Virtual reality and cognitive function rehabilitation after traumatic brain injury: a systematic review

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Abstract

Traumatic Brain Injury (TBI) is the leading cause of injury-related death worldwide. In recent years, Virtual Reality (VR) has emerged as a promising diagnostic and treatment tool capable of improving Cognitive Function (CF) after TBI. We sought to review the literature on this issue systematically. Web of Science, PubMed and PsycINFO were screened for relevant literature. Only randomized control trials whereby TBI-affected individuals underwent VR training and control groups received standard rehabilitative care were included. Screening, quality appraisal and data extraction were conducted by independent reviewers using a standardized protocol. Six studies of ~300 participants met the inclusion criteria and showed that both groups improved their overall CF post-intervention. However, non-immersive and semi-immersive VR groups had markedly better scores in all of the cognitive domains measured when compared to non-VR groups. VR is a potent post-TBI rehabilitative tool that can improve CF in this population and facilitate the return-to-work process. Future studies should adopt a similar design yet use fully immersive VR to enhance CF potentially to a greater degree.

Key Words: working memory, cognitive flexibility, inhibition, attention, return-to-work.

Eur J Transl Myol 35 (2) 13275, 2025 doi: 10.4081/ejtm.2025.12375

Traumatic brain injury

Traumatic Brain Injury (TBI) refers to a complex clinical condition of any postnatal brain damage after suffering a jolt, blunt or penetrating force to the cranium.[1] Depending on the severity of injury and clinical features, TBIs are classified as mild, moderate or severe.[2] As a consequence, TBI can lead to disruptions in multiple health aspects across all age groups – and is expected to remain a leading cause of injury-related death and disability through 2030. In addition, the socio-economic burden caused by TBI is rather alarming, costing the US alone $400 billion annually.[3] Multiple studies have shown that males are more susceptible to TBI, with more than twice the odds of having had a TBI[4-6] likely because males are more prone to engage in risk-taking behaviors such as contact sports and alcohol consumption.[7]

Health consequences of TBI manifest in survivors in a range of symptoms, from unconsciousness, confusion, memory loss and speech difficulties to disability.[8] According to the 2016 Global Burden of Disease report, TBI was responsible for 8.1 million healthy years of life lost due to TBI-related disability.[9] Cognitive Function (CF) is particularly vulnerable to TBI[1] among the affected health domains. Within CF, depending on the severity of TBI and the exact location of a lesion, executive functions (inhibition, cognitive flexibility, and working memory), characterized as a set of high-level processes orchestrated via the prefrontal cortex, might be particularly affected.[10] If impaired, this condition can further translate to limited ability of survivors to adapt under new circumstances, perform daily tasks, maintain social relationships or sustain attention, ultimately impairing survivors' Quality of Life (QoL).[10-12]

Cognitive rehabilitation after traumatic brain injury

To treat TBI survivors and optimize QoL-related cognitive functions, adequate rehabilitation is necessary. Depending on the severity of TBI, individuals can be approached with various protocols that span from cognitive training, physical training, or a combination of the two, to pharmacological aids.[8] Current rehabilitative methods to optimize CF after TBI predominately rely on an integrative cognitive approach performed within individual sessions.[13] This technique has been shown to be effective in restoring CF in TBI patients,[13] but likely lacks practical utility (return-to-work) that can be achieved through other forms of cognitive rehabilitation such as Virtual Reality Training (VRT).[14] Indeed, conventional post-TBI interventions can effectively address their specific target but do not automatically translate to improved activity and participation outcomes.

Due to the complexity of underlying mechanisms, severity of trauma and individual differences, novel approaches to facilitate TBI rehabilitation have emerged over the last two decades.[15] Recently, VR has been increasingly prevalent in health care,[16] now also slowly expanding into the field of neurorehabilitation.[17] Concerning TBI, mounting evidence indicates that VR can be used both as a diagnostic and therapeutic tool.[18]

