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Original Research Article

Effect of exergaming-based balance training on short term memory and spatial cognition in healthy young adults: a randomized controlled trial

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ABSTRACT

Background: Physical exercises are crucial in cognitive functioning. Centres in brain responsible for balance function coincide with cognitive functions centres like short term memory and spatial cognition. Young population faces immense stress which causes cognitive deterioration. Conventional balance training has shown to have positive impact on cognitive functioning. Exergaming is a relatively new frontier which creates interest among young adults. Researchers speculated that stimulating the vestibular system during the training induces the changes of the hippocampus and the parietal cortex.
Methods: Seventy healthy young individuals participated. Participants were selected using inclusion and exclusion criterion and randomly divided in two equal groups using computerized randomization. Group A and Group B had Conventional and Exergaming based balance training protocol respectively, thrice a week for six weeks. Backward digit span test and perspective taking/ spatial orientation test (PTSOT) was used to assess pre and post intervention short term memory and spatial cognition respectively. Statistical analysis and conclusion were drawn.
Results: Both groups had statistically significant improvement in post intervention backward digit span scores (p value=0.000 in each). Although, no significant difference was observed between the groups. Similarly, both groups had statistically significant improvement in post intervention PTSOT (p value <0.0001 in Group A and p value 0.0006 in Group B). Although, no significant difference was observed between the groups.
Conclusions: Conventional and exergaming-based balance exercises are equally effective in healthy young individuals to improve spatial cognition.

Keywords: Balance, Short term memory, Spatial cognition, Exergaming, Cerebellum, Hippocampus

INTRODUCTION

Physical exercises have an impact on cognitive functioning of an individual[1]. Researchers are developing several new methods to improve neuroplasticity in the light of fast improving skills and technologies.[1] Aerobic exercise is one of the most common type of physical exercise which is studied over a period of time which proves to have a positive impact on cognitive functions as well as executive functions.[1]

Physical exercises like balance training provide stimulus to three major systems, namely – neuromuscular system, proprioceptive system and vestibular system[1]. The sense of balance is coded by the vestibular detection along with proprioceptive and visual signals. The links that are connected between the vestibular nuclei and the cerebellum, hippocampus as well as the prefrontal and parietal cortices provide information for several cognitive functions.[1] These include memory, navigation and spatial functions.[1]

Balance is one of the key elements that helps a person to maintain a stable posture for performing daily activitieswhilecounteractingtheexternalandinternalconflis. [1] Biomechanically, balance is defined as the process to maintain the Centre of Gravity within Body's Base of Support. Balance is controlled by the vestibular, auditory and the proprioceptive system. Balance is majorly controlled through the cerebellum and hippocampus[1].In humans, it has been proven that balance

Skills areas are associated with an increased volume of hippocampus, the basal ganglia, and frontal and parietal brain areas.[1] It has been hypothesized that an increased stimulation of the vestibular system during the self-motion may be an important mediator between physical exercise and cognitive functioning.

Short term memory (STM) refers to systems which provide retention of limited material for a short period of time(seconds).[2] Discrete brain areas support STM. It contributes to learning of new information and aspects. STM is an ability of the mind that is both enabled and constrained by the function and structure of neural circuits and systems.[2] The human hippocampal formation has an extensive role in various aspects of memory processing.[5]

Spatial cognition includes locating points in space, determining the orientation of lines and objects and also assessing the location in depth, appreciating geometric relationships and to process information in motion and depth too.[3] Tolman, in 1940's first studied the component. Yet, limited studies are conducted on short term memory and spatial cognition.

Although it is a broad area of inquiry that includes mind and brain organization, function and development.

A few human studies have pointed out to a direct relation between hippocampal size, Navigation and spatial memory. Spatial navigation crucially depends on preserved vestibular function, even when subjects are stationary[5].

A review considers the relationship between the vestibular system and memory and suggest that evolutionary age of this primitive sensory system as well as how it detects self-motion maybe reason for its unique contribution to spatial memory.[6]

Also, the vestibular system has anatomical connections to the medial-temporal lobe along with the parieto- temporal cortical networks.[7]

Exergame, video games are designed to improve overall health and body fitness. This is a relatively new frontier in the field of physical medicine and rehabilitation. This new approach utilizes the technology to create several interventions that are easy to access, cost effective and engaging for the participants.[10]

Amongst several devices one of the popular devices which is implemented in both clinical and research domains is Nintendo Wii Fit.[10]

Young population always demands more challenges and interesting activities to continue the rehabilitation protocol.[12]

Although limited studies have been done to evaluate the effect of exergaming Based balance training spatial cognition in healthy young adults.

