EFFECT OF IMMERSIVE VIRTUAL REALITY ON BALANCE IN ELDERLY POPULATION

I AUTHOR – MUGUNDAN LAZAR
AFFILIATION – POST GRADUATE STUDENT
ADDRESS – FACULTY OF PHYSIOTHERAPY, SRI RAMACHANDRA INSTITUTE OF HIGHER EDUCATION AND RESEARCH, CHENNAI-116, INDIA.
EMAIL ID – t0320001@sriramachandra.edu.in
PHONE – 9840258729
CORRESPONDING AUTHOR and II AUTHOR – RAJESWARI MUTHUSAMY
AFFILIATION – ASSOCIATE PROFESSOR, FACULTY OF PHYSIOTHERAPY, SRI RAMACHANDRA INSTITUTE OF HIGHER EDUCATION AND RESEARCH, CHENNAI-116, INDIA.
EMAIL ID – rajeswari@sriramachandra.edu.in
PHONE – 9841417473
ORCID ID: 0000-0001-8560-509X
III AUTHOR – SIVAKUMAR RAMACHANDRAN
AFFILIATION– PROFESSOR, FACULTY OF PHYSIOTHERAPY, SRI RAMACHANDRA INSTITUTE OF HIGHER EDUCATION AND RESEARCH, CHENNAI-116, INDIA.
EMAIL ID – principal.physiotherapy@sriramachandra.edu.in
PHONE – 9840068412
ORCID ID: 0000-0002-7456-2681

402

ABSTRACT

Background: The aging population is growing and reduction in physical activity is an important problem that particularly causes impairment in balance and increased risk of falling. Older adults find routine exercise programs to be challenging in improving balance. Virtual reality systems done with non immersive devices have shown positive results in improving balance and reducing fall risk but they are found to be less beneficial and has practical constraints such as portability and distractions from environment than immersive virtual reality (IVR) system. This study intends to analyse the effect of IVR training on balance in elderly population.

Methods: Fourty four older adults were assigned to either the IVR training group with oculus quest 2 device or conventional balance training group. The outcome measures used were Berg balance Scale (BBS), Timed up and go test (TUG), Multidirectional reach test (MDRT) and Fall efficacy scale International(FES-I).

Results: Paired t test showed significant difference in all parameters except TUG in IVR group whereas conventional balance training group showed only in TUG and MDRT forward.

Unpaired t test showed IVR group improved significantly in balance parameters BBS, MDRT Forward, right, left and FES-I ($p<0.05$) than conventional balance training except TUG.

Conclusion: The findings of this study demonstrates potential benefits of IVR training on balance parameters and reduction in fall risk. IVR training is a safe and well-accepted effective intervention with enjoyable option which can be included in the standard practice of care in elderly population.

Keywords – elderly, balance, fall, fall risk, fear of fall and virtual reality

INTRODUCTION

Elderly population is defined as people aged 60 and above and they account for more than one fifth of the population globally. There were nearly 138 million elderly persons in 2021 in India which is expected to grow to almost 194 million in 2031 that needs to be addressed from a public health perspective [1]. Aging is one of the key risk factors for impaired mobility due to physical, sensory, and cognitive changes which can lead to fall and fear of fall [2].

Aging affects the functioning of all systems of the body such as cognition, vision, musculoskeletal function, vestibular and proprioception [3]. Age-related disturbances to the central nervous system and neuromuscular system result in a progressive decline in physical and psychological health causing neuromuscular deficits such as reduced muscle power, strength, speed and coordination which leads to impaired balance and reduced physical performance [4,5]. In addition, the elderly population are present with poor postural control, diminished body orienting reflexes and incoordinated gait patterns which affects the height of stepping and impaired ability to avoid falls after an accidental trip or slip. Impaired balance and reduced physical performance can lead to falls and an increased risk of falls up to 60% [6].

Balance is defined as the consistency of the body maintaining its line of gravity within its base of support which is achieved and maintained by a complex integration of multiple sensorimotor systems that include sensory inputs from vision, proprioception and vestibular systems along with feedback from the motor component from musculoskeletal system [7]. Impaired balance in elderly people can lead to fall and fear of fall which results in hospitalisation due to serious health issues such as fractures, joint dislocation, traumatic brain injury, spinal cord injury and disability. Fear of fall leads to activity limitation, anxiety about normal activities, decreased mobility, and increased dependence [8]. Fall and fear of fall can cause restricted activities of daily living, reduced quality of life and finally leading to a sedentary lifestyle [9].

Literature states that multi-component exercise and balance training programs appear to be the most effective intervention for improving balance and preventing falls [10]. Exercise programs promise effective fall prevention strategies by improving strength, endurance and body mechanics and thereby improved balance, physical function and a significant reduction in falls in the elderly [11]. Although the benefits of physical activity and exercise are widely acknowledged, elderly individuals remain sedentary since they face several internal and external barriers such as health, environmental factors and individual motivation which makes elderly challenging to participate in and practice physical exercise programs [12,13].

