

# Cognitive Outcomes following Virtual Reality Rehabilitation in Patient with Traumatic Brain Injury: A Prospective Randomized Comparative Study

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Abstract	<b>Introduction</b> Comprehensive rehabilitation is essential to enhance the quality of life				
	and cognitive performance of traumatic brain injury (TBI) survivors. Virtual reality (VR				
	has emerged as a promising tool for TBI rehabilitation due to its ability to provide ar				
	engaging and tailored environment.				
	Materials and Methods This was a randomized comparative study conducted at tertiary				
	hospital and included individuals aged between 18 and 60 with mild-to-moderate cognitive				
	impairment due to TBI. The participants were divided into a case group receiving intensive				
	VR rehabilitation and a control group receiving standard care. Cognitive assessments were				
	conducted before and after treatment, and during follow-up.				
	<b>Results</b> VR rehabilitation demonstrated significant improvements in cognitive function.				
	The VR group exhibited remarkable progress in the Montreal Cognitive Assessment				
	(MoCA), Tower of London (TOL), and Trail Making Test (TMT) scores. Baseline MoCA,				
	TOL, and TMT scores (mean value) of case group 16.5, 11.75, and 14.05 and for control				
Keywords	group 17, 10, and 13 were respectively. All the parameters of case group improved at the				
<ul> <li>traumatic brain injury</li> </ul>	time of discharge (MoCA: 24.3, TOL: 22, TMT: 27.5) and in follow-up (MoCA: 28.5, TOL:				
<ul> <li>virtual reality</li> </ul>	32.5, TMT: 42.07) as compared with control group at discharge (MoCA: 19, TOL: 13, TMT:				
<ul> <li>rehabilitation</li> </ul>	17) and in follow-up (MoCA: 21, TOL: 15, TMT: 19), which shows significant improvement in				
<ul> <li>Montreal cognitive</li> </ul>	case group ( $p < 0.001$ ) as compared with control group.				
assessment	Conclusion VR rehabilitation significantly improves cognitive outcomes in TBI				
<ul> <li>cognitive function</li> </ul>	patients. It has the potential to be a significant tool in TBI rehabilitation.				

## Introduction

Traumatic brain injury (TBI) is a medical condition that causes brain damage after receiving an external, powerful, and violent head injury (such as a fall from a height, a sports injury, or a car accident) or having an object to penetrate the skull (i.e., bullets). TBI causes the majority of long-term

article published online July 4, 2024 DOI https://doi.org/ 10.1055/s-0044-1778735. ISSN 0973-0508. disabilities and fatalities in young adults, and it is a major socioeconomic and healthcare burden.<sup>1,2</sup> Priority should be given to managing TBI patients through an integrated, tailored, thorough diagnostic, treatment, and rehabilitation program. Following a TBI, behavioral alterations and aberrant cognitive function are caused by modifications of neurotransmitter and neuroendocrine activity.<sup>3</sup> Executive

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function, problem-solving, memory, and attention are just a few of the cognitive problems that a TBI can lead to. Impaired daily living activities are regarded as executive function impairment, which is a predictive marker for rehabilitative activities. There is a shortage of comprehensive rehabilitation services in many developing nations, including India, as well as a lack of knowledge about rehabilitation and its solutions. This makes it more difficult for post-TBI survivors to work and stresses out carers. To improve both quality of life and cognitive performance after a TBI, rehabilitation is essential.

Many studies have shown the potential efficiency of cutting-edge methods, such as virtual reality (VR), during the various phases of rehabilitation following a TBI.<sup>4–6</sup> A computer-based solution known as VR produces artificial settings with special sensory stimuli that may be interacted with in real time.<sup>7</sup> VR can be nonimmersive, where virtual content is displayed on a computer screen using conventional interfaces, or immersive, where virtual content is typically displayed by a head-mounted display (giving the user the impression that he or she has entered the computer-generated artificial world). Finding items and performing tasks in VR can mimic the ecological needs of the real world, which can enhance the brain's capacity for plasticity and regeneration processes.<sup>6</sup> VR has been demonstrated to boost cognitive functions in TBI patients as a rehabilitation technique. Moreover, it increases motivation and enjoyment, two crucial elements for effective rehabilitation exercise and adherence.<sup>8</sup> In short, VR offers a fun, interactive environment that can improve patient compliance and the effectiveness of rehabilitation itself. It can also be tailored to the specific needs of the patient.