Virtual reality and traumatic brain injury

Essentially, VR can be categorized into immersive, non-immersive, and semi-immersive.[19] In fully immersive VR, users engage in a 360-degree virtual environment using high-resolution head-mounted devices (*i.e.,* headsets or goggles), which allow users to believe as if they were "inside the real world", allowing them to interact in real-time. Similarly, semi-immersive VR lets users experience elements of VR while maintaining contact with the real surroundings, whereas the non-immersive VR by no means focuses on intentional isolation from the real-world using head-mounted devices in order to enhance the immersiveness.[20] The VR technology-based interventions offer an immersive and interactive environment that can simulate real-life scenarios in a controlled and safe manner for the user.[15] Relying on the principles of neuroplasticity, the brain's ability to adjust in response to stimuli by performing targeted and repetitive tasks, VR can facilitate recovery of affected networks in control of cognitive functions.[21] For that reason, a growing number of research groups around the world is attempting to exploit VR's rather substantial potential to foster cognitive rehabilitation after TBI.[22]

The aim of the present study was to review the available literature on VRT aimed at improving CF in TBI-affected individuals. It was hypothesized that the VRT will induce greater benefits than standard post-TBI rehabilitative care. We further hypothesized that the level of VR immersivity during the session will be proportional to benefits acquired by the TBI patients.

Materials and Methods

Search strategy

To ensure transparent and accurate reporting, this review followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses 2020 (PRISMA 2020) protocol.[23] Web of Science, PubMed, and APA PsycINFO were comprehensively searched from inception to August 2024, taking into account only studies available in the English language. Keywords were gathered via expert opinions, analysis of systematic reviews and meta-analyses referring to the VR and CF following TBI, and controlled vocabulary (Medical Subject Headings: MeSH). In all databases, a Boolean search syntax with operators «AND» «OR», and «NOT» was employed. The example of the Web of Science search and applied keywords are as follows: («traumatic brain injury» OR «TBI» OR «head injury») AND («rehabilitation» OR «rehab» OR «recovery» OR «treatment» OR «therapy») AND («virtual reality» OR «VR») AND («executive function» OR «cognitive control» OR «cognition» OR «working memory» OR «updating» OR «cognitive flexibility» OR «switching» OR «shifting» OR «inhibition» OR «inhibitory control»). With regard to the additional sources of evidence, a thorough search of Google Scholar was performed. In addition, reference lists of studies that fulfilled eligibility criteria and of relevant systematic reviews and meta-analyses were also manually checked. Three reviewers (NL, BA, and MM) independently searched primary and secondary sources of evidence. Finally, to ensure that all existing literature was included, an updated search of the highlighted databases was carried out at the end of September 2024.

Selection process

Available studies were selected through three relevant phases, including reviewing titles and abstracts, evaluating studies sought for retrieval, and analysing full-text articles assessed for eligibility. Potential inconsistencies between reviewers regarding all screening aspects were resolved via discussion until an agreement was reached. Nonetheless, if it was impossible to reach a consensus authors made a final decision by consensus. Reviewers were not blinded to the journal and author names with respect to the selection of the existing literature.

Data extraction

Data was extracted using a standardized form based on the guidelines from the Centre for Reviews and Dissemination.[24] Data items included: i) Sample size and participant characteristics (age, gender, severity of TBI, time since diagnosis); ii) Intervention specifics ((type (non-immersive, semi-immersive or fully immersive VR), frequency, duration and volume of the intervention)); iii) Measurement tools (questionnaires, computer-based tests, etc.) and iv) Outcomes measured (ex. inhibition, cognitive flexibility, working memory, attention, etc.).

Risk of bias

Risk of bias was conducted through the Cochrane's Risk of Bias Tool for randomized trials (RoB-2).[25] The tool assesses risks in several experimental domains such as bias in the randomization process, deviation from the intended intervention, bias due to missing outcome data, bias in data measurement, and selection bias. The overall judgment consists in a qualitative judgment (low or high risk, or some concerns). For the purpose of the study, two independent researchers (AG and NL) assessed all the included studies. The discrepancies were solved through discussion. All the studies were judged as low risk of bias.