With the emerging and increasing use of technology in the rehabilitation setting, many researchers are exploring the effectiveness of virtual reality (VR) as an assessment and rehabilitation tool. VR systems use computer interfaces to provide immersion, simulation and interactions to participants in virtual interactive environments with a high degree of realism provided through the senses [14]. VR allows users to gain real life-like experience without exposing them to risks, thereby VR game based training improves functional outcomes of individuals who have impaired physical and/or cognitive abilities [15,16].

VR system provides the participant with multisensory feedback such as visual, auditory and tactile which are repetitive and task-specific in nature through gaming. VR systems deliver effective cognitive and neuromuscular training with entertainment value, thereby allowing the patient to exercise more regularly, effortlessly, and effectively [17]. Non-immersive VR devices are systems of choice which use external screens for projection for the participants to provide virtual environment. Newer systems are using immersive virtual reality (IVR) devices which has portable head-mounted displays with larger stereoscopic visual fields which are updated continuously using head position and rotation [18].

Previous studies on VR have shown positive results in outcomes such as Berg balance scale (BBS), Timed up and go (TUG) and Fall efficacy scale International (FES-I), thereby improved balance, reduced falls and fall risk in elderly with balance deficits which are mostly done on non-immersive VR systems [19]. They are found to be less beneficial and has practical constraints such as portability and distractions from the environment than IVR system which are portable and provides more realism, simulation and interactions in virtual environments [9,20]. In addition, participants using IVR systems perform better in cognitive functions [21,22]. Considering the benefits of VR and the lack of adequate evidence in IVR systems on balance in the elderly, this study intends to analyse the effectiveness of IVR on balance parameters with BBS, TUG, Multidirectional reach test (MDRT) and fall risk with FES-I in older adults.

Subject recruitment:

The study was conducted in old age homes in Chennai, Tamilnadu. 32 male and 12 female participants aged 60 years and above who were able to comprehends to command with a BBS score of 35-40 and corrected visual and auditory impairment were included in the study. Individuals with neurological or musculoskeletal diagnosis that could account for imbalance or fall and history of more than two falls in the past six months were excluded from the study.

Instrumentation

Immersive virtual reality system:

IVR system is defined as an advanced form of human-computer interfaces which allows the user to immerse and interact in virtual environment that reflects real life experience. These computer interfaces provide immersion, simulation and interactions to participants in virtual interactive environments with a high degree of realism provided through the senses. In this study a computer based IVR system oculus quest 2 was used. The device consists of a wireless head mount which provides visual and auditory feedback which are updated continuously using head position and rotation. A wireless Joystick for both hands which provides tactile feedback and tracked through infrared cameras in the head mount. The IVR system can be handled by self or instructor and mirroring to external device is also possible. This device has many games which are task specific and progressively challenging.

Figure 1: Immersive virtual reality system

Berg balance scale:

BBS is a tool that primarily used to evaluate both static and dynamic aspects of balance including independent sitting, standing, transfers, reaches in all directions and single-leg standing. BBS has excellent test-retest reliability and interrater/intrarater reliability

(ICC=0.97)] [23,24]. It is a 14-item test with a five-point likert scale for each item that ranges from 0 to 4 with 4 denoting the greatest level and 0 denoting the lowest level the test can be finished in around 15 minutes.

Timed up and Go test:

TUG test is a simple outcome measure predominantly assesses the dynamic balance and likelihood of falls in the elderly population with excellent test-retest reliability (ICC = 0.97) [25,26]. The patient is asked to sit in the chair and then stand up, walks three meters at moderate speed, turns around, and then return to the chair and seat down. When the patient receives instructions, the clock begins, and it stops when they are seated back.

Multidirectional reach test:

The MDRT is a clinical assessment test that determines a person's maximum voluntary reach in the anterior-posterior and medial-lateral directions while they are standing with their feet and shoulder-width apart. MDRT has excellent test-retest reliability (ICC =0.75) and internal consistency [24,27]. When standing, while maintaining a fixed base of support, measure the distance between the length of maximum reached arm in forward, right, and left side.

The falls efficacy scale international:

FES-I is a simple tool for measuring fear of fall. A 16-item survey with a score ranging from a minimum of 16 which represents no fear of falling and to a maximum of 64 which represents severe fear of falling. FES-I has excellent test-retest reliability (ICC=.96) and internal consistency [28,29]. The participants are instructed to rate their level of fear about falling during an activity on a Likert scale of 1 to 4, with 1 representing no fear at all and 4 representing extreme fear.

PROCEDURE

Participants who met the inclusion criteria were assigned to either the IVR training group or conventional balance training group by lot method after receiving the informed consent. The baseline measurements of BBS for static balance, TUG for dynamic balance, MDRT for limits of stability and FES-I for fear of falls were taken.

