



# COMPARISON OF EARLY VESTIBULAR REHABILITATION VERSUS TRADITIONAL BALANCE EXERCISES TO IMPROVE VESTIBULAR SYMPTOMS IN SUBJECTS WITH TRAUMATIC BRAIN INJURY

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## ABSTRACT

**Background and objectives:** Dizziness and imbalance are a common symptoms of a traumatic brain injury which can impede participation in rehabilitation and has been associated with poor outcomes. Early vestibular rehabilitation is one of the adjunct treatments of choice. The objective of this study was to compare the effectiveness of early vestibular rehabilitation with traditional balance exercises to improve vestibular symptoms in subjects with traumatic injury.

**Methods:** A total of 64 subjects were screened with clinical diagnosis of Traumatic Brain Injury and randomized into two groups. As per the Glasgow Coma Scale (GCS), only individuals with mild to moderate level injury were involved in the study. The subjects in group-A (N=32) early vestibular rehabilitation while the subjects in group-B (N=32) received traditional balance exercises. Intervention was given to participants daily for 4 weeks. The Dizziness Handicap Inventory (DHI) and Balance Error Scoring System (BESS) were used to assess the intervention's effectiveness.

**Results:** Independent t-test was used to compare the mean significant difference between continuous variables. Paired t-test was used to assess the statistical significance difference between pre and post test

scores. Statistical analysis of the data revealed that, both groups significantly improved in both parameters when compared within groups, but when compared between groups, the early vestibular rehabilitation group improved better than traditional balance exercise group.

**Conclusion:** After 4 weeks of intervention both Group-A and Group-B showed significant improvement in reducing dizziness and improving balance. However Early Vestibular Rehabilitation showed more improvement than Traditional Balance Exercises. Thus, this study concludes that Early Vestibular Rehabilitation is a useful adjunct in TBI.

**Keywords:** Traumatic Brain Injury (TBI), Glasgow Coma Scale (GCS), Early Vestibular Rehabilitation, Traditional Balance Exercises, Dizziness Handicap Inventory (DHI), Balance Error Scoring System (BESS).

## INTRODUCTION

Traumatic brain injury (TBI) is one of the most common acquired neurological condition occurring in people.<sup>1</sup> It can result from a number of inciting events<sup>2</sup> such as motor vehicle accidents, a slip and fall, a violent shaking force, or sporting events, accident at work or a quarrel.<sup>3</sup> Traumatic brain injury forces to the head that disrupts the function of brain,<sup>4</sup> may also cause abnormalities in the otolith system or other structures that cause dizziness, unsteadiness,<sup>5,6,7,8</sup> poor balance and postural stability have been reported in many studies.

Globally the dizziness is a frequent symptom of trauma and has been reported occur in 23-81% of cases in the first days after injury, estimates of the prevalence of persistent dizziness after traumatic brain injury vary widely from months to years.<sup>9</sup> In India, it is estimated that nearly 1.5 to 2 million people are injured, 2 million people die nearly and nearly 1 million people require rehabilitation every year.<sup>10</sup> RTIs are the leading cause (60%) followed by falls (20%-25%) and violence (10%), Alcohol involvement is known to be present among (15 -20%) of TBIs at the time of injury.<sup>11</sup>

Despite advances in our knowledge of the complex pathophysiology of TBI, the underlying mechanisms are yet to be fully elucidated. According to the unique physical mechanisms of insult, TBI can be divided into four categories:<sup>12,13</sup>

Those from external forces hitting the head or head hitting hard enough to cause brain movement. Direct blow to the head can cause coup injuries (at the site of impact) and counter coup injuries (distant from the site of impact)

Severe acceleration and deceleration of the head, which can cause severe TBI without the head hitting an object for instance, shaken baby syndrome.<sup>14</sup>

Penetrating TBI results when foreign body penetrates the skull and traverses through the dura into brain parenchyma. Similar to closed laceration of brain tissue primarily causes focal damages, intracranial haemorrhage, cerebral oedema and ischemia.<sup>15,16</sup>

Blast injuries in this the brain is compromised by rapid pressure shock waves generated from explosion, which transmits a tremendous amount of energy from the skull into the enclosed brain parenchyma.<sup>17,18</sup>

Symptoms vary greatly depending on the severity of the head injury, they may include vomiting, lethargy, headache, confusion, paralysis, loss of consciousness, dilated pupils, vision changes (blurred vision or

double vision, unable to tolerate bright light, loss of eye movement, blindness), Cerebrospinal fluid (CSF) appear from the otorrhea or rhinorrhoea, dizziness and balance concerns, sensitive problems, breathing problems, cognitive difficulties, inappropriate emotional responses, speech difficulties.<sup>12</sup>

The dizziness was evaluated by following questionnaires and they are dizziness handicap inventory (DHI), postural perceptual dizziness (PPD) and balance was evaluated by Balance error scoring system (BESS), dynamic posturography, Romberg's test and limits stability.<sup>19</sup>

The management of dizziness and balance symptoms of TBI patients is based on pharmacological and non-pharmacological therapy. The pharmacological therapy includes betaserc and betahistine dihydrochloride for dizziness<sup>20</sup> and the non-pharmacological therapy includes conventional therapy, which includes standing, walking and weight shifting for balance.

Vestibular rehabilitation was first described by Cooksey and cawhtorne who developed and described a group exercise program designed to decrease dizziness in patients with vestibular rehabilitation dysfunction after head injuries.<sup>21</sup> In most cases because of patients physical and emotional condition, vestibular rehabilitation is initiated in chronic stage of disease and it can be very challenging in early stage.