Results

Search outcomes and study specifics

A detailed description of search findings is depicted in Figure 1. After applying eligibility criteria, six studies were included in the final analysis of 282 participants.[18,26-30] Studies were of good quality according to the risk of bias scale (Table 1). All participants suffered various degrees of TBI,

Table 1. *Risk of bias of the included studies.*

Study ID	D1	D2	D3	D4	D5	Overall
De Luca et al., 2019	+	+	+	+	+	+
De Luca et al., 2022	+	+	+	+	+	+
De Luca et al., 2023	+	+	+	+	+	+
Jacoby et al., 2013	+	+	+	+	+	+
Man et al., 2013	+	+	+	+	+	+
Sharma et al., 2024	+	+	+	+	+	+

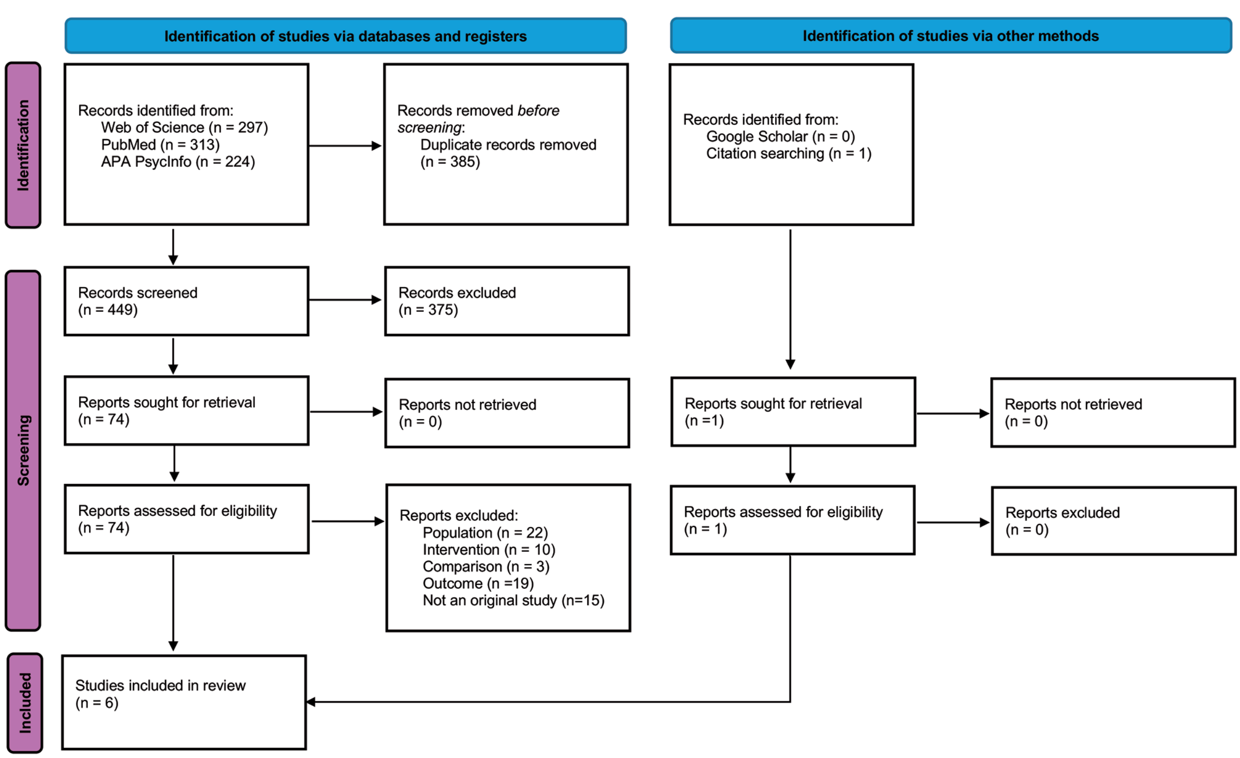

Figure 1. *PRISMA flow diagram.*

whereby three studies recruited people who have suffered mild to moderate TBI,[18,26,30] one recruited moderate to severe TBI patients,[28] and two studies did not report on the severity of TBI within the sample.[27,29] Participants varied vastly in age ranging from 18 up to 60 and were subjected to VRT for 3-6 months since TBI,[26-28] while two studies did not report on time periods since TBI (Figure 1).[18,26]
Patients underwent various forms of VRT whereby the majority of studies employed non-immersive VRT with only one study using semi-immersive VRT[1]. Frequency of VRT was about 3-4 times per week with sessions ranging from 25 to 60 minutes. Four studies lasted for 8 weeks,[26-28] while one study did not report on intervention duration.[18] Majority of VRT sessions were active in nature, meaning they had a physical activity component to it, whereas some were sedentary and required participants only to solve prespecified tasks while sitting. Control groups were subjected to standardized post-TBI care. No participants have reported adverse side effects due to VR training (Table 1).