Stress is an adaptive biological mechanism that enhances alertness to environmental demands and mobilizes coping resources. The stress mechanism gets activated by the perception of possible threats, which may arise due to excessive demands imposed on an individual. Chronic stress gives rise to elevation of glucocorticoids that damages brain structures, hippocampus and amygdala.[13]

Young population is the major productive population of the society. They have to be more efficient in their professional and personal lives too. Hippocampal atrophy due to stress thus leads to problems with higher cognitive abilities which includes short term memory and spatial cognition.[15-17]

Cognitive functioning in geriatric population is a major research topic of interest as there is deterioration of cognitive function as age advances.[17] Limited studies focus on young individuals.

Exergaming is a type of exercise where young population would indulge more and would be more interesting and challenging to them. There are limited studies done to understand the effect of exergaming Based balance training on short term memory and spatial cognition in healthy young adults.

Hence the need of the study arises.

METHODS

This study was an experimental research design in the form of a randomized controlled trial (RCT) conducted over a period of 1 years, from 24th November 2023 to 25th November 2024. The research targeted healthy young adults as the population of interest, with a total sample size of 70 participants. A convenience sampling method was employed for participant recruitment. The study was conducted at the Neurophysiotherapy Outpatient Department of Chaitanya Medical Foundation's College of Physiotherapy, Chinchwad, Pune.

Continues variable expressed as mean and SD. The data was initially explored to assess its distribution using the Shapiro-Wilk test. The results indicated that the data for the Backward Digit Span Test outcome was not normally distributed, whereas the data for the Perspective

Taking/spatial orientation test outcome was normally distributed. Based on these findings, appropriate statistical tests were applied. For the Backward Digit Span (BDS) test, the Wilcoxon Signed-Rank Test was used to assess within-group (pre/post) differences, and the Mann-Whitney U Test was used to evaluate between-group (pre/post) differences. In contrast, for the perspective taking/spatial orientation test, a paired t-test was employed to analyze within-group (pre/post) differences, and an unpaired t-test was used for between-group (pre/post) comparisons.

Materials

Wobble board, WII FIT device

Procedure

A total 70 healthy young individuals were selected using inclusion and exclusion criterion and randomly divided in two equal groups using computerized randomization. Group A and B were trained for thrice a week for six weeks. Backward digit span (BDS) test and perspective taking/ spatial orientation test was used as the outcome measure.

Inclusion criteria

Young adults aged between 18-22 years having a Stork Balance test score between 25-39 seconds and Backward Digit Span Test score between 3-7 were included in the study.

Exclusion criteria

Subjects who had fractures or had undergone any surgeries in past six months were excluded. Also. Participants with congenital deformities and who had previously played exergames were excluded.

Ethical clearance was received from the Ethical Board of the Chaitanya Medical Foundation's College of Physiotherapy, Pune.

Data collected from outcome measure: Backward digit span test and perspective taking/ spatial orientation test was entered into MS Excel and master chart was created.

The data was entered in Microsoft Excel in Microsoft Excel 2022. Microsoft: 2019 and analyzed using WINPEPI version 11.65 and Graph pad INSTAT version 3.05.

Protocol

Group A: Conventional balance exercise

Tandem standing on firm surface with eyes open – 30 seconds and 3 repetitions.

Tandem standing on firm surface with eyes closed – 30 seconds and 3 repetitions.

Unilateral standing on firm surface with eyes open- 30 seconds and 3 repetitions Unilateral standing on firm surface with eyes closed – 30 seconds and 3 repetitions Standing with narrow base of support with eyes open on wobble board – 30 seconds and 3 repetitions. Standing with narrow base of support with eyes closed on wobble board – 30 seconds and 3 repetitions.

Tandem standing on wobble board with eyes open – 30 seconds and 3 repetitions. Tandem standing on wobble board with eyes closed – 30 seconds and 3 repetitions. Unilateral standing on wobble board with eyes open – 30 seconds and 3 repetitions Unilateral standing on wobble board with eyes closed – 30 seconds and 3 repetitions

Group B: Exergaming

Exergaming

Using WIIFIT device Balance training protocol will be given to the subjects.

Three Balance games will be played by the subjects and each game will be played three times per session.

Following are the games

Table tilt

Subject will be asked to stand on the balance board that is paired with the WII fit device. Subjects have to balance themselves by maintaining the COG over the BOS. They have to put the balls shown on the screen in the holes given for it. Lateral and forward backward shifts will be used to maintain the balance and complete the task. It is a time-based game.