This study was conducted to evaluate the role of VR rehabilitation in cognitive assessment and rehabilitation in individuals affected by TBI and to observe whether the benefits of in-patient VR rehabilitation are sustainable by assessing the patients in follow-up examination a minimum after 1 month of discharge.

## **Materials and Methods**

After obtaining institutional ethical committee approval, this randomized prospective comparative study was conducted from July 1, 2021, to December 31, 2022. The patients were enrolled in the study after obtaining informed and written consent. No extra financial burden would be incurred for the patient.

A total 80 patients with TBI after obtaining written and informed consent were enrolled in study. Patients with following characteristics were included: Aged between 18 and 60 years, ability to sit for at least 15 minutes (Including at least 1 minute without support), presence of mild-tomoderate cognitive impairment (Montreal Cognitive Assessment [MOCA] from 10 to 26). Patients with global aphasia, poor comprehension, and comorbidities interfering with rehabilitation, known case of psychiatric or central nervous system pathology or medical and surgical disease

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that interfere with the study and patient with multiple injuries that interfere with the uses of VR user interface were excluded from the study.

The rehabilitation program was started on patients with a history of TBI after completing the initial clinical assessment within 48 hours of admission. After obtaining their written informed consent, all patients were evaluated with detailed clinical examination, and sociodemographic, educational, current neurological and radiological and biochemical data were recorded. Assessment of motor, cognitive and functional outcomes was done at three points: prior training, after 15 days, and after 1 month (follow-up).

All patients were divided into case and control groups randomly; the control group received standard care that includes antiepileptics, analgesics, and physiotherapy focused to improve locomotion, spasticity reduction, balance improvement, positioning, resistive, and stretching exercises and graded gait training and for tic-tac-toe, matchmaking and Sudoku like exercises for cognitive rehabilitation. At the time of discharge, these patients were advised home-based program and asked to report for follow-up after 15 and 30 days from the date of TBI.

All patients in the case group received standard care similar to the control group along with intensive VR training sessions once a day for 6 days a week; first session was conducted after 2 days of admission. Each VR session was a one-on-one session, using the patient-centered approach with the level of individual task difficulty varied according to the participant's level of performance; each session was conducted with a registered clinician

There were three different VR exercises and each exercise had 10 difficulty levels and it scores were according to patient performance ranging from 1 to 3 stars. If the patient got 2 or more than 2 stars, then only he proceeded to the next level; otherwise he shifted to another exercise for that particular VR session.

### **Outcome Measures**

Each participant was assessed using neuropsychological evaluation before the training, at the time of discharge and during the follow-up by using the MOCA and a group of tests that include the Tower of London (TOL) test, trailmaking test, and go and no go test to assess cognitive function.

**1) Montreal Cognitive Assessment:** MOCA was a screening tool for cognition and is found to be more sensitive and specific for the detection of mild cognitive deficits compared with Folstein mini-mental state examination.<sup>9</sup> MOCA tests visuospatial executive, naming, memory, attention, language, abstraction, delayed recall and orientation aspects of cognition. The total MOCA score was calculated by summing the score of all domains from 0 to 30. Scores less than 10 indicate severe, 10 to 17 moderate, and scores between 18 and 26

suggestive of mild impairment. A score more than 26 is interpreted as normal cognition.

Patient with MOCA score ranging from 10 to 26 was included in the study and was further assessed by a group of quantitative cognitive and functional assessment tests that include the TOL test and trail-making test; these group of tests will be done by another clinician to reduce the bias.

