evidence on effectiveness of physical therapy interventions for improving balance in post TBI patients. In other words, the different types of interventions, including VR, didn't have a significant advantage over other interventions. This paper was also lacking in patient numbers and trials, with no specific mention of exact VR type.

[3]	Berg Balance Scale (BBS) Functional Reach Scale (FRS)	N/A	Aim to propose a research methodology that engineers can use to improve the designing and reporting processes of the clinical trials in the use of vision-based serious games and virtual reality systems for motor rehabilitation programs	There has been a notable increase in studies of vision based serious games in recent years. With the "downs and black" checklist that the authors used, they concluded that the papers need better reporting, standardization of measurements, and detailed descriptions of participants and interventions. The paper also highlighted the need for long-term efficacy studies, better reporting of industrial applications, and monitoring of body movements to prevent potential harm, especially in elderly participants.

[4]	Cognitive improvement measured in: VMET scores, range 8-16 (virtual multiple errands test)	N/A	Different VRs (namely for brain injury) such as the virtual apartment and supermarket environments were implemented on subjects with brain injury. In the supermarket case, the virtual multiple errands test was completed.	It was found "significant differences in the VMET scores but not in traditional tests between PD patients and control subjects, particularly in cognitive flexibility" indicating that this virtual test was able to detect and measure executive impairments accurately. VR is said to improve patients motivation as a key point in this study- patients are more willing to engage and enjoy training . VMall trials found TBI patients improve in "complex everyday tasks". Overall, VR leads to more motivated patients, quicker improvement in executive functions compared to other methods of rehabilitation (not VR).
[5]	Binocular function assessment (Cyberdome1400) Misalignment test led to consistent results (Oculus rift)	Significant improvement in stereoacuity (StereoGraphics crystal eyes shutter goggles)	Different studies were examined with their general results in relation to strabismus assessments.	It was found that the different VR technologies were all accurate/led to consistent results that would align with other, more well-approved studies such as Lee's screen. VR is an accurate assessment tool in examining strabismus motor skills.

[6]	Barthel Index scale for functional capacity (CyberGlove) Gait (spatiotemporal parameters and stability measures) and Activities-specific Balance Confidence (ABC) Scale	Statistically significant ($p < 0.05$) results in: Motor function improvement (virtual reality driving simulator) Motor function improvement, balance improvement (GRAIL)	Researchers investigated the effects of different VR-based rehabilitation after spinal cord injury.	Although focus itself is on rehabilitation after spinal cord injury, there exists evidence for TBI rehabilitation. Different VR technologies such as GAIT and other simulators can significantly aid in motor rehabilitation
[7]	The use of virtual reality exercise (VRe) helped to improve motor recovery. VRe was used to stimulate real-life settings. There, patients were asked to work on self-care (difficult to stimulate in a hospital setting). Virtual reality was also adapted to other therapies such as action observation therapy. There was also mention of a study conducted by Triantafilou et al. (2018) in which patients were asked to change the arrangement of 8 glasses in a virtual dining room and received acoustic feedback if a mistake was made. In addition, while VR was used during visuomotor tasks brain imaging indicated the presence of brain circuits in frontal and parietal cortical areas. This helped to conclude that when a task is performed and when it is imagined, the use of virtual reality that stimulates these areas would help motor recovery.	Patients experienced an improvement in motor function. Virtual reality provides stimulus strengthening for both motor and visual abilities.	Authors from several universities in Italy conducted a systematic review to explore the relationship between cognition and motion. They also aimed to explore emerging technologies and methods used to rehabilitate both cognition and motion.	Virtual reality is a promising technology that can provide settings and stimulation that is difficult to provide in hospital/clinical settings. It also stimulates different areas of the brain improving motor function.

[8]	N/A	N/A	Authors from a variety of American universities conducted a systematic review that could be used for vestibular assessment and rehabilitation in operational environments however the	N/A
[9]	Two of the studies reviewed used the Catherine Bergego Scale (CBS) - " allows for the detection of the presence and the degree of abandonment during the observation of everyday life situations". Another two studies used Behavioral Inattention Test (BIT) - "composed of conventional sub-tests and behavioral sub-tests for the assessment of neglect". Two studies used the line bisection test - "conventional sub-test of the BIT, that evaluates peripersonal neglect".	There was a significant improvement in visual perception and head movement as a result of using VR both 3 months after treatment and immediately after treatment	Authors from a variety of universities conducted a systematic review aimed to document the use of Immersive Virtual Reality in the treatment of Unilateral Spatial Neglect due to stroke.	Virtual reality demonstrated effectiveness in rehabilitation patients with USN (improving head movement and visual perception). Virtual reality is customizable and can provide the setting for repetitive treatment which can maximize treatment results.
[10]	N/A		Romanian researchers conducted research in rehabilitation centers using stationary and portable exoskeletons like Lokomat, G-EO, and others.	The integration of VR with robotic-assisted therapies is considered to have potential added benefits in enhancing outcomes. VR is used to augment feedback, increase motivation, and make the rehabilitation exercises more engaging. However, some studies indicate that VR may not significantly outperform conventional