Tightrope

Subject will be asked to walk in a straight line. A rope will be displayed the screen. Person has to cross the two buildings walking on the rope. If he/she fails to balance, the person on screen falls down. It concentrates mainly on maintaining the COG over the BOS.

Penguine slide

It is a game that majorly concentrates on the lateral balance of an individual. Person has to stand on the board paired with WIIFIT and has to catch the fishes given on screen. Truncal activity is a major component to complete this task. It is a time-Based game.

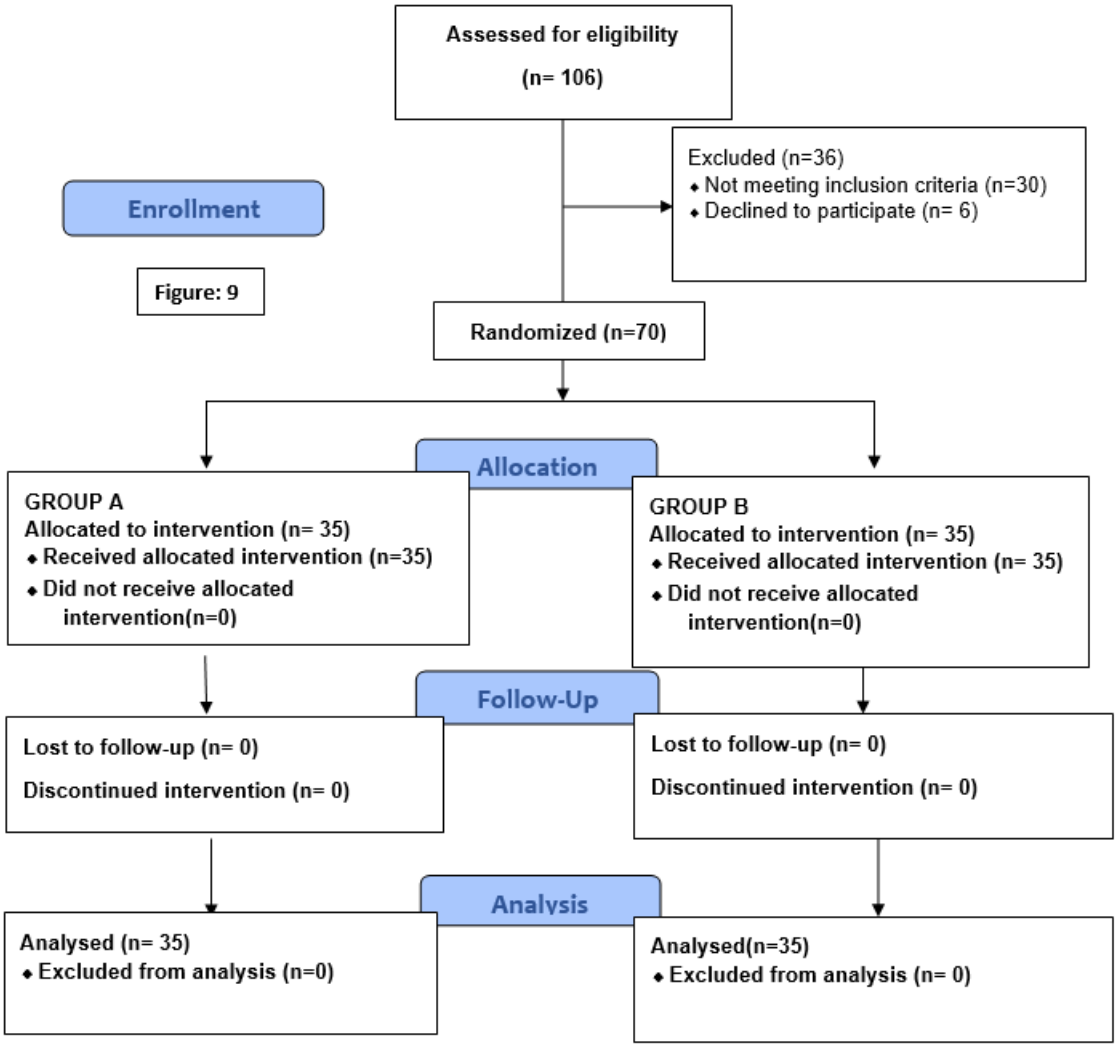

Figure 1: CONSORT diagram.

RESULTS

Short term memory

In Group A, the mean score increased from 3.86 (Pre) to 4.94 (Post). T value of 7.2424 with a p value less than 0.0001, was achieved indicating that the improvement was statistically significant.