The two groups underwent a 4-week program with three sessions per week. Each session consisted of 5 minutes of warm-up and 30 minutes of training. The conventional balance training group was trained with a combination of mobility, weight shifting, strengthening and multiple reach exercise. IVR training group was trained using IVR gaming using oculus quest 2 device. The games were task-specific and allow participants to move multidirectional. All participants were guarded by a physical therapist with a gait belt in the event of loss of balance. Adequate education about the device was given. The physical therapist handled the controls of the IVR device. A chair was available for rest periods if participants required a break. All safety precautions was taken to prevent the spread of COVID 19. After the 4 weeks program both the groups were assessed with same outcome measure.

IVR training

- Deep breathing exercise – 5reps/3 sets
- Neck, shoulder, elbow, hip, knee and ankle range of motion exercises – 10reps/set

Game	Description	Duration
First steps	Getting adapted to IVR headset and its controls	5 mins
Beat saber	Multiple goal-oriented reaches with arms	10 mins
Roller coaster	Trunk mobility with vestibular training	5 mins
FITXR	Multiple goal-oriented reaches with whole body movements	10 mins

Conventional balance training

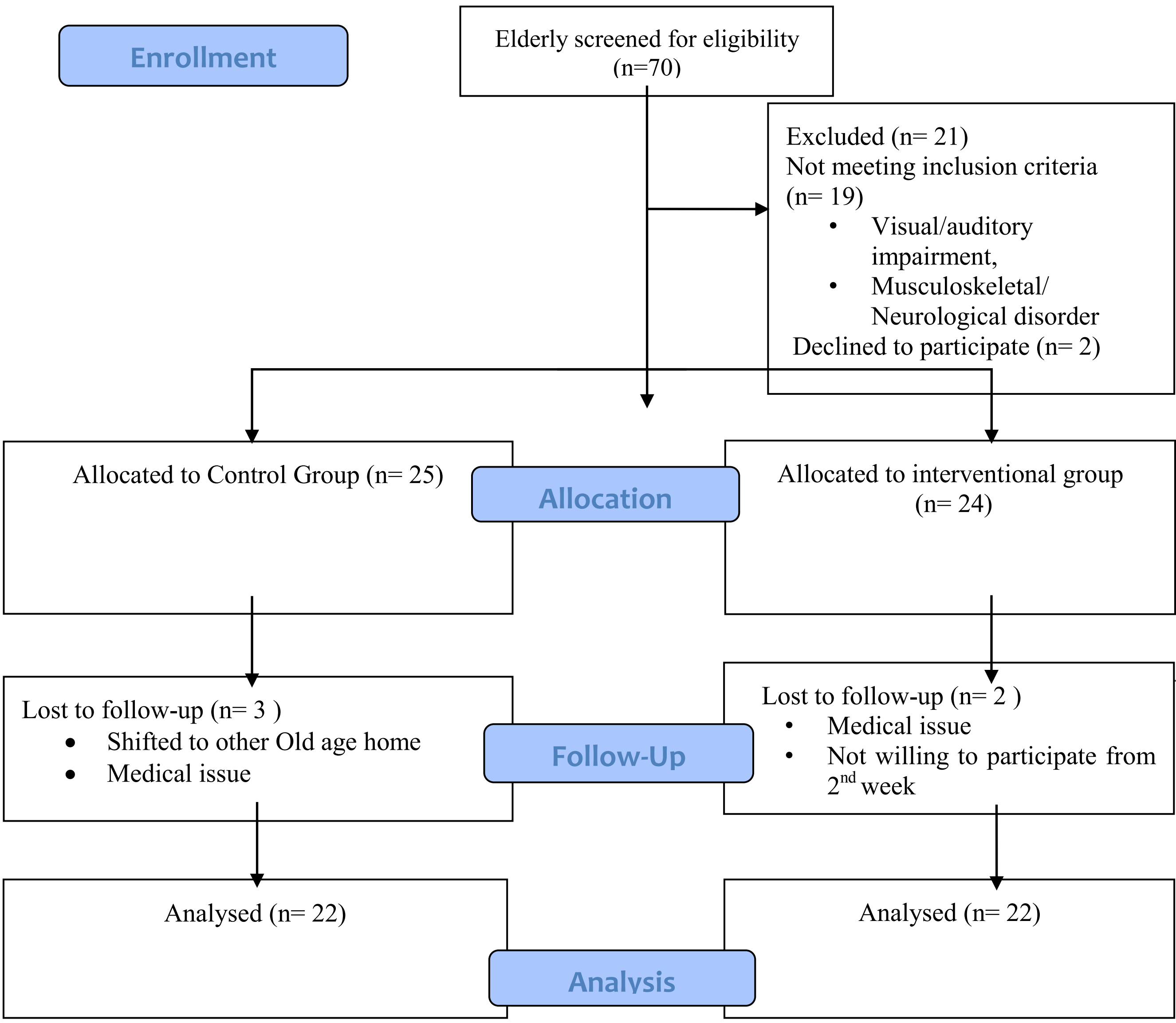
Exercise	Repetition
Deep breathing exercise	5reps/2 sets
Neck, shoulder, elbow, hip, knee and ankle range of motion exercises	10reps/set
Forwards and sidewards walking	10steps/2sets
Single leg standing	10counts/2sets