Key findings

Four studies have used Montreal Cognitive Assessment (MoCA) to assess CF in various cognitive domains including sustained attention, spatiotemporal orientation, visuospatial function, executive function, verbal memory, language, naming, and abstract thinking.[26-28] All four studies have shown significantly better improvement in abovementioned domains post VRT when compared to CG.
Similarly, four studies have employed the Trail Making Test to test complex attention, cognitive flexibility, inhibition and working memory.[26-28,30] All four studies showed significantly better outcomes after VRT compared to CG.
Two studies have used the Tower of London Test to investigate executive planning proficiency, incorporating integration, delineation, and organization of behaviors necessary to achieve a goal.[18-30] Both studies showed significantly better outcomes after VRT compared to CG.
One study used the Go-No-Go Test to assess inhibition and concluded that VRT group had significantly better scores post-intervention when compared to CG group.[28]
One study used Multiple Errands Test (simplified version) to detect changes in executive function deficits and found significantly better scores post-intervention in the VRT group compared to CG.[29] The same study assessed executive function pertaining to activities of daily living (initiation/starting, organization/setup, sequencing/completing steps in proper order, determining safety/judgment, and task completion understanding) and found significantly better outcomes in the VRT group compared to CG.
One study assessed cognitive reasoning via the Wisconsin Card Sorting Test and found that the VRT group had significantly better outcomes post-intervention compared to the CG.[18] Detailed information of each study is depicted in *Supplementary Material, Table 1*.

Discussion

Main takeaways

The goal of the present study was to review the available literature on the effects of VR-based training aimed at recovering CF in TBI affected individuals. All of the included studies have shown that VRT elicited better outcomes in almost all of the cognitive domains measured when compared to CGs. These findings are largely analogous to what has been revealed in previously published reviews of similar scope and support our initial hypothesis. Namely, it seems that there is an overall consensus that VRT of 10-12 sessions, 20-40 min in duration per session with 2-4 sessions per week can optimize CF in patients recovering from TBI.[31]
Beyond CF, VRT shows promising results in the rehabilitation of balance and mobility which, in consequence, improves the overall QoL of TBI patients.[14] However, evidence on the effects of VR on limb function is rather limited and necessitates further investigation.

Practical considerations

Although VRT participants showed better overall outcomes, it is important to delineate several key factors that might have affected the results. First, the age of the participants varied vastly among the included studies (ranging from 18 to 60). In healthy, non-TBI-affected subjects, despite ongoing debate, it seems that younger individuals have better neuroplasticity than older ones.[32] In a similar fashion, better outcomes in some individuals might be due to age differences, yet intervention specifics (quality, adherence, design specifics *per se*, etc.) and its impact should not be foreseen. Namely, included studies varied in terms of nature, frequency, volume and intensity of the intervention, ultimately determining the intervention quality of a given study. Lastly, the recruited sample within the included studies consisted of individuals suffering from TBI of various severity, ranging from mild to moderate and moderate to severe. Undoubtedly, the severity of TBI can impact the effectiveness of an intervention ultimately affecting the outcomes of it.