				rehabilitation therapy in certain metrics, such as upper limb function or balance
[11]	Memory functions were measured using standardized cognitive tests such as the Mini-Mental State Examination, Wechsler Memory Scale, Rey Complex Figure, Trail Making Test, and others. The focus was on assessing changes in cognitive functions such as memory recall, visuospatial abilities, working memory, and attention after VR-based interventions	Summary of effect sizes for memory measures outcome where d represents effect of the study on a scale from -1.41 to 1.41 based on Cohen's classification Schreiber, 1999 Non-immersive VE A chat with a psychologist d=1.41 Man, Chung & Lee, 2012 Non-immesive VE Therapist-led training similar to the VR d= 0.36 Yip & Man, 2013 Non-immersive VE Reading and table games activities d= 0.54 Faria et al., 2016 Non-immersive VE Conventional rehabilitation d= 0 Man, 2018 Non-immersive VR Tutor-administered rehabilitation d= –1.41 Man, 2018 Non-immersive VR Waiting list d= 0.25 Faria et al., 2018 Non-immersive VE Conventional occupational therapy d=0 Ettenhoffer et al., 2019 Non-immersive VE Waiting list d= 0.54 Park et al., 2019 Immersive VE Computerized-cognitive training d= 0.29 Faria et al., 2020 Non-immersive VE Adaptive	The studies were conducted in clinical and rehabilitation settings, where VR interventions were used as part of routine rehabilitation programs.	VR-based rehabilitation used on patients with brain injuries shows improvements in memory, however the extent of these improvements varies based on the study.

		paper-and-pencil training d= 0.32 Maier et al., 2020 Non-immersive VE Standard cognitive tasks at home d= 0.15		
[12]	Custom Measurement Instruments, Questionnaires	N/A	The research focuses on breaking down what research has already been conducted in regards to VR type devices and its implementation in healthcare.	Rehabilitation, treatment and therapy make up 73.1% of articles examined, demonstrating that there is a significant portion of research being conducted on how VR type technology can be used to improve cognitive function
[13]	Virtual Reality Shopping Task (VRST): Tested Prospective Memory Banville et al.: Tested Multitasking and Prospective Memory Virtual Library Task (VLT): Tested planning, dual task management, inhibition, and prospective memory	Virtual Reality Shopping Task: Significant and moderate correlations were found between the VRST and the Lexical Decision Prospective Memory Task (LDPMT) for event-based PM (control group: ($r = 0.584$, $p < 0.01$); TBI group: ($r = 0.657$, $p < 0.01$)), but no correlations for time-based PM (control group: ($r = 0.312$, $p > 0.05$); TBI group: ($r = 0.288$, $p > 0.05$)) Banville et al.: 71% of participants were classified into the correct group Virtual Library Task (VLT): Reliability: Strong inter/intra rate ($r = 1.0$, $p < 0.001$), ($r = 1.0$, $p < 0.001$) Convergent validity: Correlation between virtual and real tasks ($r = 0.68$, $p < 0.01$). Moderate correlations between VLT and Verbal Fluency, Zoo Map, and Modified Six Elements test Divergent validity: Non-significant correlation	The primary focus was not TBI research however, the study examined the overall impact of serious games on cognitive improvement for a wide variety of patients	Using Virtual Reality to simulate serious games can effectively assess the cognitive functioning of TBI patients and provide insight on the degree of cognitive functioning in terms of prospective memory, multitasking, and executive functions

		between VLT and immediate attention External validity: Significant associations between (DEX) and VLT scores. (Student's t-test t(57) = 55.04, $p < 0.01$; $r = 0.56$)		
[14]	N/A	N/A	The study conducted delves possible areas for rehabilitation research one of which being VR, however the study does not have a focus on TBIs, however it provides reasoning to try to integrate VR into cognitive rehabilitation	VR and AR can be used in rehabilitation "to guide users through specific movements, simulate real-world scenarios, and integrate elements of gaming and entertainment into their training"
[15]	Measured using the VR version of the multiple errand test (VMET), visuomotor tasks, and EEG to monitor brain activity. Rehabilitation gaming systems (RGS) were also highlighted for tracking motor improvements in real time	N/A	Clinical settings.	Rehabilitation Gaming Systems are VR-based rehabilitation techniques that use serious games in a VR format to help rehab various elements of cognitive/motor functions

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Synthesis of Findings

After the synthesis was conducted, several themes were found that supported the notion that virtual reality can act as an effective tool for cognitive and motor rehabilitation in patients with traumatic brain injury. The following table includes the recurring patterns and themes the team found:

Study(s) Referenced (#)	**Theme**	**Analysis**

9, 24, 50	*Virtual reality results in more motivated patients for better results*	Virtual reality offers the ability to create unique and immersive environments, such as driving simulators, that would be challenging or impractical to replicate in real-world settings [6]. It was found that these virtual reality settings could successfully simulate real-world scenarios, integrating elements of gaming and entertainment for a more dopaminergic experience [13]. These simulations are highly engaging especially when compared to traditional clinical treatments- stimulating patients' cognitive processes and increasing their motivation to participate in training ultimately for faster improvement in executive function rehabilitation [4].
1, 11, 13	*Virtual Reality has a positive effect on the working and prospective memory of patients who have sustained brain injuries.*	Virtual reality based rehabilitation consistently displays a positive impact on both the working and prospective memory of patients. One study by Ettenhoffer et al. (2019), found that patients with chronic TBI had significantly improved working memory and visual search cognitive abilities compared to a control group after consistently partaking in a VR driving simulator with cognitive tests over a 6 week period. [11] In another study by Caglio et al. (2009), VR rehabilitation sessions showed a significant improvement in the patients' spatial memory and delayed recall capability. [1] The usage of simulation programs in VR provide patients an engaging opportunity to practice their cognitive capabilities in a controlled environment.
50, 36	*Virtual reality is an accurate tool that can measure the effects of different cognitive and motor impairments*	Virtual reality was found to be an accurate means of measuring motor skills in traumatic brain injury conditions, such as strabismus [5]. It was found that the usage of virtual reality technologies led to results that aligned with those of more industry-approved studies such as Lee's screen test in the context of strabismus. In another study, results from the virtual reality shopping task (VRST) and lexical decision prospective memory task (LDPMT) were compared (see Appendix A), in which significant and moderate correlations were found between the two [13]. This task is focused more on cognitive measures, and this result would indicate that the VRST is an accurate measure given it can lead to similar general results despite the slight differences in task design.
2, 7, 10, 15	*Virtual Reality has mixed results when used to rehabilitate motor function.*	Virtual therapy based rehabilitation techniques are not consistently effective at improving motor function. Clinical trials highlighted in systematic reviews [7], [10], [15] displayed how VR helped in improving motor function through repetitive, simulations of real-world activities. For

		instance, a study by De Bartolo et al. (2019) [7] demonstrated simulations of daily tasks through VR helped to greatly improve motor coordination. However, systematic review [2] reported little evidence that VR based rehabilitation is more effective than traditional physical rehabilitation. Evidence from various forms of motor rehabilitation including physical therapy and VR-based exercises indicate the lack of a significant advantage with using VR-centric methods compared to traditional ones.

Discussion/Conclusion

The use of VR in clinical settings has gained momentum in recent years, and has shown promise for the future. While some of the papers included in this review do veer from some of the prescribed focuses of the protocol, many describe how effective VR was in general rehabilitation, and in rehabilitating conditions that can stem from traumatic brain injuries. Some of the outlined VR benefits include the flexibility to produce immersive environments otherwise difficult to simulate in a real-world setting, positive effects on the working and prospective memory in TBI patients, and its accuracy pertaining to measuring the effects of different cognitive and motor impairments. These benefits point to the conclusion that virtual reality has potential to be a prominent rehabilitation tool. However, there is still a need for more research pertaining to how effective virtual reality is in treating traumatic brain injuries. It is proposed that there should be new clinical studies conducted with a focus on the progression of traumatic brain injury patients being rehabilitated by use of VR. These studies should be conducted in a clinical trial setting, and should include men and women of varying ages, with a focus on age cohorts of 65 years or older and 15-19 as these age groups are most likely to sustain a traumatic brain injury [16]. These new findings would provide the extra data needed in order to conclude that VR is an effective tool in treating traumatic brain injuries.

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Appendices

Appendix A: Raw Data Extraction: Minsoo Park

Paper Title	Cognitive rehabilitation post traumatic brain injury: A systematic review for emerging use of virtual reality technology [1]	Effects of physical therapy interventions on balance ability in people with traumatic brain injury: A systematic review [6]	Vision-based serious games and virtual reality systems for motor rehabilitation: A review geared toward a research methodology [8]
Author	Alashram, Anas R; Annino, Giuseppe; Padua, Elvira; Romagnoli, Cristian; Mercuri, Nicola Biagio	Alashram, Anas R; Annino, Giuseppe; Raju, Manikandan; Padua, Elvira	Ayed, Ines; Ghazel, Adel; Jaume-i-Capo, Antoni; Moya-Alcover, Gabriel; Varona, Javier; Martínez-Bueso, Pau
Country of Origin	Italy	Italy	Spain, Tunisia
Year	2019	2020	2019
Study URL	https://d1wqtxts1xzle7.cloudfront.net/94102383/j.jocn.2019.04.026202211121-1-1gknw42-libre.pdf?1668246433=&response-content-disposition=inline%3B+filename%3DCognitive_rehabilitation_post_traumatic.pdf&Expires=1732944800&Signature=Tu2aFb703bzWRAqgkG5Kp1Wd0tSFMmaB6VF2Im-xDUU5AekRgXN9gyUOgptumrD~GAvtydHfikKAyni5bWu9r8FRb49Ej989y2804SNbNdRvB-I5BtrM6jhr7msjka-Xdd~WdHYtJGB3PELDNsyS80TpLVEm9lzuICz3kyb5HI1vu~RJgw~FDvqRyNJakZICvWQgDAg119R14P8N96WZ2rBwHFNWERIhjRnXC28F-V~OodwAOf5qqSU2rmesD3pKtwfFeYavmpo25G03p5qjx28mw1m3~4i6jjfgm7V2AxOU3Xz9gVQMXcpLj~pH2zibioxeZk2M	https://content.iospress.com/download/neurorehabilitation/nre203047?id=neurorehabilitation%2Fnre203047	https://d1wqtxts1xzle7.cloudfront.net/63427589/Vision-based-serious_games.DEF.20192020052626-6595-146nu12-libre.pdf?1590481977=&response-content-disposition=inline%3B+filename%3DVision_based_serious_games_DEF.pdf&Expires=1733047129&Signature=NQPiHzcXCfcy1FjK26U1C-ApyeXLCx3G8yeGwBkzg3uo3OOf7ZO5idBe6i8ybtPkO8l~svFeZyEL7PjqAbcCGn6HP5jQIOEPi6h8pdDZNUauAVDgjsKWC-IAWxpvc3S6N-DhZ2pHett7ZXI1E8u~Wdu-ds2pOxgvo9~xXVcg3rb3EEm3y-Ot20vs5e~YkKMamc6luJnzHMQDS0joz5PTSCFfn3d9G-er8IMXzjSH600AtwS4VphIOpUNBzf-yK~TUWN53uqwUFKLV6JqkQVd8FQrIV7bywIdZvo-mJ1hS1iOp3WOg7z9HdOQUY5