Sit to stand	10 reps/2sets
Multiple reaches in sitting and standing	10counts/2sets
Back leg raises with support	10counts/2sets
Side leg raises with support	10counts/2sets
Partial squatting with support	10counts/2steps
Tandem walking	10steps/2sets
Step up	10counts/2steps

Figure 2 and 3: Participant receiving IVR game based balance training

Figure 4 and 5: Participant receiving conventional balance training

Consort flow diagram



Ethical approval

This research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Ethics Committee of Sri Ramachandra Institute of Higher Education and Research (CSP/22/APR /109/309).

Informed consent

Informed consent has been obtained from the all individuals included in this study.

STATISTICAL ANALYSIS AND RESULTS

Statistical analysis was done with SPSS version 21.0. The values of BBS, TUG, MDRT and FES-I was used for data analysis. Paired t test was used to find out differences within the group and unpaired t test was used to find out differences between the groups.

In this study data from 44 participants were analysed, the baseline characteristics for each group are shown in Table 1. No significant between-group differences were found at baseline. Paired t test showed that conventional balance training group improved significantly in TUG and MDRT forward and IVR training group improved significantly in BBS, FES-I, MDRT forward, right and left at p<0.05. (Table 2) Unpaired t test showed IVR training group improved significantly in balance parameters such as BBS, MDRT forward, right, left and FES-I (p<0.05) than conventional balance training group except TUG. (Table 2)

Table 1 : Baseline characteristics

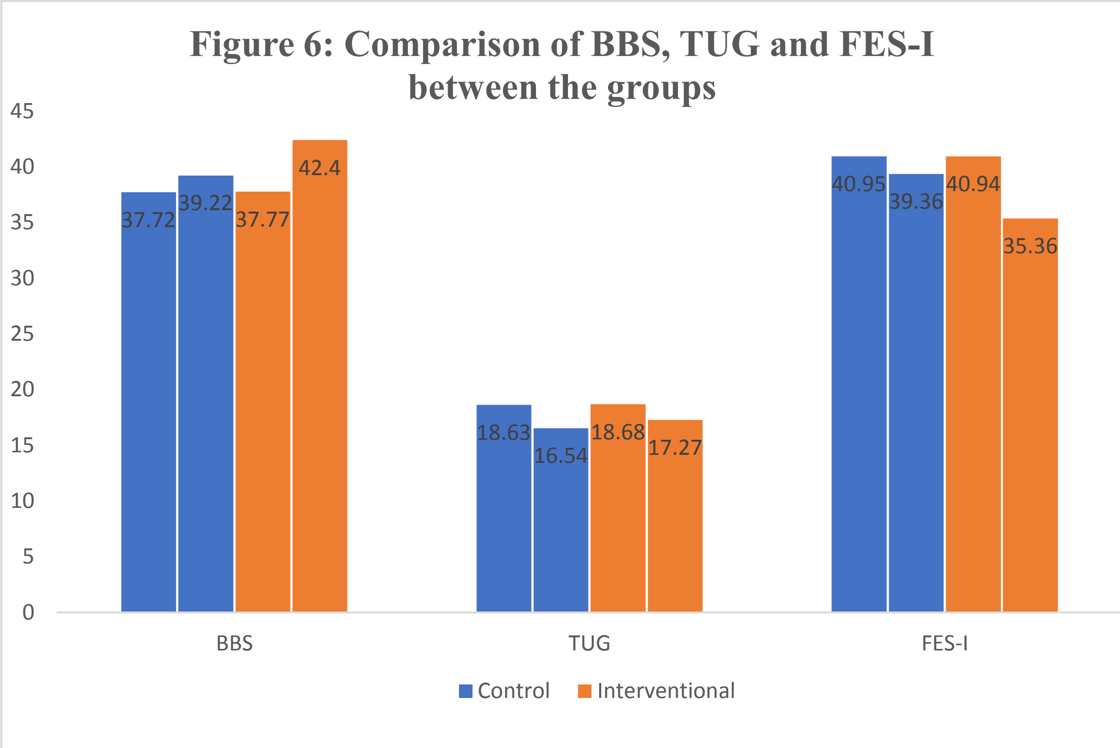
	MEAN CONTROL (SD)	MEAN INTERVENTIONAL (SD)
AGE	66.33(6.51)	69.44(6.66)
GENDER M/F	15/7	17/5
BBS	37.72(1.88)	37.77(2.11)
TUG	18.63(1.32)	18.68(2.27)
FES-I	40.95(1.70)	40.54(1.84)
MDRT FORWARD	5.52(1.31)	5.8(1.34)
MDRT RIGHT	5.08(1.11)	4.63(1.22)
MDRT LEFT	4.64(1.28)	4.24(0.98)