**2) Tower of London test:** The TOL was a test used for the assessment of executive functioning specifically to detect deficits in planning.<sup>10,11</sup> The TOL test includes transferring three-colored disks between three vertical rods, from an initial position to a prespecified goal arrangement. Solving the TOL problem within a limited number of moves requires planning the sequence of action before starting to move the discs. It is, therefore, considered a planning test.

**3) Trail-making test:** This test can provide information about visual search speed, scanning, speed of processing, mental flexibility, as well as executive functioning.<sup>12</sup> Trail-making requires a subject to connect a sequence of 25 consecutive targets on a sheet of paper or computer screen.

# **Data Analysis**

Numerical variables were summarized as mean and standard deviation and were analyzed by using various parametric tests. Nominal/categorical variables were presented as proportions and were analyzed using the chi-squared test and other suitable nonsuitable, nonparametric tests.

*p*-Value less than 0.05 would be considered statistically significant.

# Results

**Sociodemographic characteristics of study population:** In **► Table 1**, the mean age of cases was 49.73 years, and the mean age of control was 56.17 years. Both in cases and control, there was male preponderance. Their education level shows no significant difference.

**Clinical characteristics of study population:** As described in **-Table 2**, our study showed maximum prevalence of mild injury, followed by moderate and then severe. Among cases, the major reason behind TBI was a fall in 21 patients, while among controls, the reason was motor vehicle accidents in 22 cases. Time since trauma in both cases and control had no significant difference; mean time since trauma was approximately 7 hours. In both groups, the lesion was more common on the left side of cerebral hemisphere.

**Cognitive and functional score (MOCA, TOL and TMT) in patient with TBI:** In **- Table 3**, it is observed that variables MoCA, TOL, and TMT represented significant differences after VR sessions, while in the control group, there is no significant difference.

**Cognitive domain score using MOCA scale: -Table 4** describes therapeutic use of VR had positive and significant

Characteristic	Case	Control	p-Value	
Total n	40	40	-	
Age, years (mean)	49.73 (9.05)	56.5 (7.13)	0.43	
Male (%)	28	27	0.9	
Female	22	23		
Education				
Up to primary (1–5 <sup>th</sup> )	12	14	0.71	
Up to Sr. secondary (6–12 <sup>th</sup> )	9	7		
Graduation	8	5		
Professional	5	5		
Home maker	6	9		

Table 2 Clinical characteristics of study population

Characteristic	Case	Control	p-Value
Total, n	40	40	-
Injury Severity			0.37
Mild (%)	25	13	
Moderate (%)	10	25	
Severe (%)	5	2	
Mode of injury			0.61
Falls	19	18	
Motor vehicle accident	21	22	
Time since trauma (in hours)	7.1±6.7	$7.25\pm6.8$	0.917
Lesion site			0.84
Right	11	13	
Left	29	27	

effects on cognitive function in individuals; there was a significant improvement in the subcategories such as global cognition, executive function, language, abstraction, recall, orientation, and attention when compared with the control group.

## Discussion

Current literature demonstrates that VR could be useful as a rehabilitation tool in cognitive recovery post-TBI. However, the evaluation protocols with VR have been mainly applied in mild TBI, which is difficult to evaluate with traditional tools. Instead, VR treatment protocols for cognitive rehabilitation are most widely used (i.e., from mild-tosevere conditions), although the efficacy of these interventions should be further explored indeed, although

Variables	Groups	Mean value on admission	Mean value at discharge	Mean values at follow-up	Degree of freedom	<i>p</i> -Value
MoCA	Case	16.5	24.3	28.5	1	< 0.001
	Control	17	19	21	1	0.081
TOL	Case	11.75	22	32.5	1	< 0.001
	Control	10	13	15	1	0.061
ТМТ	Case	14.05 s	27.5 s	42.07 s	1	< 0.001
	Control	13 s	17 s	19 s	1	0.068

Table 3 Cognitive and functional score (MOCA, TOL, and TMT) in patient with traumatic brain injury

Abbreviations: MoCA, Montreal Cognitive Assessment; TMT, Trail Making Test; TOL, Tower of London.