	W1J-~tjIDDNMAQ__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA		EioD0ET4yeq3f6CItOcbF0CzAYg__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA
Objectives	Examine the effects of virtual reality (VR) training interventions on cognitive function in patients with traumatic brain injury (TBI). Identify effective VR treatment protocols for cognitive rehabilitation on patients.	Access the effectiveness of different therapy interventions such as VR or VRT (vestibular rehabilitation therapy), or other traditional physical therapy	Review the use of vision-based serious games and virtual reality systems in motor rehabilitation programs
Type of Study	Systematic Review	Systematic Review	Systematic Review
No. of participants	131	259	15
Participant Demographic	83.52% male, 16.48% female mean average ranging from 20 ~ 40.3"	27.41% female, 72.59% male 18+ patients 1.4 ~ 6 months post TBI patients"	30.6 years old average
VR Usage Frequency	90 minutes in duration ; 3 times per week ; 5 weeks	18 sessions of 60 minutes (3 sessions per wk for 6 wks)"	N/A
Type of VR Technology	3DVisor head mounted display system (HMD)	N/A	Microsoft Kinect
Number of Additional Therapies (other patient rehabilitations independent of VR)	Table Game Activities Psycho-educational vocational training	Vestibular Rehabilitation Therapy Video Game Therapy Elliptical Trainer Device Mobility Training	Prototype games: Virtual Teacher (VT), Virtual Challenger (VC), Courtyard, Skateboard, Boat, and Octopus
Measures of Cognitive/Motor Function	Improvement measured in: Corsi's Supraspan Test Real-life behavioral PM test	Berg Balance Scale (BBS) Dynamic Gait Analysis (DGI)	Berg Balance Scale (BBS) Functional Reach Scale (FRS)

	CAMPROMPT–CV total score (prospective memory performance) HKLLT (effectiveness of learning and memory) etc.	Limits of StabilityReaction Time Backwards LOS (RT-B) Motor Control Test (MCT) Balance Error Scoring System (BBES) Community Balance and Mobility Scale (CB&M)"	
Degree of Improvement After VR Interventions	Corsi's Supraspan Test: Improvement from 1 to 3 Real-life behavioral PM test: Event-based tasks Pre 8.74 ± 3.38, Post 12.26 ± 3.03 Time-based tasks Pre 3.37 ± 2.20, Post 6.26 ± 3.26 Ongoing tasks Pre 0.96 ± 0.08, Post 0.91 ± 0.16 CAMPROMPT-CV total score: Pre 20.53 ± 4.10, Post 24.53 ± 4.34 HKLLT: Learning slope Pre 1.50 ± 1.25, Post 1.84 ± 1.33"	"BBS: improvement of 0.19 points per day CB&M: Enhancement, no specific numbers	N/A
Setting / Context	Authors affiliated with several universities in Italy wanted to find effective measures of VR for rehabilitation after TBI.	There were no systematic reviews on the impact of physical therapy intervention on TBi patients, specifically their balance impairment.	Aim to propose a research methodology that engineers can use to improve the designing and reporting processes of the clinical trials in the use of vision-based serious games and virtual reality systems for motor rehabilitation

			programs
Major Findings	According to study results, VR training interventions led to various cognitive function improvements such as memory, executive function and attention. Even though there is further research needed on the effects on attention, it showed that there were no apparent adverse effects of the VR approach. Limitations included small sample sizes of research as well as not enough information on long term effects of VR on TBI rehabilitation.	There was limited evidence on effectiveness of physical therapy interventions for improving balance in post TBI patients. In other words, the different types of interventions, including VR, didn't have a significant advantage over other interventions. This paper was also lacking in patient numbers and trials, with no specific mention of exact VR type.	There has been a notable increase in studies of vision based serious games in recent years. With the downs and black checklist that the authors used, they concluded that the papers need better reporting, standardization of measurements, and detailed descriptions of participants and interventions. The paper also highlighted the need for long-term efficacy studies, better reporting of industrial applications, and monitoring of body movements to prevent potential harm, especially in elderly participants.