Recent studies have suggested that early vestibular rehabilitation can obviate dizziness associated with head trauma and be beneficial in traumatic brain injury patients, The vestibularrehabilitation involves the use of specific, targeted exercises in order to decrease dizziness and improve balance and overall function of the patients.<sup>22</sup>

The targeted exercises are followed some principles and those principles are habituation, adaptation/gaze stability exercises and balance relearning.<sup>23</sup> The habituation exercises for motor sensitivity and central post traumatic dizziness, gaze stability exercises for symptoms exhibited during eye- head coordination and reduced vestibulo ocular reflex, exercises for reduced balance focusing on improvement sensory integration.<sup>24,25</sup>

The studies stated that traditional balance exercises are helpful to decrease dizzinessand improve balance and it includes standing, walking, weight shifting, the standing exercisesincluded multidirectional stepping, single and double leg standing, walking exercises involvedforward, back ward and side walking, and weight shifting exercises consisted of lunge, half squat leaning and reaching.<sup>26</sup>

Several previous studies on vestibular rehabilitation have been conducted. however, they concern on peripheral vestibular system disorders, such as rupture of the round window membrane, peri lymphatic fistula and endolymphatic hydrops and don't focus on decrease of dizziness and improving balance, there has been limited research on the early rehabilitation, which has been performed as an effective treatment in decreasing dizziness and improving balance in subjects with traumatic brain injury. Therefore, the present study is to know the effect of early vestibular rehabilitation to improve vestibular symptoms in subjects with traumatic brain injury.

## **NEED OF THE STUDY**

Traumatic brain injury is a common cause of long-term disability in the areas of physical, cognitive, behavioural and emotional functioning in patients. Dizziness and imbalance are most common symptoms

after traumatic brain injury, are reported to have a prevalence of 23 to 81%. The previous studies explained that vestibular rehabilitation can improve symptoms associated with head trauma, but it is initiated in chronic stage of disease due to physical and emotional disturbances and it is challenging at early or acute stage. Few studies have suggested that early vestibular rehabilitation can be beneficial and also helpful in improving the quality of life, so the need of the study arises to evaluate the effect of early intervention to improve symptoms like dizziness and balance.

## **MATERIALS AND METHODS**

**STUDY DESIGN:** Quasi experimental study

### **ETHICAL CLEARANCE AND INFORMED CONSENT:**

The study protocol was approved by the ethical committee of GSL Medical College & General Hospital, the investigator explained the purpose of the study and given the patient information sheet. The participants were requested to provide their consent to participate in the study. All the participants signed the informed consent and the rights of the included participants have been secured.

**STUDY POPULATION:** Subjects with traumatic brain injury clinically diagnosed by Neurologist.

**STUDY SETTING:** The study was conducted at department of physiotherapy, GSL general hospital, Rajamahendravaram, Andra Pradesh, India.

**STUDY DURATION:** The study was conducted for a period of one year

**TREATMENT DURATION:** 30-40 minutes per session, daily for 4 weeks

**SAMPLE SIZE:** A total of 76 subjects were screened in that 64 subjects, both men and women with dizziness and imbalance who are willing to participate in the study were included in this study, All the recruited participants were explained about the study. After obtaining informed consent form and meeting the criteria, a total 64 subjects were allocated into two groups equally by convenience sampling method.

**STUDY SAMPLING METHOD:** Convenience sampling method

**GROUP A:** Early Vestibular rehabilitation (32 subjects)

**GROUP B:** Traditional balance exercises (32 subjects)

### **MATERIALS USED:**

Surfaces

Obstacle course

Picking up / carrying objects

Data collection forms

## **CRITERIA FOR SAMPLE SELECTION**

### **INCLUSION CRITERIA:**

- Subjects with traumatic brain injury
- Subjects 18 to 60 years of age
- GCS higher than 13
- Subjects with mild to moderate on dizziness handicapped inventory scale



**EXCLUSION CRITERIA:**

- Severe psychological disease or substance abuse in their medical report
- Subjects with external injuries
- Other comorbidities affecting mobility and independent gait
- History of previous balance disorders