Rehabilitative assets of VR

Due to its ecological validity, *i.e.*, mimicry of the real-world setting, VR has the capacity to enhance brain plasticity and facilitate processes of rehabilitation. No study in the present review used the fully immersive VR to rehabilitate CF in TBI affected individuals. To that end, our results coincide with the existing evidence by Riva *et al.*,[33] who found that VRT neurorehabilitation as an effective measure of restoring executive functions and visuospatial abilities without firm evidence on improving measures of memory, and attention outcomes. It should be highlighted that the included studies in our review did not utilize the "full potential" of high-resolution head-mounted devices to fully deliver the immersiveness in addition to other beneficial effects of VRT. This is despite increased availability of VR tools on the market over the past several years, in addition to significant reductions in pricing of and rise in commercially available devices (*i.e.*, Meta Quest) some of which do not require a computer to run unlike others (Oculus, HTC Vive).[34] However, except pricing, differences in graphics play a major role, which can determine the level of immersiveness of the delivered "world" can distinctly differ between high-end and budget/portable VR systems, ultimately affecting the delivered quality and experience of the virtual world or elements. Furthermore, limited research on safety of VR suggests it to be safe tool with minimal risks for patients; in fact, in a study with TBI patients, out of 51 participants completing the post-intervention survey, none reported any issues nor discomfort, apart from minimal adverse effects like mild dizziness[35] which is similar to our findings, although individual/subjective perception of VR should be considered.[36,37] However, one should not overlook the fact that protocols utilizing the VR headsets to fully experience the immersiveness must account and possess adequate room for body movements/spatial orientation in fully/semi-immersive VR environments. Likewise, unlike conventional TBI rehabilitation, VRT can reduce boredom and enhance sense of motivation and enjoyment,[38-40] which are crucial elements of an effective intervention, especially if the goal is for this behavior to be repeated once the intervention is ceased. Moreover, due to pediatric population being heavily affected by TBI,[41] inherent elements of "gamification" may exert additional positive behavioral responses in younger populations, especially since use of smartphones, personal computers, video consoles and VR headsets for purposes of both casual and competitive gaming (*i.e.,* e-sports) made it to the list as an everyday activity of the modern age. A growing evidence suggests that game-based interventions have already proven effective in boosting several aspects of cognition, including the grey matter of multiple cerebral regions responsible for optimal CF.[42] Next, return-to-work is one of the most essential objectives of TBI rehabilitation[43] and VR can be of exceptional utility in this case given its ability to mirror the work environment by offering manifold sensual experience which ultimately facilitates this process. This is a profound advantage over conventional paper and pencil approach which can enhance CF, but lacks practical utility, *i.e.* ecological validity. Additionally, VRT may be individually tailored and adjusted to the needs of client and treatment objectives, whereby difficulty of a specific task is increased by decreasing the reliance on the support and guidance of a therapist.[14]

Strengths and limitations

This review is not without limitations. Only six studies have met the inclusion criteria and were fully analyzed and extrapolated which led to less than 300 participants being included. These studies were, according to the risk of bias scale, of good quality but were mostly testing the validity and feasibility of VR after TBI. Furthermore, as all studies were pilot studies in nature with mostly small sample sizes, the generalizability of presented findings is rather limited, but identified gap in the literature can be a "fertile ground" for future studies in this scope of science, especially given the availability, increasing affordability and utility of VR in diagnosis and treatment of cognitive dysfunction following TBI.

By contrast, strengths of the present review are derived from strict eligibility criteria, accurate and transparent presentation of the extracted data and confirmed hypothesis on the better cognitive gains acquired by the VR groups. Namely, as anticipated, VRT produced greater improvements in virtually all of the domains measured. Indeed, it seems that there is a great potential for VRT in the TBI rehabilitation that is currently underutilized.[44] However, the second part of our hypothesis on the level of impressiveness and the magnitude of benefits could not be proven or disproven as none of the studies used fully immersive VR.

Conclusions

Our findings indicated that VRT is a potent tool in d rehabilitating CF in TBI-affected individuals. All the included studies consistently demonstrated that VRT yields superior outcomes across nearly all measured cognitive domains compared to control groups. These findings align closely with those reported in prior reviews of similar scope, thereby substantiating our initial hypothesis. Beyond cognitive improvements, VRT also exhibits significant potential in rehabilitating balance and mobility, which subsequently enhances the overall QoL for TBI patients. More studies using fully immersive VR and recruiting larger sample sizes are merited.

List of abbreviations

TBI, traumatic brain injury
CF, cognitive function
QoL, quality of life
VR, virtual reality
VRT, virtual reality training

Conflict of interest

The authors declare no conflict of interest.

Funding

The study was supported by The Ministry of Science and Higher Education of the Russian Federation (the Research Project 075-15-2024-526).