Appendix B: Raw Data Extraction: Trinity Edl

Paper Title	From movement to thought and back: A review on the role of cognitive factors influencing technological neurorehabilitation [30]	Leveraging Technology for Vestibular Assessment and Rehabilitation in the Operational Environment: A Scoping Review [23]	Exploring the potential of immersive virtual reality in the treatment of unilateral spatial neglect due to stroke: a comprehensive systematic review [19]
Author	De Bartolo, Daniela; Spitoni, Grazia Fernanda; Iosa, Marco; Morone, Giovanni; Ciancarelli, Irene; Paolucci, Stefano; Antonucci, Gabriella	Hoppes, Carrie W; Lambert, Karen H; Whitney, Susan L; Erbele, Isaac D; Esquivel, Carlos R; Yuan, Tony T	Martino Cinnera, Alex; Bisirri, Alessio; Chioccia, Ilaria; Leone, Enza; Ciancarelli, Irene; Iosa, Marco; Morone, Giovanni; Verna, Valeria
Country of Origin	Italy	USA	N/A

Year	2019	2024	2022
Study URL	https://www.researchgate.net/profile/Daniela-De-Bartolo/publication/341680634_From_movement_to_thought_and_back_A_review_on_the_role_of_cognitive_factors_influencing_technological_neurorehabilitation/links/5ecea173458515294515e48e/From-movement-to-thought-and-back-A-review-on-the-role-of-cognitive-factors-influencing-technological-neurorehabilitation.pdf	https://www.mdpi.com/2306-5354/11/2/117	https://www.mdpi.com/2076-3425/12/11/1589
Objectives	"highlight the relationship between cognition and motion and, in the light of new rehabilitation technologies, to better define how aspects of cognition can affect motor rehabilitation."	"This scoping review aimed to examine the literature for technologies that can be utilized for vestibular assessment and rehabilitation in operational environments."	"The present review aims to explore the use of Immersive Virtual Reality (IVR) in the treatment of visual perception in Unilateral Spatial Neglect (USN) after a stroke."
Type of Study	Systematic Review	Systematic Review	Systematic Review
No. of participants	N/A	N/A	77 with Unilateral Spatial Neglect (USN) and 134 healthy
Participant Demographic	Children and adults with motor deficits	N/A	51% male USN from a stroke
VR Usage Frequency	N/A	N/A	N/A
Type of VR Technology	N/A	VIRVEST wearable virtual reality-based system, head-mounted display (C-SVV® goggles), (Convergence VR Tech Labs Pvt. Ltd.)	N/A
Number of Additional Therapies (other patient rehabilitations independent of VR)	Action observation therapy, mirror therapy, real or virtual actuators, sensors, serious exergames, etc.	N/A	N/A

Measures of Cognitive/Motor Function	The use of virtual reality exercise (VRe) helped to improve motor recovery. VRe was used to stimulate real-life settings. There, patients were asked to work on self-care (difficult to stimulate in a hospital setting). Virtual reality was also adapted to other therapies such as action observation therapy. There was also mention of a study conducted by Triandafilou et al. (2018) in which patients were asked to change the arrangement of 8 glasses in a virtual dining room and received acoustic feedback if a mistake was made. In addition, while VR was used during visuomotor tasks brain imaging indicated the presence of brain circuits in frontal and parietal cortical areas. This helped to conclude that when a task is performed and when it is imagined, the use of virtual reality that stimulates these areas would help motor recovery.	N/A	Two of the studies reviewed used the Catherine Bergego Scale (CBS) - " allows for the detection of the presence and the degree of abandonment during the observation of everyday life situations". Another two studies used Behavioral Inattention Test (BIT) - "composed of conventional sub-tests and behavioral sub-tests for the assessment of neglect". Two studies used the line bisection test - "conventional sub-test of the BIT, that evaluates peripersonal neglect".
Degree of Improvement After VR Interventions	Patients experienced an improvement in motor function. Virtual reality provides stimulus strengthening for both motor and visual abilities.	N/A	There was a significant improvement in visual perception and head movement as a result of using VR both 3 months after treatment and immediately after treatment.
Setting / Context	Authors from several universities in Italy conducted a systematic review to explore the relationship between	Authors from a variety of American universities conducted a systematic review that could be used for vestibular	Authors from a variety of universities conducted a systematic review aimed to document the use of

	cognition and motion. They also aimed to explore emerging technologies and methods used to rehabilitate both cognition and motion.	assessment and rehabilitation in operational environments	Immersive Virtual Reality in the treatment of Unilateral Spatial Neglect due to stroke.
Major Findings	Virtual reality is a promising technology that can provide settings and stimulation that is difficult to provide in hospital/clinical settings. It also stimulates different areas of the brain improving motor function.	N/A	Virtual reality demonstrated effectiveness in rehabilitation patients with USN (improving head movement and visual perception). Virtual reality is customizable and can provide the setting for repetitive treatment which can maximize treatment results.