Cognitive subdomains	Descriptive statistics	Admission	Discharge	Follow-up	p-Value
Visuospatial/Executive	Case	$0.5\pm0.23$	$0.81 \pm 0.15$	$0.96 \pm 0.08$	0.041
	Control	$0.48\pm0.18$	$0.51\pm0.09$	$0.59\pm0.08$	0.82
Naming	Case	$0.64 \pm 0.14$	0.7±0.16	$0.84\pm0.08$	0.002
	Control	$0.63\pm0.09$	$0.64\pm0.12$	$0.65\pm0.01$	0.72
Attention	Case	$0.76\pm0.19$	$0.77\pm0.15$	$0.99 \pm 0.03$	0.004
	Control	$0.75\pm0.18$	$0.75\pm0.12$	$0.78\pm0.15$	0.91
Language	Case	$0.65\pm0.13$	$0.68\pm0.15$	$0.84\pm0.05$	0.048
	Control	$0.62\pm0.14$	$0.64\pm0.14$	$0.71\pm0.16$	0.062
Abstraction	Case	$0.68\pm0.18$	$0.71\pm0.19$	$0.82\pm0.21$	0.001
	Control	$0.67\pm0.14$	$0.64\pm0.12$	$0.68\pm0.16$	0.92
Delayed recall	Case	$0.71\pm0.21$	$0.75\pm0.24$	$0.81\pm0.26$	0.037
	Control	$0.69\pm0.14$	$0.71\pm0.14$	$0.71\pm0.16$	0.91
Orientation	Case	$0.72\pm0.19$	$0.75\pm0.21$	$0.81\pm0.23$	0.048
	Control	0.70±0.18	0.71±0.18	$0.73\pm0.20$	0.82

 Table 4
 Cognitive domain score using MoCA scale

Abbreviation: MoCA, Montreal Cognitive Assessment.

studies suggest that VR training can provide innovative treatment options for TBI. Hence, the study<sup>13</sup> was conducted to evaluate the role of VR rehabilitation in cognitive assessment and rehabilitation in individuals affected by TBI.

In our study, the mean age of cases was 49.73 years, and the mean age of control was 56.17 years. Both in cases and control, there was male preponderance. Their education level shows no significant difference. Similarly, a study by Lui et al showed more males were admitted acutely for TBI, which was consistent with other demographic studies, as male sex has been established as a risk factor for TBI.<sup>14,15</sup> The suggested reasons for higher TBI risk in males were related to males often participating in more risk-taking behavior, contact sports, and alcohol consumption.<sup>16</sup>

Similarly, a study by Liew et al<sup>17</sup> showed a peak incidence of TBI in elderly patients, especially those aged between 45 and 60 years, with falls being the predominant mechanism of TBI in the elderly, whereas road traffic accident was the leading cause in younger patients. This was also the case in a recent study by Liew et al that reported a shift in local TBI demographics toward an older population, with an increased incidence of falls.

The severity of injury in our study showed maximum prevalence of mild injury, followed by moderate and then severe. Among cases, the major reason behind TBI was motor vehicle accidents in 21 patients, while among controls, the reason was motor vehicle accidents in 22 cases. Time since trauma in both cases and control had no significant difference; mean time since trauma was approximately 7 hours. In both groups, the lesion was more common on the left side.

Similar results were observed in articles of Hanson et al<sup>18</sup>, Ponsky et al,<sup>19</sup> and Macpherson et al<sup>20</sup> where motor vehicle collision are common mechanisms of TBI.