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References

1. McDonald BC, Flashman LA, Saykin AJ. Executive dysfunction following traumatic brain injury: neural substrates and treatment strategies. Neuro Rehabilitation 2002;17:333–44.
2. Chieregato A, Martino C, Pransani V, et al. Classification of a traumatic brain injury: the Glasgow Coma scale is not enough. Acta Anaesthesiol Scand 2010;54:696–702.
3. Maas AIR, Menon DK, Manley GT, et al. Traumatic brain injury: progress and challenges in prevention, clinical care, and research. Lancet Neurol 2022;21:1004–60.
4. Lui SK, Fook-Chong SMC, Teo QQ. Demographics of traumatic brain injury and outcomes of continuous chain of early rehabilitation in Singapore. Proc Singapore Healthc 2020;29:33–41.
5. Langlois JA, Rutland-Brown W, Thomas KE. Traumatic brain injury in the United States: emergency department visits, hospitalizations, and deaths. Centre for Disease Control and Prevention; 2006. Available from: https://stacks.cdc.gov/view/cdc/12294
6. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. J Head Trauma Rehabil 2006;21: 375–8.
7. Frost RB, Farrer TJ, Primosch M, Hedges DW. Prevalence of traumatic brain injury in the general adult population: a meta-analysis. Neuroepidemiology 2013;40:154–9.
8. Dang B, Chen W, He W, Chen G. Rehabilitation treatment and progress of traumatic brain injury dysfunction. Neural Plast 2017;2017:1582182.
9. Global, regional, and national burden of traumatic brain injury and spinal cord injury, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet Neurol 2019;18:56–87.
10. Blair C. Educating executive function. Wiley Interdiscip Rev Cogn Sci 2017;8:10.1002/wcs.1403.
11. Carlozzi NE, Kratz AL, Sander AM, et al. Health-related quality of life in caregivers of individuals with traumatic brain injury: development of a conceptual model. Arch Phys Med Rehabil 2015;96:105–13.
12. Corrigan JD, Cuthbert JP, Harrison-Felix C, et al. US population estimates of health and social outcomes 5 years after rehabilitation for traumatic brain injury. J Head Trauma Rehabil 2014;29:E1-9.
13. Julien A, Danet L, Loisel M, et al. Update on the efficacy of cognitive rehabilitation after moderate to severe traumatic brain injury: a scoping review. Arch Phys Med Rehabil 2023;104:315–30.
14. Alashram AR, Padua E, Annino G. Virtual reality for balance and mobility rehabilitation following traumatic brain injury: A systematic review of randomized controlled trials. J Clin Neurosci 2022;105:115–21.
15. Rizzo A "Skip", Kim GJ. A SWOT Analysis of the field of virtual reality rehabilitation and therapy. Presence Teleoperators Virtual Environ 2005;14:119–46.
16. Kyaw BM, Saxena N, Posadzki P, et al. Virtual reality for health professions education: systematic review and meta-analysis by the digital health education collaboration. J Med Internet Res 2019;21:e12959.
17. Gunawan H, Gunawan I, Hambarsari Y, et al. Virtual reality intervention for improving cognitive function in post-stroke patient: A systematic review and meta-analysis. Brain Disord 2024;15:100152.
18. Man DWK, Poon WS, Lam C. The effectiveness of artificial intelligent 3-D virtual reality vocational problem-solving training in enhancing employment opportunities for people with traumatic brain injury. Brain Inj 2013;27:1016–25.
19. Kozhevnikov M, Dhond RP. Understanding immersivity: image generation and transformation processes in 3D immersive environments. Front Psychol 2012; 3:284.
20. LaValle SM. Virtual reality. Cambridge university press; 2023.
21. Faria AL, Andrade A, Soares L, I Badia SB. Benefits of virtual reality based cognitive rehabilitation through simulated activities of daily living: a randomized controlled trial with stroke patients. J Neuroeng Rehabil 2016;13:96.
22. Banville F, Nolin P, Rosinvil T, et al. Assessment and rehabilitation after traumatic brain injury using virtual reality: A systematic review and discussion concerning human-computer interactions. In: Virtual reality for psychological and neurocognitive interventions. Springer Nature Switzerland AG; 2019. p. 327–60.
23. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71.