Appendix C: Raw Extraction Data: Shreya Perumal

Paper title and citation details	A retrospective analysis and systematic review of the areas of entertainment computing and persuasive technologies for health [42]	Trends on the application of serious games to neuropsychological evaluation: A scoping review [50]	Leveraging Emerging Technologies to Expand Accessibility and Improve Precision in Rehabilitation and Exercise for People with Disabilities [33]
Author	Silva, Paula Alexandra; Bermúdez i Badia, Sergi; Cameirão, Mónica S	Valladares-Rodríguez, Sonia; Pérez-Rodríguez, Roberto; Anido-Rifón, Luis; Fernández-Iglesias, Manuel	Willingham, T Bradley; Stowell, Julie; Collier, George; Backus, Deborah
Country of Origin	Portugal	Spain	United States of America
Year	2023	2016	2024
Study URL	https://www.frontiersin.org/journals/computer-science/articles/10.3389/f	https://www.sciencedirect.com/science/article/pii/S1532046416301563	https://www.mdpi.com/1660-4601/21/1/79

	comp.2023.1124183/full		
Objectives	Examine the impact of entertainment computing and pervasive technologies in healthcare.	To conduct a scoping review to map key concepts and developments in the use of serious games for neuropsychological evaluation.	To determine the barriers in physical rehabilitation and assess how new technology can create improvements.
Type of study	Systematic Review	Systematic Review	Systematic Review
Number of participants	N/A	N/A	N/A
Participant Demographic	Healthy Participants Patients	Healthy Individuals; People with: Mild Cognitive Impairment, Alzheimers, TBI, ASD	Various disabilities (ex. cognitive impairment, mobility issues, visual/auditory impairment, etc...)
VR Usage Frequency	N/A	N/A	N/A
Type of VR Technology	2D & 3D VR	VR Headset	VR Integrated Devices (such as treadmills, eyewear, etc...)
Number of Additional Therapies (other patient rehabilitations independent of VR)	Augmented Reality, Mixed Reality, Mobile Games	N/A	N/A
Measures of Cognitive/Motor Function	Custom Measurement Instruments, Questionnaires	Virtual Reality Shopping Task (VRST): Tested Prospective Memory Banville et al.: Tested Multitasking and Prospective Memory Virtual Library Task (VLT): Tested planning, dual task management, inhibition, and prospective memory	N/A

Degree of Improvement After VR Interventions	N/A	Virtual Reality Shopping Task: Significant and moderate correlations were found between the VRST and the Lexical Decision Prospective Memory Task (LDPMT) for event-based PM (control group: ($r = 0.584$, $p < 0.01$); TBI group: ($r = 0.657$, $p < 0.01$)), but no correlations for time-based PM (control group: ($r = 0.312$, $p > 0.05$); TBI group: ($r = 0.288$, $p > 0.05$)) Banville et al.: 71% of participants were classified into the correct group Virtual Library Task (VLT): Reliability: Strong inter/intra rate ($r = 1.0$, $p < 0.001$), ($r = 1.0$, $p < 0.001$) Convergent validity: Correlation between virtual and real tasks ($r = 0.68$, $p < 0.01$). Moderate correlations between VLT and Verbal Fluency, Zoo Map, and Modified Six Elements test Divergent validity: Non-significant correlation between VLT and immediate attention External validity: Significant associations between (DEX) and VLT scores. (Student's t-test $t(57) = 55.04$, $p < 0.01$; $r = 0.56$)	N/A
Setting/Context	The research focuses on breaking down what	The primary focus was not TBI research	The study conducted delves possible areas

	research has already been conducted in regards to VR type devices and its implementation in healthcare.	however, the study examined the overall impact of serious games on cognitive improvement for a wide variety of patients	for rehabilitation research one of which being VR, however the study does not have a focus on TBIs, however it provides reasoning to try to integrate VR into cognitive rehabilitation
Major Findings	Rehabilitation, treatment and therapy make up 73.1% of articles examined, demonstrating that there is a significant portion of research being conducted on how VR type technology can be used to improve cognitive function	Using virtual reality to simulate serious games can effectively assess the cognitive functioning of TBI patients and provide insight on the degree of cognitive functioning in terms of prospective memory, multitasking, and executive functions	VR and AR can be used in rehabilitation "to guide users through specific movements, simulate real-world scenarios, and integrate elements of gaming and entertainment into their training"