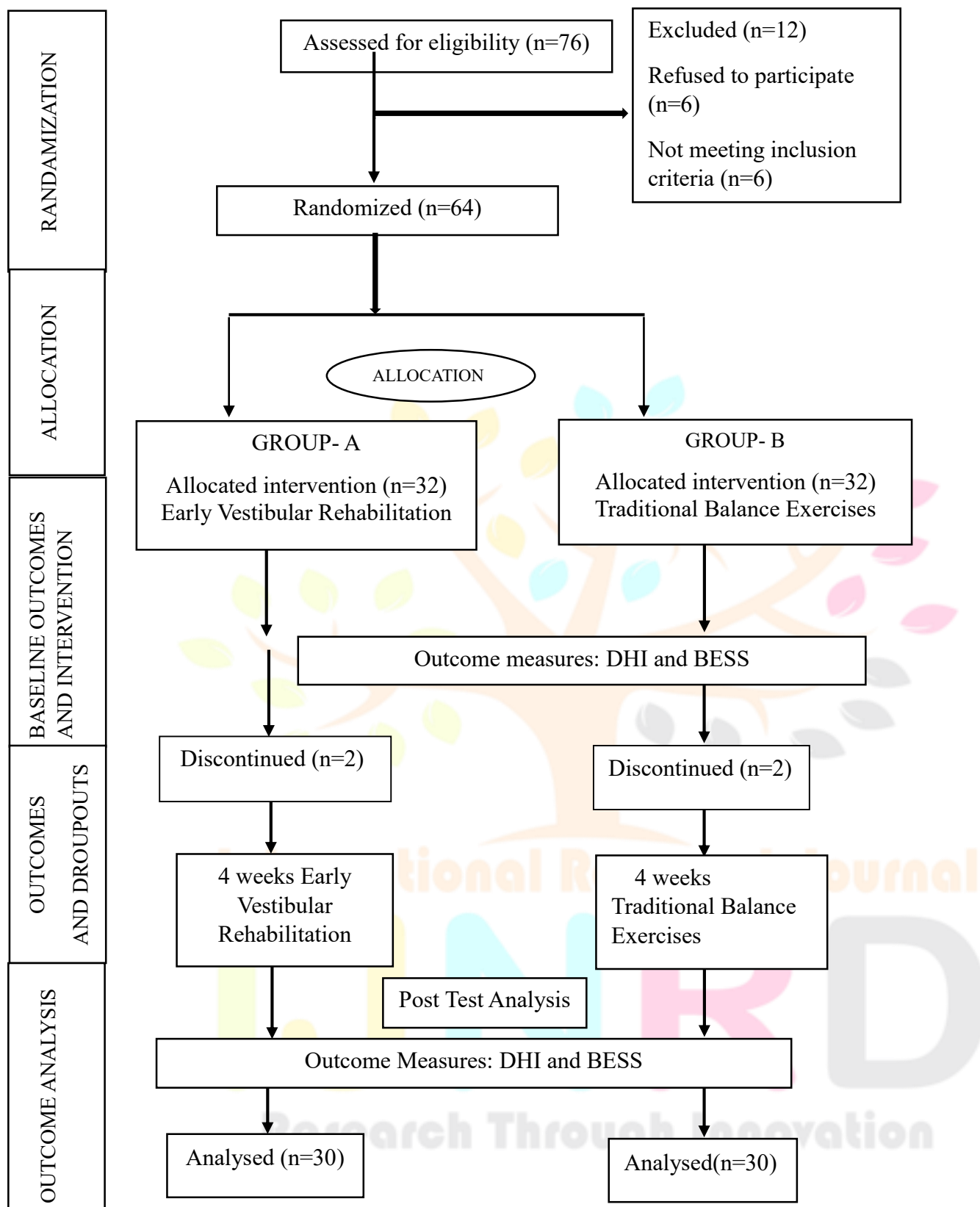
**OUTCOME MEASURES**

**DIZZINESS HANDICAP INVENTORY (DHI)<sup>27</sup>:** The Arch Otolaryngology Head Neck Surg Jacobson Gp, Newman was developed the Dizziness Handicap Inventory (DHI) in 1990 to evaluate the self-perceived handicapping effects imposed by dizziness. The dizziness handicap inventory consists of 25 questions divided into three areas of a patient's life such as physical (7), emotional (9), functional (9). Each item is assigned 0 (No), 2 (Sometimes), +4 (Yes) points, with total DHI score ranging from 0 to 100 points, the interpretation of DHI is 16-34 points (Mild handicap), 36-52 (Moderate handicap), 54+ (Severe handicap).

**BALANCE ERROR SCORING SYSTEM (BESS)<sup>28</sup>:** BESS was developed by the researchers and clinicians of the North Carolina's sports medicine research laboratory, Chapel Hill to assess the effects of mild head injury on static postural stability by using tools in subjects with imbalance. BESS can be performed in nearly any environment and it takes approximately 10 minutes to conduct, and the tools are like testing surfaces, stop watch, an assistant to act as a spotter, BESS testing protocol, BESS score card. The score of BESS was the maximum number of errors for a single condition is 10. The interpretation of BESS was 0-60 (Lower scores indicate better balance and less errors). Number of errors in each trail are added together to obtain a total score (out of 60).



## FLOW CHART



## INTERVENTION

A total of 60 subjects with traumatic brain injury were involved in this study with outcome assessments as Dizziness handicap inventory and Balance error scoring system. All the participants were screened and recruited according to the inclusion and exclusion criteria, by employing simple convenience sampling patients were randomly assigned into two groups, Group A (Early vestibular rehabilitation) and Group B (Traditional balance exercises) each containing 30 subjects. Pre intervention baseline measures were taken before the first intervention day and then the groups underwent a 30-40 min treatment protocol of daily for four weeks duration. The post baseline outcome measures were recorded immediately after the end of treatment.

### GROUP A: EARLY VESTIBULAR REHABILITATION <sup>24,25</sup>

Group A was received Early vestibular rehabilitation intervention program for 4 weeks. The categories of exercises most frequently provide in early vestibular rehabilitation follows the principles of habituation, adaptation/ substitution and balance relearning exercises. The exercises were based on signs, symptoms and functional challenges at each patient's base line assessment.

#### HABITUATION EXERCISES:

The habituation exercises are used to treat motion provoked dizziness and to reduce symptoms of dizziness by repetitive exposure to the movements that provoke the symptoms and those exercises are:

- Head turns horizontally and vertically
- Rolling supine to left side and supine to right side
- Diagonals head to knee
- Diagonals head to floor
- Turning 90° and 180°

#### ADAPTATION EXERCISES:

The Adaptation/substitution exercises are used to restore gaze stability by exercises that promote adaptation of an uncompensated vestibular ocular reflex (VOR) and those exercises are:

- x1 viewing exercise: the patient focuses on a stationary target while turning his/her head back and forth, while sitting, standing and walking
- x2 viewing exercise: the target moves in the opposite direction of the head movement, while sitting

#### BALANCE RELEARNING EXERCISES:

The balance relearning exercises help to improve the organization of sensory information for balance control and to promote utilization of vestibular cues for balance while standing and walking, standing divided into 2 types:

First one is standing static balance exercises, second one is standing dynamic balance exercises.