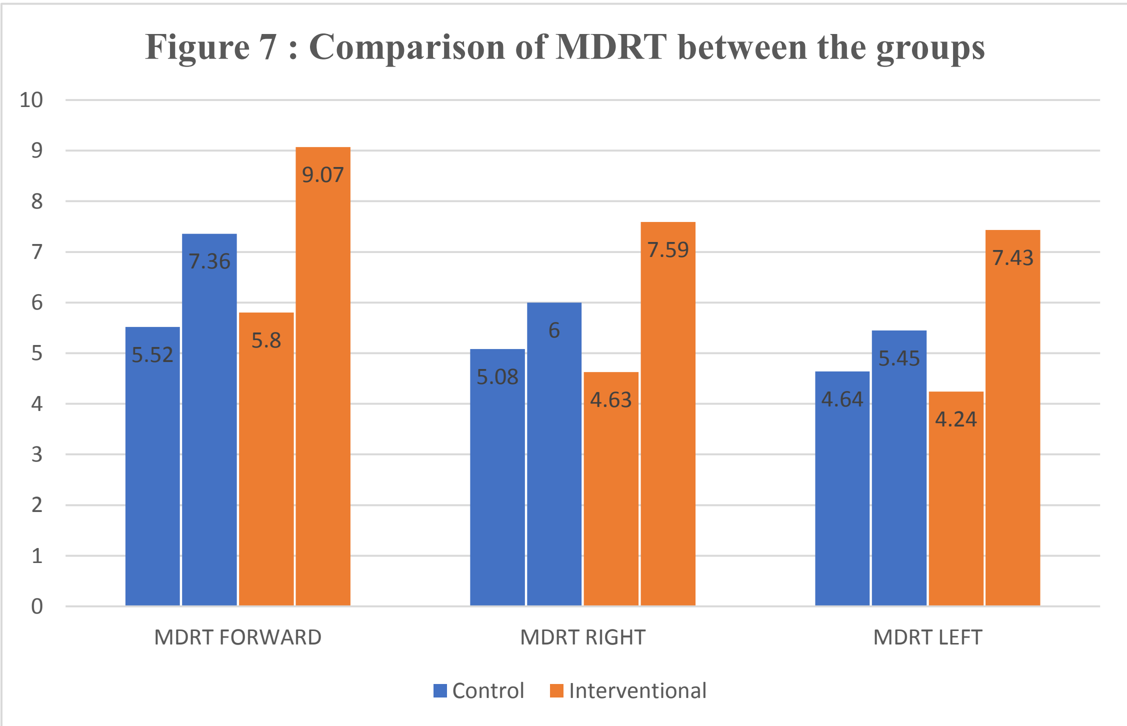
Table 2: Comparison of BBS, TUG, FES-I and MDRT within the groups and between the groups

Outcome	Within the groups						Between the groups
	Control (*n* = 22)			Interventional (*n* =22)			
	Pre Mean (SD)	Post Mean (SD)	*p* value	Pre Mean (SD)	Post Mean (SD)	*p* value	*p* value
BBS	37.72(1.88)	39.22(4.36)	0.746	37.77(2.11)	42.40(2.03)	<0.001*	0.003*
TUG	18.63(1.32)	16.54(1.71)	<0.001*	18.68(2.27)	17.27(2.62)	0.080	0.288
FES-I	40.95(1.70)	39.86(2.56)	0.093	40.54(1.84)	35.36(2.05)	<0.001*	<0.001*

MDRT FORWARD	5.52(1.31)	7.36(1.23)	<0.001*	5.8(1.34)	9.07(1.41)	<0.001*	0.001*
MDRT RIGHT	5.08(1.11)	6(1.87)	0.601	4.63(1.22)	7.59(0.95)	<0.001*	0.009*
MDRT LEFT	4.64(1.28)	5.45(1.52)	0.921	4.24(0.98)	7.43(0.88)	<0.001*	<0.001*

Paired and Unpaired t test p < 0.05* significant





eISSN 1303-5150

DISCUSSION

The consistency of the body in maintaining its line of gravity within the base of support continuously plays a vital role in preventing falls and serious injuries. VR is one of the most valuable applications with technology in the domain of rehabilitation playing an important role in rehabilitating physical and cognitive system [30]. In this study we have assessed the effectiveness of IVR on balance, fall and fear of fall in elderly population where 32 males and 12 females participated.

IVR system stresses the balance and multisensory sensory systems of body under safe and closely supervised environment which is not physically exhausting compared to usual balance training exercises. An additional advantage of this system is that they also train cognitive function by engaging the patient with entertainment value which motivates the elderly population to exercise regularly, effortlessly and effectively through IVR gaming. Participants in both the groups were trained with components which include progressive change in the base of the support, dynamic movements that changes the centre of gravity and strengthening to postural control muscles .