Appendix D: Raw Extraction Data: Jet Chang

Paper Title	Available Virtual Reality-Based Tools for Executive Functions: A Systematic Review [24]	Design and assessment of amblyopia, strabismus, and myopia treatment and vision training using virtual reality [36] Efficacy of Virtual Reality Rehabilitation after Spinal Cord Injury: A Systematic Review [9]	Efficacy of Virtual Reality Rehabilitation after Spinal Cord Injury: A Systematic Review [9]
Author	Francesca Borgnis; Francesca Baglio; Elisa Pedroli; Federica Rossetto; Lidia Uccellatore; Jorge Alexandre; Gaspar Oliveira; Giuseppe Riva; Pietro Cipresso	Hoi Sze Chan; Yuk Ming Tang; Chi Wai Do; Horace Ho Yin Wong; Lily YL Chan; Suet To;	Amanda Vitória Lacerda de Araújo; Jaqueline Freitas de Oliveira Neiva; Carlos Bandeira de Mello Monteiro; Fernando Henrique Magalhães
Country of Origin	Italy	China	Brazil
Year	2022	2023	2019
Study URL	https://www.frontiersin.o	https://journals.sagepub	https://onlinelibrary.wile

	rg/journals/psychology/articles/10.3389/fpsyg.2022.833136/full	.com/doi/full/10.1177/20552076231176638	y.com/doi/full/10.1155/2019/7106951
Objectives	Examine the effects of virtual reality (VR) training interventions on cognitive function in patients with traumatic brain injury (TBI). Identify effective VR treatment protocols for cognitive rehabilitation on patients.	Review the use of virtual reality-related interventions in amblyopia, strabismus, and myopia research. Focus on strabismus (TBI related) and relation to research question	VR-Based rehabilitation efficacy after spinal cord injury VR rehabilitation after traumatic brain injury, balance control, gait recovery after stroke and other TBI
Type of Study	Systematic Review	Systematic Review	Systematic Review
No. of participants	N/A	N/A	N/A
Participant Demographic	N/A	N/A	N/A
VR Usage Frequency	3-4 days a week, 45 mins a day in the VMALL (virtual mall) trial Otherwise N/A	N/A	N/A
Type of VR Technology	(used in) VR-DOT (virtual apartment environment) VAP-S (virtual supermarket environment)	Cyberdome 1400 StereoGraphics crystal eyes shutter goggles Oculus Rift	Virtual reality driving simulator CyberGlove® Gait Real-time Analysis Interactive Lab (GRAIL)
Number of Additional Therapies (other patient rehabilitations independent of VR)	N/A	N/A	N/A
Measures of Cognitive/Motor Function	Cognitive improvement measured in: VMET scores, range 8-16 (virtual multiple errands test)	Binocular function assessment (Cyberdome1400) Misalignment test led to consistent results	Barthel Index scale for functional capacity (CyberGlove) Gait (spatiotemporal parameters and stability

		(Oculus rift)	measures) and Activities-specific Balance Confidence (ABC) Scale
Degree of Improvement After VR Interventions	N/A	Significant improvement in stereoacuity (StereoGraphics crystal eyes shutter goggles)	Statistically significant ($p < 0.05$) results in: Motor function improvement (virtual reality driving simulator) Motor function improvement, balance improvement (GRAIL)
Setting / Context	Different VRs (namely for brain injury) such as the virtual apartment and supermarket environments were implemented on subjects with brain injury. In the supermarket case, the virtual multiple errands test was completed.	Different studies were examined with their general results in relation to strabismus assessments.	Researchers investigated the effects of different VR-based rehabilitation after spinal cord injury.
Major Findings	It was found significant differences in the VMET scores but not in traditional tests between PD patients and control subjects, particularly in cognitive flexibility indicating that this virtual test was able to detect and measure executive impairments accurately. VR is said to improve patients motivation as a key point in this study- patients are more willing to engage and enjoy training . VMall trials found TBI patients improve in ""complex everyday tasks"". Overall, VR leads to more motivated	It was found that the different VR technologies were all accurate/led to consistent results that would align with other, more well-approved studies such as Lee's screen. VR is an accurate assessment tool in examining strabismus motor skills."	Although focus itself is on rehabilitation after spinal cord injury, there exists evidence for TBI rehabilitation. Different VR technologies such as GAIT and other simulators can significantly aid in motor rehabilitation

	patients, quicker improvement in executive functions compared to other methods of rehabilitation (not VR)."		

Appendix E: Raw Extraction Data: Harini Mohan

Paper Title	Augmentation and Rehabilitation with Active Orthotic Devices [48]	What is the future for immersive virtual reality in memory rehabilitation? A systematic review [14]	IoT-driven augmented reality and virtual reality systems in neurological sciences [33]
Author	"Gelu Onose, Maria Veronica Morcov, Corina Sporea, Andrada Mirea, and Vlad Ciobanu "	Adela Plechata, Tereza Nekovarova, and Iveta Fajnerova	Mehar Sahu, Rohan Gupta, Rashmi K. Ambasta, Pravir Kumar
Country of Origin	Romania	Czechia	India
Year	2021	2021	2024
Study URL	https://d1wqtxts1xzle7.cloudfront.net/96219156/978-3-030-54564-2_24-libre.pdf?1671736584=&response-content-disposition=inline%3B+filename%3DAugmentation_and_Rehabilitation_with_Act.pdf&Expires=1733076084&Signature=HLrW6UGCoIgoJXeDmqtfvi72ZsRNIPlCJqkP2vs9-LdvqiLcD53EIMp-SPh8AvW3gbv6XZ3BTxs~YaQq-2VCplY2PEKQCXiIkD-QnTXtHtchhvfhusIryjrZ38GdeNMXmh~BWBQT3VUS-oypAVW9q51FOcGPCGFkaIOgBfaCCVvBbUPMBb5MIrV6d6SUn-oX40hKY5yVRB4CG4AmAicqDB9AoLIF4pkWagCpN1TtXnNZqtES3uRenvcPMkJMqhwlpuArliP6K7PT7xRfuSOcRd6hmIupKNxuBb	https://doi.org/10.1017/S136898000999022X	https://www.sciencedirect.com/science/article/pii/S2542660524000404?via%3Dihub