24. Tacconelli E. Systematic reviews: CRD's guidance for undertaking reviews in health care. Lancet Infect Dis 2010;10:226.
25. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ 2019;366:l4898.
26. De Luca R, Maggio MG, Maresca G, et al. Improving cognitive function after traumatic brain injury: a clinical trial on the potential use of the semi-immersive virtual reality. Behav Neurol 2019;2019:9268179.
27. De Luca R, Bonanno M, Rifici C, et al. Does non-immersive virtual reality improve attention processes in severe traumatic brain injury? Encouraging data from a pilot study. Brain Sci. 2022 Sep;12(9).
28. De Luca R, Bonanno M, Marra A, et al. Can virtual reality cognitive rehabilitation improve executive functioning and coping strategies in traumatic brain injury? A pilot study. Brain Sci 2023;13:578.
29. Jacoby M, Averbuch S, Sacher Y, et al. Effectiveness of executive functions training within a virtual supermarket for adults with traumatic brain injury: a pilot study. IEEE Trans neural Syst Rehabil Eng a Publ IEEE Eng Med Biol Soc 2013;21:182–90.
30. Sharma A, Sharma A, Jain S, et al. Cognitive outcomes following virtual reality rehabilitation in patient with traumatic brain injury: a prospective randomized comparative study. Indian J Neurotrauma 2024; DOI:10.1055/s-0044-1778735
31. Alashram AR, Annino G, Padua E, et al. Cognitive rehabilitation post traumatic brain injury: A systematic review for emerging use of virtual reality technology. J Clin Neurosci Off J Neurosurg Soc Australas 2019;66:209–19.
32. Mahncke HW, Bronstone A, Merzenich MM. Brain plasticity and functional losses in the aged: scientific bases for a novel intervention. In: Møller ARBT-P in BR, editor. Reprogramming of the Brain. Elsevier; 2006. p. 81–109. Available from: https://www.sciencedirect.com/science/article/pii/S0079612306570062
33. Riva G, Mancuso V, Cavedoni S, Stramba-Badiale C. Virtual reality in neurorehabilitation: a review of its effects on multiple cognitive domains. Expert Rev Med Devices 2020;17:1035–61.
34. Altunkaya J, Craven M, Lambe S, et al. Estimating the economic value of automated virtual reality cognitive therapy for treating agoraphobic avoidance in patients with psychosis: findings from the gamechange randomized controlled clinical trial. J Med Internet Res 2022;24:e39248.
35. Lim I, Cha B, Cho DR, et al. safety and potential usability of immersive virtual reality for brain rehabilitation: a pilot study. Games Health J 2023;12:34–41.
36. Selivanov V V, Selivanova LN, Babieva NS. Cognitive processes and personality traits in virtual reality educational and training. Psychol Russ State Art 2020;13:16–28.
37. Menshikova GY, Kovalev AI, Barabanshchikova VV, Klimova OA. The application of virtual reality technology to testing resistance to motion sickness. Psychol Russ 2017;10:151.
38. Pietrzak E, Pullman S, McGuire A. Using virtual reality and videogames for traumatic brain injury rehabilitation: a structured literature review. Games Health J 2014;3:202–14.
39. Rogers JM, Duckworth J, Middleton S, et al. Elements virtual rehabilitation improves motor, cognitive, and functional outcomes in adult stroke: evidence from a randomized controlled pilot study. J Neuroeng Rehabil 2019;16:56.
40. Tieri G, Morone G, Paolucci S, Iosa M. Virtual reality in cognitive and motor rehabilitation: facts, fiction and fallacies. Expert Rev Med Devices 2018;15:107–17.
41. Taylor HG, Swartwout MD, Yeates KO, et al. Traumatic brain injury in young children: postacute effects on cognitive and school readiness skills. J Int Neuropsychol Soc 2008;14:734–45.
42. Välimäki M, Mishina K, Kaakinen JK, et al. Digital gaming for improving the functioning of people with traumatic brain injury: randomized clinical feasibility study. J Med Internet Res 2018;20:e77.
43. Bloom B, Thomas S, Ahrensberg JM, et al. A systematic review and meta-analysis of return to work after mild traumatic brain injury. Brain Inj 2018;32:1623–36.
44. Nikonova E, Rupchev G, Morozova M, Burminskiy D. Using virtual reality for relaxation in patients with schizophrenia. A pilot study. Natl Psychol J 2023;18: 78–89.

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Submitted: 21 October 2024.
Accepted: 28 February 2025.
Early access: 10 April 2025.

Online supplementary material:

Table 1. Study characteristics.