The IVR games demands and allows maximal use of active movements of all joints and muscles at higher rate which could have brought improvement in the muscle strength thereby balance in elderly population. The baseline mean BBS score of conventional balance training and IVR training group was 37.72 and 37.77 respectively which shows that they would have had increased risk of falls as shown by the study done by Viverio et.al, 2019 [31]. The post intervention value of BBS shows a change of 39.22 and 42.40 in conventional balance training and IVR training group respectively which shows a significant improvement in balance parameters ($p<0.05$) especially in components of standing unsupported, sitting to standing, transfers and reaching forward.

The minimal detectable change of BBS with an initial score of 35-44 in elderly population requires 5 points change as studied by Donoghue and stokes 2009. This true change in BBS scores is seen only in the IVR training group and this is concordance with the study done by Noorolla et.al 2021 where the participants were trained with non-immersive VR system which showed improvement in mean score of balance, as BBS was enhanced among elderly people after the intervention. The findings revealed that receiving visual feedbacks in virtual environment could lead to the increased awareness of their balance control and enhanced self- efficacy [9].

Limits of stability determines the maximal voluntary reach which is prerequisite for functional mobility and prevention of falls. Games played by the participants allowed them to stretch their limits of stability in all directions than of conventional balance training making the participant to train for their maximal potential. The baseline mean MDRT score of conventional balance training and IVR training group was 5.52 and 5.8 in forward, 5.8 and

4.63 in right and 4.64 and 4.24 in left respectively which shows that they have reduced limits of stability when compared to normative values for elderly population leading to fear of fall as denoted by the study Newton, 2001 [27]. Maximum difference was seen in MDRT forward when compared to normative values which could result in increased fear of forward reach with planned activities.

The post interventional mean MDRT score of conventional balance training and IVR training group shows a change of 7.36 and 9.07 in forward, 5.45 and 7.59 in right and 5.45 and 7.43 in left respectively which shows significant improvement in interventional group ($p<0.05$), thereby improved limits of stability in all directions which prevents fall episodes. This is supported by the study Holbein et.al 2007 which addresses limits of stability as valid indicator for the balance and fall risk which could be useful in predicting posture, movement and compensatory stepping reactions [24].

VR gaming gives real life experience with a continuous change in the direction, speed and spontaneity of movements which are mentally and physically challenging for the participants [32]. As a result, post training the participant achieves increased information processing, body balance control and increased confidence resulting in reduced fear of fall. FES-I scores has shown significant change in IVR training group from 40.54 to 35.36 ($p<0.001$) which could be due to reduced fear of fall, increased awareness of body and enhanced self-efficacy thereby improving functional well-being and active lifestyle in elderly population [33].

TUG test predominantly projects the dynamic balance which is found to be significant in conventional balance training than IVR training group which is probably due to gaming techniques. IVR games played by the subjects were confined to a specific diameter whereas the conventional balance training group were trained for walking in all directions which could have improved TUG values. A study done by Steven Phu et al., 2019 in older adults on VR showed similar improvements in balance parameter and fall risk as assessed with TUG and FES-I on both control and intervention group which is in contrast with the finding of this study [34].

IVR balance training in elderly population has shown better improvements in balance parameters such as BBS, MDRT and reduction in fall risk with FES-I. IVR training is a safe and well-accepted effective intervention with enjoyable option for elderly population that could become a successful intervention for falls prevention in elderly in the near future.

CONCLUSION

The findings of this study demonstrates potential benefits of IVR balance training which has shown improvements on balance parameters such as BBS, MDRT and reduction in fall risk with FES-I. IVR training is a safe and well-accepted effective intervention with enjoyable option for elderly population that could become a successful intervention for fall prevention in elderly in the near future.

Conflict of interest

The authors state no conflict of interest.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