Similarly, Group B, the mean score increased from 3.80 (Pre) to 4.89 (Post). Group B yielded a T value of 6.7549 and a p value less than 0.0001, also indicating a statistically significant improvement.

To compare the magnitude of improvement between the two groups, a test was conducted on the difference in mean change scores. The result showed a difference of mean equal to 0, with a T value of 0 and a pP value of 1, suggesting that there was no statistically significant difference in improvement between Group A and Group B.

This shows that both interventions are equally statistically significant.

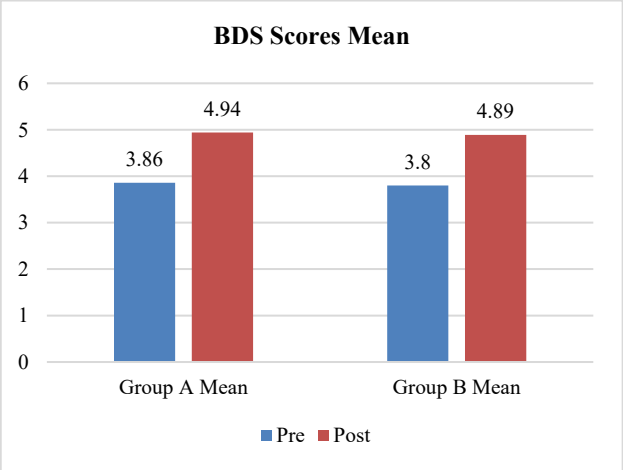

Figure 2: Mean values of BDS scores.

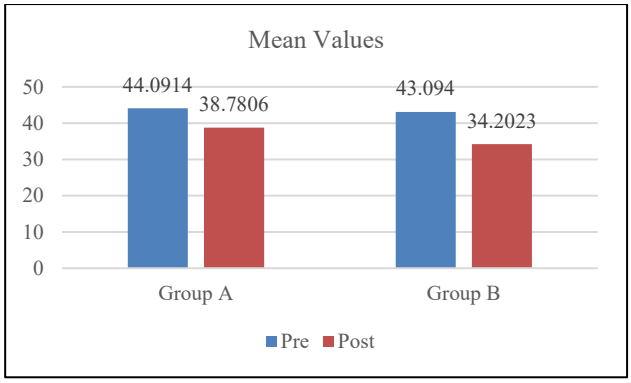

Figure 3: Mean degree of error of perspective taking/spatial orientation test.

Figure 4: Tandem standing eyes open/closed.

Figure 5: Unilateral standing eyes open/closed.

Figure 6: Narrow base on wobble board eyes open/ closed.

Figure 7: Tandem standing on wobble board eyes open/ closed.

Spatial cognition

In Group A, the mean score decreased from 44.0914 (Pre) to 38.7806 (Post). T value of 7.2520 with a p value less than 0.0001, was achieved indicating a statistically significant decrease in scores.

Figure 8: Unilateral standing on wobble board eyes open/ closed.

Figure 9: Exergaming based balance training protocol.

In Group B, the mean score also decreased from 43.0940 (Pre) to 34.2023 (Post). This change was likewise statistically significant, with a t value of 3.7980 and a p value of 0.0006.

To assess whether the magnitude of change between the two groups was significantly different, a comparison of mean differences was performed. The difference of mean change was 3.5831, with a T value of 1.4622 and a p value of 0.1483. This indicates that the difference in improvement between Group A and Group B was not statistically significant.

This shows that both interventions are equally statistically significant.

DISCUSSION

The purpose of this study was to find the effect of exergaming-based balance training on short-term memory and spatial cognition in healthy young adults. Various studies have proved that a systematic protocol of physical activity can help to improve cognitive function. Concentration, attention, and memory, along with academic and employee performance, are strongly associated with physical activity.[27] Although previous research has highlighted the importance of physical activity, adults have adapted to a more sedentary lifestyle. This technology-driven lifestyle, along with increasing stress, leads to harmful impacts on cognitive centers in the brain, namely the hippocampus. This creates the need for interesting interventions that can motivate young adults to be physically active.[27-29]

Balance and cognitive domains like memory and spatial cognition are mainly controlled by the prefrontal cortices, parietal cortices, and the hippocampus. Recent articles state that there is a positive correlation between balance and hippocampal volume.[30]