##### a) Static exercise contains:

- Feet apart, varied arm positions
- Tandem varied arm positions

- Feet together, eyes closed tandem
- On compliant surfaces, eyes open and closed with both legs
- On compliant surfaces, eyes open with one leg
- Different foot positions with head motion

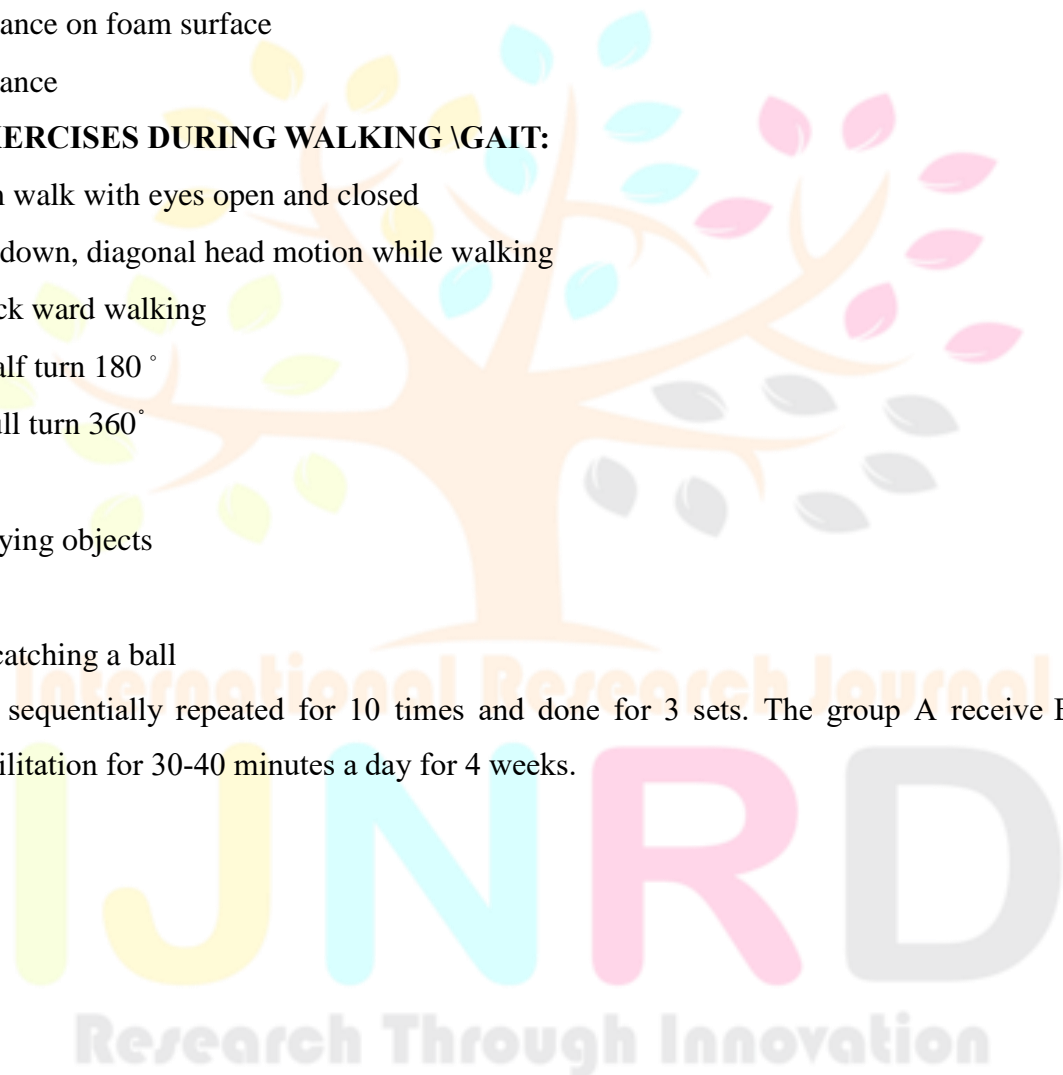
**b) Dynamic exercise contains:**

- Weight shifts anterior/ posterior
- Marching in place on floor
- Throwing/ catching/bouncing a ball
- Stepping up/ down forward and sideways
- Reactive balance on foam surface
- Reactive balance

**BALANCE EXERCISES DURING WALKING \GAIT:**

- Heel-toe tandem walk with eyes open and closed
- Side to side, up/down, diagonal head motion while walking
- Forward and back ward walking
- Walking with half turn 180 °
- Walking with full turn 360 °
- Cross overs
- Picking up/ carrying objects
- Obstacle course
- Walking while catching a ball

This process is sequentially repeated for 10 times and done for 3 sets. The group A receive Early vestibular rehabilitation for 30-40 minutes a day for 4 weeks.





## 1. HABITUATION EXERCISES:



Fig no. 1 Individual performing head turns horizontally and vertical.



Fig no. 2 Individual performing diagonals head to knee.

## 2. ADAPTATION EXERCISES:

### a) X1 viewing exercises:



Fig.no 3 Individual performing x<sub>1</sub> while sitting.