REFERENCES

1. ELDERLY in INDIA 2021 [Internet]. Available from: https://mospi.gov.in/web/mospi/reports-publications.
2. Who falls fact sheet, Page 1 ageing and life course, family and community health who global report on falls prevention in older age, 2007.
3. Lord, S. R., Delbaere, K., & Sturnieks, D. L. (2018). Aging. *Handbook of clinical neurology*, *159*, 157–171. https://doi.org/10.1016/B978-0-444-63916-5.00010-0
4. Granacher U, Muehlbauer T, Gruber M. A qualitative review of balance and strength performance in healthy older adults: impact for testing and training. J Aging Res. 2012;2012:708905. doi: 10.1155/2012/708905. Epub 2012 Jan 23. PMID: 22315687; PMCID: PMC3270412.
5. Gschwind YJ, Kressig RW, Lacroix A, Muehlbauer T, Pfenninger B, Granacher U. A best practice fall prevention exercise program to improve balance, strength / power, and psychosocial health in older adults: study protocol for a randomized controlled trial. BMC Geriatr. 2013 Oct 9;13:105. doi: 10.1186/1471-2318-13-105. PMID: 24106864; PMCID: PMC3852637.
6. Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. Age Ageing. 2006 Sep;35 Suppl 2:ii37-ii41. doi: 10.1093/ageing/afl084. PMID: 16926202.
7. Manchester, D., Woollacott, M., Zederbauer-Hylton, N., & Marin, O. (1989). Visual, vestibular and somatosensory contributions to balance control in the older adult. *Journal of Gerontology, 44*(4), m118–m127. https://doi.org/10.1093/geronj/44.4.M118
8. Institute of Medicine (US) Division of Health Promotion and Disease Prevention. The Second Fifty Years: Promoting Health and Preventing Disability. Berg RL, Cassells JS, editors. Washington (DC): National Academies Press (US); 1992. PMID: 25144081.
9. Zahedian-Nasab N, Jaberi A, Shirazi F, Kavousipor S. Effect of virtual reality exercises on balance and fall in elderly people with fall risk: a randomized controlled trial. BMC Geriatr. 2021 Sep 25;21(1):509. doi: 10.1186/s12877-021-02462-w. PMID: 34563120; PMCID: PMC8465759.

10. Cadore EL, Rodríguez-Mañas L, Sinclair A, Izquierdo M. Effects of different exercise interventions on risk of falls, gait ability, and balance in physically frail older adults: a systematic review. Rejuvenation Res. 2013 Apr;16(2):105-14. doi: 10.1089/rej.2012.1397. PMID: 23327448; PMCID: PMC3634155.
11. Lesinski M, Hortobágyi T, Muehlbauer T, Gollhofer A, Granacher U. Effects of Balance Training on Balance Performance in Healthy Older Adults: A Systematic Review and Meta-analysis. Sports Med. 2015 Dec;45(12):1721-38. doi: 10.1007/s40279-015-0375-y. Erratum in: Sports Med. 2016 Mar;46(3):457. PMID: 26325622; PMCID: PMC4656699.
12. Justine M, Azizan A, Hassan V, Salleh Z, Manaf H. Barriers to participation in physical activity and exercise among middle-aged and elderly individuals. Singapore Med J. 2013 Oct;54(10):581-6. doi: 10.11622/smedj.2013203. PMID: 24154584.
13. Petrella AFM, Gill DP, Petrella RJ. Evaluation of the Get Active Questionnaire in community-dwelling older adults. Appl Physiol Nutr Metab. 2018 Jun;43(6):587-594. doi: 10.1139/apnm-2017-0489. Epub 2018 Jan 17. PMID: 29342366.
14. Laver KE, Lange B, George S, Deutsch JE, Saposnik G, Crotty M. Virtual reality for stroke rehabilitation. Cochrane Database Syst Rev. 2017 Nov 20;11(11):CD008349. doi: 10.1002/14651858.CD008349.pub4. PMID: 29156493; PMCID: PMC6485957.
15. Cao S. Virtual reality applications in rehabilitation. In: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). Springer Verlag; 2016. p. 3–10, DOI:10.1007/978-981-4560-52-8_2-1
16. Donath L, Rössler R, Faude O. Effects of Virtual Reality Training (Exergaming) Compared to Alternative Exercise Training and Passive Control on Standing Balance and Functional Mobility in Healthy Community-Dwelling Seniors: A Meta-Analytical Review. Sports Med. 2016 Sep;46(9):1293-309. doi: 10.1007/s40279-016-0485-1. PMID: 26886474.
17. Calabrò RS, Naro A, Russo M, Leo A, De Luca R, Balletta T, Buda A, La Rosa G, Bramanti A, Bramanti P. The role of virtual reality in improving motor performance as revealed by EEG: a randomized clinical trial. J Neuroeng Rehabil. 2017 Jun 7;14(1):53. doi: 10.1186/s12984-017-0268-4. PMID: 28592282; PMCID: PMC5463350.
18. Soltani P, Andrade R. The Influence of Virtual Reality Head-Mounted Displays on Balance Outcomes and Training Paradigms: A Systematic Review. Front Sports Act Living. 2021 Feb 9;2:531535. doi: 10.3389/fspor.2020.531535. PMID: 33634259; PMCID: PMC7902044.
19. Duque G, Boersma D, Loza-Diaz G, Hassan S, Suarez H, Geisinger D, Suriyaarachchi P, Sharma A, Demontiero O. Effects of balance training using a virtual-reality system in older fallers. Clin Interv Aging. 2013;8:257-63. doi: 10.2147/CIA.S41453. Epub 2013 Feb 28. PMID: 23467506; PMCID: PMC3588606.