Stress levels in young adults have increased exponentially compared to past decades. This negatively impacts the cognitive centers of the brain. The influence of stress has been related to stress-induced activation of both the hypothalamus–pituitary–adrenal axis (HPA-axis) and the sympathetic nervous system (SNS). The release of cortisol, the end product of HPA-axis activity, and several SNS biomarkers (e.g., catecholamines) can influence cognitive processes.[31,32]

In this study, participants were enthusiastic about the exergaming training protocol compared to the conventional exercise group. This finding aligns with Prensky (2001), who stated that young adults demand interesting activities to complete exercise regimens. Exergames could serve as a significant alternative. As digital natives, young adults show greater enthusiasm and intrinsic motivation when using devices.[33] Studies have demonstrated that different games can be helpful for cognitive stimulation. The interactive dynamics of play and exercise engage young adults effectively. Active video games or exercise-based games can be a novel strategy to increase physical activity levels in young adults.[34]

Exergames-based balance exercises have recently gained significant importance. A study by Peter C in 2012 concluded that exergaming has both psychological and physiological benefits and may be used in young adults as an alternative to traditional aerobic exercise.[35] Another

study concluded that there is improvement in balance and strength, but not in somatosensory measures, using the Wii Fit device.[36] Similarly, Roopchand et al found significant improvements in Berg Balance Scale scores ($p=0.004$), star excursion balance test scores ($p<0.001$ both legs), and multidirectional reach test scores ($p=0.002$) after 6 weeks of Wii Fit training. However, no significant change was seen in the modified clinical test for sensory integration in balance.[37]

Thus, Wii Fit appears to be an enjoyable exergame for adolescents and adults, stimulating light-to-moderate intensity activity while modifying typically sedentary leisure behaviour.[38] The present study also shows significant improvement in short-term memory and spatial cognition in healthy young adults in both groups (conventional and exergaming) who underwent balance training. These results align with Stroth et al who found a significant increase in visuospatial memory performance and positive affect after an exercise protocol, concluding that physical activity regimens can improve visuospatial memory.[39]

Exergames, video games, and game-based exercises yield better results due to higher adherence among young participants. In exergames, the reward system motivates and engages individuals, making the Wii Fit device a potentially significant tool for cognitive improvement. Previous studies in elderly individuals (Taheri et al, Langoni et al) also found improvements in psychomotor performance, cognitive functions, endurance, and balance through exercise and exergaming interventions.[40] Collectively, these findings support the view that cognitive improvement is directly proportional to physical activity.

According to past studies, the benefits of exercise may lead to neurophysiological alterations such as increased hippocampal volume, Gray matter, and brain tissue plasticity. Balance training stimulates compensatory reactions, which involve selective attention and information processing speed. Short-term plasticity is known to support both memory and attentional functions, and may even serve as a prerequisite for perceptual learning. Thus, balance, strength, and dual-task training are all helpful in improving cognitive functions and daily living skills.

Physical and cognitive components are essential for balance across all age groups. Shubert et al. concluded that multicomponent exercise programs that include strength, aerobic, and balance training yield positive outcomes on both cognition and physical health.[47] With technological advancements, exergaming approaches have become increasingly relevant for adolescents and young adults.

In the present study, both proactive (conventional training) and reactive (exergaming training) balance strategies showed significant improvements. Proactive training used feedforward mechanisms, where participants made corrections before stepping on the wobble board, while reactive training used feedback mechanisms, where corrections were made after feedback from the screen. This explains why both groups showed similar post-intervention results.

Executive functions, supported by frontal lobe structures, are particularly sensitive to aging and stress. Shrinkage of medial temporal lobe structures has been observed not only in older adults but also in middle age. Some studies indicate episodic memory decline starting as early as the second decade of life. The relatively lower pre-intervention scores in this study align with such findings. Since young adults' neuronal circuitry is still developing, their executive and hippocampal functions may be more responsive to exercise interventions. This explains the improvements seen in short-term memory and spatial cognition following balance training.

Thus, it is evident that balance training helps to improve short-term memory and spatial cognition in healthy young adults. Both proactive and reactive balance training approaches were effective, though future research could compare identical training modes for clearer outcomes.

A limitation of this study was that the carryover effect of the training was not analyzed.

CONCLUSION

Physical exercises like balance training helps to improve short term memory and spatial cognition. Conventional and Exergaming Based Balance Exercises are equally effective in healthy young individuals to improve short term memory and spatial cognition.

Clinical implication

Thus, young adults should always indulge in physical activities so as to maintain their cognitive abilities.

Future scope

Long term implication of Balance training on cognitive functions could be analyzed. Comparison between genders could be done.

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