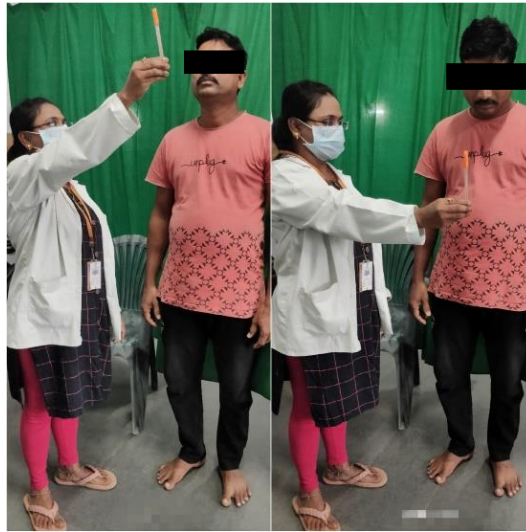


Fig. no 4 Individual performing x<sub>1</sub>viewing while standing.

b) X<sub>2</sub> viewing exercises:



Fig.no 5 Individual performing x<sub>2</sub>viewing exercise while sitting.

3. BALANCE EXERCISES:

a. Standing static balance exercises:



**Fig.no 6 Individual performing static-feet apart, varied arm positions.**



**Fig.no 7 Individual performing static-tandem varied arm positions.**

**b. Standing dynamic balance exercises:**



**Fig. no 8 Individual performing weight shifts anterior/posterior.**



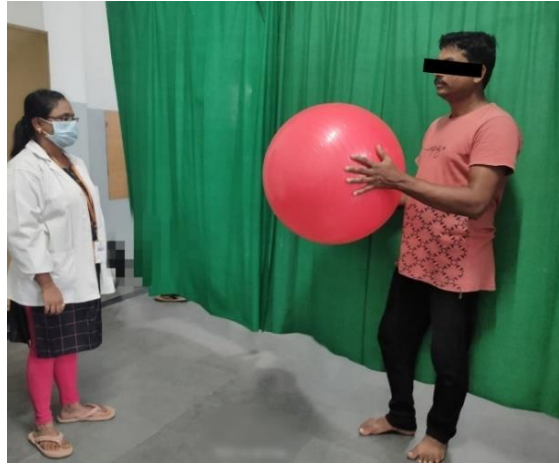


Fig.no 9 Individual performing throwing/catching/ bouncing a ball.

#### 4. BALANCE EXERCISES DURING WALKING/GAIT:



Fig.no 10 Individual performing walking forward/ backward.

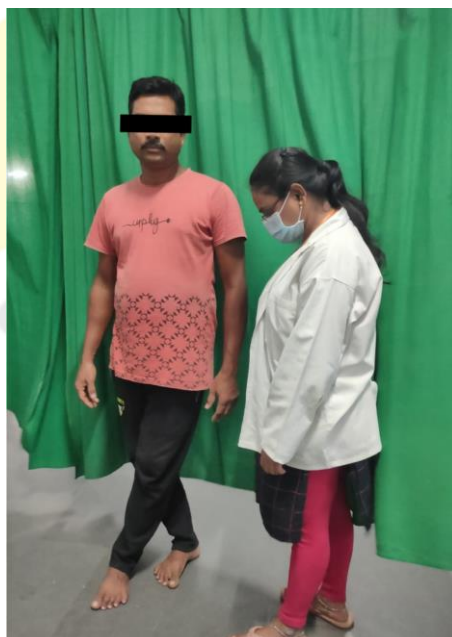


Fig.no 11 Individual performing cross overs.

## **GROUP B: TRADITIONAL BALANCE EXERCISES<sup>26</sup>**

Group B received Traditional balance exercises, which consists of categories of exercises includes standing, walking and weight shifting.

### **STANDING EXERCISES:**

- Multidirectional stepping
- Single and double leg standing

### **WALKING EXERCISES:**

- Forward walking
- back ward walking
- side walking

### **WEIGHT SHIFTING EXERCISE**

- Lunge
- Half- squat
- Leaning and reaching

This process is sequentially repeated for 10 times and done for 3 sets. The group B receive traditional balance exercises for 30-40 minutes a day for 4 weeks.

### **1. STANDING EXERCISES:**



**Fig.no 12 Individual performing multidirectional stepping.**



## 2. WALKING EXERCISES:



Fig.no 13 Individual performing forward walking.

## 3.WEIGHT SHIFTING EXERCISES:



Fig.no 14 Individual performing lunge.

## STATISTICAL ANALYSIS

All statistical analysis was done by using SPSS software version 21.0 and Microsoft excel-2007. Descriptive data was presented in the form of mean  $\pm$  standard deviation and mean differences and percentages were calculated and presented.

Within the groups: paired student “t” test was performed to assess the statistical difference within the groups for Dizziness and Balance from pre-test and post-test values.