Similar data of severity were stated by McMahon et al,<sup>21</sup> where the majority of patients selected for VR were older patients with mild TBI. Functional impairment is prevalent in mild TBI, and studies have shown that mild TBI can result in cognitive and psychosocial impairment. Older patients with mild TBI have an increased risk of poor cognitive

performance, which could explain their need for inpatient rehabilitation, despite the mild severity.

In our study, all patients in the case group received standard care similar to the control group along with intensive VR training sessions once a day for 6 days a week; first session was conducted after 2 days of admission. Each VR session had a one-on-one session, using a patient-centered approach with the level of individual task difficulty varied according to the participant's level of performance each session was conducted with a registered clinician. Virtual rehabilitation will be conducted in a private room at the hospital, free of distraction using handheld objects, the participant engaged in a virtual environment presented on an LCD screen with a built CPU by using a Tyro motion machine. The patient will interact with virtual scenarios and audiovisual stimuli, creating a multiple sensory involvement that facilitates attention, visual-spatial, memory, and executive skills. There were three different VR exercises and each exercise had 10 difficulty levels and it scored according to the patient, ranging from 1 to 3 stars.

There were several tools for VR in other studies that can be used with different costs and complexity. Currently, studies with VR use advanced and complex instruments. An example in the CAREN used by Onakomaiya et al.<sup>22</sup> In a study of Levy et al,<sup>23</sup> a VR grocery store was used as an assessment and intervention tool. However, in the study of Besnard et al<sup>24</sup>, a nonimmersive virtual coffee task—a virtual kitchen to assess daily-life activities, was used. In a study of Canty et al,<sup>25</sup> prospective memory task (i.e., the VR shopping task) was used, whereas Larson et al used VR<sup>26</sup> and robotics technology.

In our study, it is observed that variables MoCA, TOL, and TMT represented significant differences after VR sessions, while in the control group, there is no significant difference. Therapeutic use of VR had positive and significant effects on cognitive function in individuals;, there was a significant improvement in the subcategories such as global cognition, executive function, language, abstraction, recall, orientation, and attention when compared with the control group.

Similarly, in study of Kim et al,<sup>27</sup> there was significant improvement in the subcategories such as global cognition (mean difference [MD] = -1.15, 95% confidence interval [CI]: -2.83 to 0.53), executive function (MD = -2.56, 95% CI: -8.94to 3.82), working memory (MD = 0.08, 95% CI: -0.93 to 1.10), memory function (MD = -0.26, 95% CI: -0.73 to 0.22), and attention (MD = -0.61, 95% CI: -1.26 to 0.05) when compared with the control group. Our results are also similar to the results, reported in previous meta-analyses of Kim et al and Yu et al<sup>28</sup>, which showed significant improvements in global cognition after VR. A previous meta-analysis by Zhu et al<sup>29</sup> showed significant improvements in executive function and memory function. However, another meta-analysis by Wu et al<sup>30</sup> and Zhong et al<sup>31</sup> reported no positive effects on memory function, execution function, and attention after VR.

Similar results were observed in the systemic review of Shin and Kim<sup>32</sup> where the types of VR programs that have

been used in cognitive evaluations of patients with brain injury were identified and studies of cognitive interventions were reviewed according to PICO methods. In the included studies, the VR programs could distinguish the cognitive disability of patients in comparison with healthy subjects. Thus, VR could be used as a new assessment method of the cognitive function of patients with brain injury.

Hence, in this study, the therapeutic application of VR in individuals with TBI was more effective in improving cognitive function when compared with the control group; subcategories of cognitive function also showed significant improvement.

## Conclusion

Therefore, by seeing the results from the following charts and tables as depicted above, we can say that in this study, the therapeutic application of VR in individuals with TBI was more effective in improving cognitive function when compared with the control group.

### Limitations

Assessment of cognitive and functional outcomes was done at three points: prior training; after 15 days, and after 1 month (follow-up). However, we were not able to analyze the efficacy of a particular program in improving cognition. Study with larger sample size and with longer follow up is necessary.

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