20. Yeşilyaprak SS, Yıldırım MŞ, Tomruk M, Ertekin Ö, Algun ZC. Comparison of the effects of virtual reality-based balance exercises and conventional exercises on balance and fall risk in older adults living in nursing homes in Turkey. Physiother Theory Pract. 2016;32(3):191-201. doi: 10.3109/09593985.2015.1138009. Epub 2016 Apr 6. PMID: 27049879.
21. Ventura S, Brivio E, Riva G, Baños RM. Immersive Versus Non-Immersive Experience: Exploring the Feasibility of Memory Assessment Through 360° Technology. Front Psychol. 2019 Nov 14;10, https://doi.org/10.3389/fpsyg.2019.02509
22. Rendon AA, Lohman EB, Thorpe D, Johnson EG, Medina E, Bradley B. The effect of virtual reality gaming on dynamic balance in older adults. Age Ageing. 2012 Jul;41(4):549–52*doi:10.1093/ageing/afs053* *PMID: 22672915*
23. Conradsson M, Lundin-Olsson L, Lindelöf N, Littbrand H, Malmqvist L, Gustafson Y, Rosendahl E. Berg balance scale: intrarater test-retest reliability among older people dependent in activities of daily living and living in residential care facilities. Phys Ther. 2007 Sep;87(9):1155-63. doi: 10.2522/ptj.20060343. Epub 2007 Jul 17. PMID: 17636155.
24. Holbein-Jenny MA, Billek-Sawhney B, Beckman E, Smith T. Balance in personal care home residents: a comparison of the Berg Balance Scale, the Multi-Directional Reach Test, and the Activities-Specific Balance Confidence Scale. J Geriatr Phys Ther. 2005;28(2):48-53. PMID: 16236228.
25. Teresa Steffen, Megan Seney, Test-Retest Reliability and Minimal Detectable Change on Balance and Ambulation Tests, the 36-Item Short-Form Health Survey, and the Unified Parkinson Disease Rating Scale in People With Parkinsonism, *Physical Therapy*, Volume 88, Issue 6, 1 June 2008, Pages 733–746, https://doi.org/10.2522/ptj.20070214
26. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc. 1991 Feb;39(2):142-8. doi: 10.1111/j.1532-5415.1991.tb01616.x. PMID: 1991946.
27. Roberta A. Newton, Validity of the Multi-Directional Reach Test: A Practical Measure for Limits of Stability in Older Adults, *The Journals of Gerontology: Series A*, Volume 56, Issue 4, 1 April 2001, Pages M248 M252, https://doi.org/10.1093/gerona/56.4.M248
28. Yardley L, Beyer N, Hauer K, Kempen G, Piot-Ziegler C, Todd C. Development and initial validation of the Falls Efficacy Scale-International (FES-I). Age Ageing. 2005 Nov;34(6):614-9. doi: 10.1093/ageing/afi196. PMID: 16267188.
29. Dewan N, MacDermid JC. Fall Efficacy Scale-International (FES-I). J Physiother. 2014 Mar;60(1):60. doi: 10.1016/j.jphys.2013.12.014. Epub 2014 May 3. PMID: 24856947.
30. Hee CHo G, HwanGbo G, Soo SHin H. The Effects of Virtual Reality-based Balance Training on Balance of the Elderly, J Phys Ther Sci. 2014 Apr; 26(4): 615–617. Published online 2014 Apr 23. doi: 10.1589/jpts.26.615

31. Viveiro LAP, Gomes GCV, Bacha JMR, Carvas Junior N, Kallas ME, Reis M, Jacob Filho W, Pompeu JE. Reliability, Validity, and Ability to Identity Fall Status of the Berg Balance Scale, Balance Evaluation Systems Test (BESTest), Mini-BESTest, and Brief-BESTest in Older Adults Who Live in Nursing Homes. J Geriatr Phys Ther. 2019 Oct/Dec;42(4):E45-E54. doi: 10.1519/JPT.0000000000000215. PMID: 30407272.
32. de Vries AW, Faber G, Jonkers I, Van Dieen JH, Verschueren SMP. Virtual reality balance training for elderly: Similar skiing games elicit different challenges in balance training. Gait Posture. 2018 Jan;59:111-116. doi: 10.1016/j.gaitpost.2017.10.006. Epub 2017 Oct 5. PMID: 29028622.
33. Pua YH, Ong PH, Clark RA, Matcher DB, Lim EC. Falls efficacy, postural balance, and risk for falls in older adults with falls-related emergency department visits: prospective cohort study. BMC Geriatr. 2017 Dec 21;17(1):291. doi: 10.1186/s12877-017-0682-2. PMID: 29268720; PMCID: PMC5740922.
34. Phu S, Vogrin S, Al Saedi A, Duque G. Balance training using virtual reality improves balance and physical performance in older adults at high risk of falls. Clin Interv Aging. 2019 Aug 28;14:1567-1577. doi: 10.2147/CIA.S220890. PMID: 31695345; PMCID: PMC6717859.