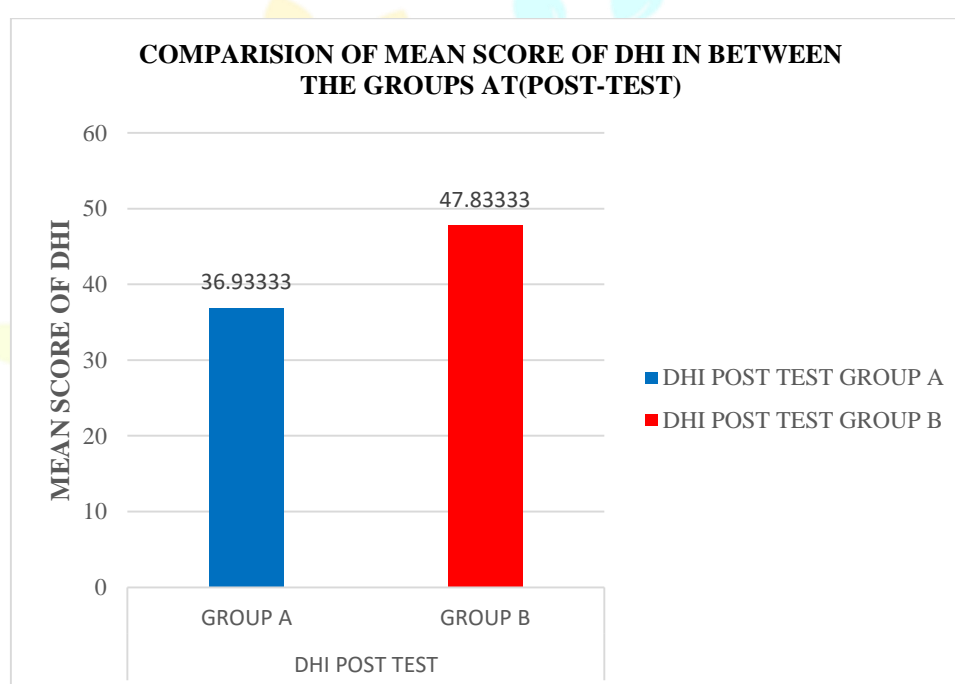
Between the groups: Independent student “t” test was performed to assess the statistically significant difference in mean value between the groups for Dizziness handicap inventory for Dizziness and Balance error scoring system for Balance.

For all statistical analysis,  $p < 0.05$  will be considered as statistically significant.

## RESULTS

### COMPARISON OF MEAN SCORE OF DHI IN BETWEEN THE GROUPS (POST-TEST)

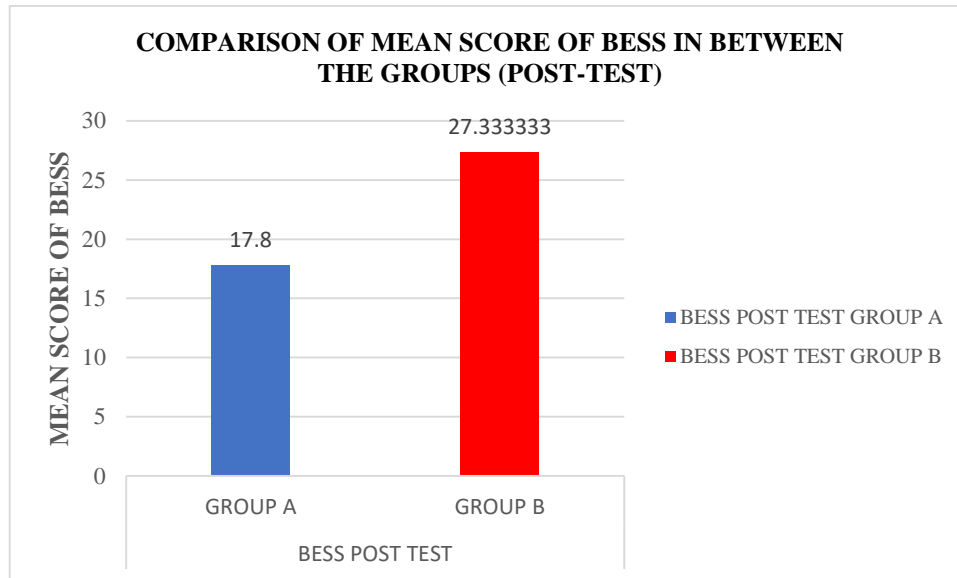
DHI		MEAN	SD	P VALUE	INFERENCE
POST-TEST	GROUP A	36.9333	6.776905	0.0001	Highly Significant
	GROUP B	47.8333	4.355601		



**RESULTS:** The above table and graph shows the post-test measurement of mean score in between the groups. DHI mean score in GROUP -A 36.9333 and GROUP-B is 47.8333 which were found to be statistically highly significant ( $P < 0.0001$ ).

### COMPARISON OF MEAN SCORE OF BESS IN BETWEEN GROUPS (POST-TEST)

BESS		MEAN	SD	P VALUE	INFERENCE
POST-TEST	GROUP A	17.8	3.527264	0.0001	Highly Significant
	GROUP B	27.333	3.753925		



**RESULTS:** The above table and graph shows the post-test measurement of mean score in between the groups. BESS mean score in GROUP-A is 17.8 which were found to be statistically highly significant ( $P < 0.0001$ ).

## DISCUSSION

The aim of this study was to investigate the effect of early vestibular rehabilitation versus traditional balance exercises on vestibular symptoms in subjects with traumatic brain injury. Recently vestibular rehabilitation has been used increasingly in otolaryngologic and neurologic disorders. Several studies have reported positive effects of vestibular rehabilitation use on vestibular symptoms, but there were limited studies on exploring the effect of early VR on vestibular symptoms in TBI subjects.