	NTXMieGBeVaGotj2XRko9ChJC1HO2RMcU~7U6PFIH32aVoSC6xBw__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA		
Objectives	To determine the effectiveness and use of active orthotic devices and exoskeletons, as well as using VR technology, in the rehabilitation of neuromotor impairments.	Determine the effectiveness of virtual reality based rehabilitation in enhancing memory functions.	Explore the use of Internet of Things AR and VR in diagnosing and treating neurological disorders. It highlights the potential impact of these technologies on neurorehabilitation and neurosurgical practices.
Type of Study	Systematic Review	Systematic Review	Systematic Review
No. of participants	N/A	N/A	N/A
Participant Demographic	Participants mainly included individuals with neuromotor impairments, paraplegia, or stroke patients	People with neurological and mental conditions, such as Alzheimer's disease, depression, schizophrenia, and stroke patients. People with TBI or acquired brain injuries.	N/A
VR Usage Frequency	VR technologies were mentioned as an adjunctive treatment but not quantified for frequency of use	VR therapy sessions range from weekly sessions to daily exercises. The specific frequency depended on the study, but many studies involved sessions multiple times per week for a duration of several weeks.	N/A
Type of VR Technology	N/A	Both immersive and non-immersive VR technologies. Immersive VR involved head-mounted displays , while non-immersive	Head-mounted displays, semi-immersive setups, and mixed reality environments.

		VR used standard monitors and screens.	
Number of Additional Therapies (other patient rehabilitations independent of VR)	VR combined with robotic-assisted therapy for enhanced rehabilitation outcomes, including systems like Lokomat and G-EO	Many studies included traditional therapist-led cognitive training, conventional rehabilitation, or personalized paper-pencil exercises.	Conventional therapist-led cognitive training and physical rehabilitation alongside AR/VR applications
Measures of Cognitive/Motor Function	N/A	Memory functions were measured using standardized cognitive tests such as the Mini-Mental State Examination, Wechsler Memory Scale, Rey Complex Figure, Trail Making Test, and others. The focus was on assessing changes in cognitive functions such as memory recall, visuospatial abilities, working memory, and attention after VR-based interventions	Measured using the VR version of the multiple errand test (VMET), visuomotor tasks, and EEG to monitor brain activity. Rehabilitation gaming systems (RGS) were also highlighted for tracking motor improvements in real time
Degree of Improvement After VR Interventions	N/A	"Summary of effect sizes for memory measures outcome where d represents effect of the study on a scale from -1.41 to 1.41 based on Cohen's classification Schreiber, 1999 Non-immersive VE A chat with a psychologist d=1.41 Man, Chung & Lee, 2012 Non-immersive VR Therapist-led training similar to the VR d= 0.36 Yip & Man, 2013 Non-immersive VE Reading and table games activities d= 0.54 Faria et al., 2016 Non-immersive VE Conventional	N/A

		rehabilitation d= 0 Man, 2018 Non-immersive VR Tutor-administered rehabilitation d= –1.41 Man, 2018 Non-immersive VR Waiting list d= 0.25 Faria et al., 2018 Non-immersive VE Conventional occupational therapy d=0 Ettenhofer et al., 2019 Non-immersive VE Waiting list d= 0.54 Park et al., 2019 Immersive VE Computerized-cognitive training d= 0.29 Faria et al., 2020 Non-immersive VE Adaptive paper-and-pencil training d= 0.32 Maier et al., 2020 Non-immersive VE Standard cognitive tasks at home d= 0.15"	
Setting / Context	Romanian researchers conducted research in rehabilitation centers using stationary and portable exoskeletons like Lokomat, G-EO, and others.	The studies were conducted in clinical and rehabilitation settings, where VR interventions were used as part of routine rehabilitation programs.	Clinical settings.
Major Findings	The integration of VR with robotic-assisted therapies is considered to have potential added benefits in enhancing outcomes. VR is used to augment feedback, increase motivation, and make the rehabilitation exercises more engaging. However, some studies indicate that VR may not significantly outperform conventional	VR-based rehabilitation used on patients with brain injuries shows improvements in memory, however the extent of these improvements varies based on the study.	Rehabilitation Gaming Systems are VR-based rehabilitation techniques that use serious games in a VR format to help rehab various elements of cognitive/motor functions

	rehabilitation therapy in certain metrics, such as upper limb function or balance		

Appendix F: *VRST and LDPMT Correlations:*

“Convergent validity—Significant and moderate correlations were found between the VRST and the LDPMT for event-based PM (control group: $r = 0.584$, $p < 0.01$; TBI group: 0.657, $p < 0.01$), but no correlations were found for time-based PM (control group: $r = -0.312$, $p < 0.5$; TBI group: 0.288, $p < 0.5$)” [13]