Subjects are assessed for dizziness and imbalance at baseline and at the of intervention using the DHI for dizziness and BESS for imbalance. There were 2 dropouts in Group – A (Early vestibular rehabilitation) 1 participant due to severe dizziness and 1 due to recurrent dizziness and in Group – B (Traditional balance exercises) there were 2 dropouts due to severe dizziness and 1 participant due to syncope attack. In GROUP-A shows statistically more significant improvement in DHI ( $p < 0.0001$ ) and BESS ( $p < 0.0001$ ). According to Ingerid kleffelgaard, Helene lundgaard soberg etal, in his study stated that an eight-week modified, group-based vestibular rehabilitation intervention, in addition to the usual multidisciplinary traumatic brain injury rehabilitation, can speed up recovery in dizziness- related disability and mobility after a mild to moderate TBI.

The mechanism by which the primary ideas of the intervention were derived from the science of motor control to enhance balance and the theory of positive psychology to managing the burden and pressure of symptoms. The principles of habituation, adaptation/ gaze stability, substitution exercises and balance relearning were included into well-established vestibular rehabilitation therapies.<sup>29</sup>

In a study Lucy Yardley, Sandra beech etal, in his study stated that vestibular rehabilitation is a simple, inexpensive, beneficial treatment and may be an appropriate first stage of management for many dizzy patients. The mechanism by which the programme movements of graded exercises consisting of eye, head and body movements is the central component of this therapy.

These are intended to stimulate the vestibular system and as a result, promote central compensation, while also allowing patients to overcome their aversion to certain activities. May cause disorientation and the need to regain both skill and confidence balance.<sup>30</sup>

On other hand, group-B also shows significant improvement in DHI ( $p < 0.0001$ ) and BESS ( $p < 0.0001$ ). According to Anas R. Alashram, Giuseppe Annino et al, in his study stated that there is paucity in studies that investigate the effects of physical therapy interventions on balance impairments post- TBI to date, the selection of physical therapy intervention should depend on the cause of balance deficits. We propose that stimulation of multi-systems at the same time may alert the neuroplasticity in patients with balance impairments.

The mechanism by which using motor learning principles specifically designed to treat postural deficits, traditional rehabilitation therapies have been shown in an open trail to improve balance, body stability and reduce dizziness in patients with mild to moderate TBI.<sup>31</sup>

In terms of comparing the two groups after 4 weeks of intervention program, both the Early Vestibular Rehabilitation and Traditional Balance Exercises were individually beneficial in reducing dizziness and improving balance, when post treatment values of group-A and group-B are compared, findings suggest that Early Vestibular Rehabilitation was more effective than Traditional Balance Exercises in subjects with TBI. Thus, this study concludes that Early Vestibular Rehabilitation as an useful adjuvant therapeutic in improving dizziness and balance.

### **LIMITATIONS**

- Small and relatively heterogenous group of patients constituted as the sample population
- Lower functioning and severely injured individuals after brain injury have been less represented in the present study sample
- No blinding evaluators of outcomes was done

### **RECOMMENDATIONS OF FURTHER RESEARCH**

- There are less studies on till date on early vestibular rehabilitation on Traumatic Brain Injury
- Studies could be taken with follow-up period to assess the long-term benefits of this intervention

### **CONCLUSION**

The present study concludes both early vestibular rehabilitation group and traditional balance exercises group showed significant improvement on vestibular symptoms in subjects with traumatic brain injury. However early vestibular rehabilitation group is more effective when compared to traditional balance exercises group.

From the findings of this study, it can recommend that the Early vestibular rehabilitation is opted to decrease dizziness and increase balance in subjects with traumatic brain injury.

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## REFERENCES

1. Rutland-Brown W, Langlois JA, Thomas KE, Xi YL. Incidence of traumatic brain injury in the United States, 2003. *The Journal of head trauma rehabilitation*. 2006 Nov 1;21(6):544-8.
2. Gurley, bryan D. hujsak and Jennifer L. kelly physical therapy program, mercy college, ny, usa. etal. vestibular rehabilitation following mild traumatic brain injury, United States, 2003. *The Journal of head trauma rehabilitation*. 2006 Nov 1;21(6):544-8. 2. James.
3. Jafarzadeh S, Pourbakht A, Bahrami E, Jalaie S, Bayat A. Effect of early vestibular rehabilitation on vertigo and unsteadiness in patients with acute and sub-acute head trauma. *Iranian journal of otorhinolaryngology*. 2018 Mar;30(97):85.
4. Alsalaheen BA, Mucha A, Morris LO, Whitney SL, Furman JM, Camiolo-Reddy CE, Collins MW, Lovell MR, Sparto PJ. Vestibular rehabilitation for dizziness and balance disorders after concussion. *Journal of Neurologic Physical Therapy*. 2010 Jun 1;34(2):87-93.
5. Bruusgaard, arettego pripp, maria sandhuug and birgitta langhammer, etal. 2018. The effects of vestibular rehabilitation on dizziness and balance problems in patients after traumatic brain injury: a randomized controlled trial. *Clinical rehabilitation*. 2019 Jan;33(1):74-84.
6. Skóra W, Stanczyk R, Pajor A, Jozefowicz-Korczynska M. Vestibular system dysfunction in patients after mild traumatic brain injury. *Annals of Agricultural and Environmental Medicine*. 2018;25(4).
7. ingerid kleffegaard, helene lunghammet, etal. 2015 Vestibular rehabilitation after traumatic brain injury: case series. *Physical therapy*. 2016 Jun 1;96(6):839-49.
8. Dr. todhiaki yagi department of otolaryngology, Nippon medical school, Tokyo, japan department of neurology, mayo clinic college of medicine, etal. Positioning and positional nystagmus testing: background and techniques. *Handbook of Clinical Neurophysiology*. 2010 Jan 1; 9:101-10.
9. Shumway-Cook A, Olmscheid R. A systems analysis of postural dyscontrol in traumatically brain-injured patients. *The journal of head trauma rehabilitation*. 1990 Dec 1;5(4):51-62.
10. Dewan MC, Rattani A, Gupta S, Baticulon RE, Hung YC, Punchak M, Agrawal A, Adeleye AO, Shrime MG, Rubiano AM, Rosenfeld JV. Estimating the global incidence of traumatic brain injury. *Journal of neurosurgery*. 2018 Apr 27;130(4):1080-97.



11. Jourdan C, Azouvi P, Genêt F, Selly N, Josserean L, Schnitzler A. Disability and health consequences of traumatic brain injury: national prevalence. *American journal of physical medicine & rehabilitation*. 2018 May 1;97(5):323-31.
12. Shao F, Wang X, Wu H, Wu Q, Zhang J. Microglia and neuroinflammation: crucial pathological mechanisms in traumatic brain injury-induced neurodegeneration. *Frontiers in Aging Neuroscience*. 2022 Mar 25; 14:825086.
13. Kochanek PM, Clark RS, Jenkins LW. TBI: pathobiology. *Brain injury medicine*. NY: Demos medical publishing. 2007:81-92.
14. McIntosh TK, Smith DH, Meaney DF, Kotapka MJ. Neuropathological sequelae of traumatic brain injury: Relationship to neurochemical and biomechanical. *Laboratory investigation*. 1996 Feb;74(2):315.
15. Burns TG, Semmel ES, Reisner A. A longitudinal evaluation of a penetrating traumatic brain injury: Theories of plasticity and vulnerability. *Applied Neuropsychology: Adult*. 2022 Jul 4;29(4):881-6.
16. Werner C, Engelhard K. Pathophysiology of traumatic brain injury. *British journal of anaesthesia*. 2007 Jul 1;99(1):4-9.
17. Ng SY, Lee AY. Traumatic brain injuries: pathophysiology and potential therapeutic targets. *Frontiers in cellular neuroscience*. 2019 Nov 27; 13:528
18. Bryden DW, Tilghman JI, Hinds SR. Blast-related traumatic brain injury: current concepts and research considerations. *Journal of experimental neuroscience*. 2019 Sep; 13:1179069519872213.
19. Jafarzadeh S, Pourbakht A, Bahrami E, Jalaie S, Bayat A. Effect of early vestibular rehabilitation on vertigo and unsteadiness in patients with acute and sub-acute head trauma. *Iranian journal of otorhinolaryngology*. 2018 Mar;30(97):85.
20. Strupp M, Brandt T. Diagnosis and treatment of vertigo and dizziness. *Deutsches Ärzteblatt International*. 2008 Mar;105(10):173.
21. Guskiewicz KM, Riemann BL, Perrin DH, Nashner LM. Alternative approaches to the assessment of mild head injury in athletes. *Medicine and science in sports and exercise*. 1997 Jul 1;29(7): S213-21.
22. Maskell F, Chiarelli P, Isles R. Dizziness after traumatic brain injury: overview and measurement in the clinical setting. *Brain Injury*. 2006 Jan 1;20(3):293-305.
23. Kleffelgaard, I., Roe, C., Sandvik, Leiv., Hellstrøm, T., Soberg, HL. (2013). Measurement Properties of the High-Level Mobility Assessment Tool for Mild Traumatic Brain Injury. *Physical Therapy*. Volume 93: Number 7: p. 900-910.
24. Jafarzadeh S, Pourbakht A, Bahrami E, Jalaie S, Bayat A. Effect of early vestibular rehabilitation on vertigo and unsteadiness in patients with acute and sub-acute head trauma. *Iranian journal of otorhinolaryngology*. 2018 Mar;30(97):85.
25. Kleffelgaard I, Soberg HL, Bruusgaard KA, Tamber AL, Langhammer B. Vestibular rehabilitation after traumatic brain injury: case series. *Physical therapy*. 2016 Jun 1;96(6):839-49.
26. Molhemi F, Monjezi S, Mehravar M, Shaterzadeh-Yazdi MJ, Salehi R, Hesam S, Mohammadianinejad E. Effects of virtual reality vs conventional balance training on balance and falls in

- people with multiple sclerosis: a randomized controlled trial. Archives of physical medicine and rehabilitation. 2021 Feb 1;102(2):290-9.
27. Jacobson GP, Newman CW. The development of the dizziness handicap inventory. Archives of Otolaryngology–Head & Neck Surgery. 1990 Apr 1;116(4):424-7.
28. Finnoff JT, Peterson VJ, Hollman JH, Smith J. Intrarater and interrater reliability of the Balance Error Scoring System (BESS). Pm&r. 2009 Jan 1;1(1):50-4.
29. Kleffelgaard I, Soberg HL, Tamber AL, Bruusgaard KA, Pripp AH, Sandhaug M, Langhammer B. The effects of vestibular rehabilitation on dizziness and balance problems in patients after traumatic brain injury: a randomized controlled trial. Clinical rehabilitation. 2019 Jan;33(1):74-84.
30. Yardley L, Beech S, Zander L, Evans T, Weinman J. A randomized controlled trial of exercise therapy for dizziness and vertigo in primary care. British Journal of General Practice. 1998 Apr 1;48(429):1136-40.
31. Alashram AR, Annino G, Raju M, Padua E. Effects of physical therapy interventions on balance ability in people with traumatic brain injury: A systematic review. Neurorehabilitation. 2020 Jan 1;46(4):455-66.

