Efficacy of Wii Balance Board based Exergame Training among individuals with Cerebellar Ataxia: A Feasibility Study

Sayan Pratihar[1*], Karthiga Rajasekaran[1], Shanmuga Priya Raji Reddy Parasuraman[1]

1. SRM College of Physiotherapy, Faculty of Medicine & Health Sciences, SRM Institute of Science and Technology , Chennai, Tamil Nadu, India.

***Corresponding Author:** Sayan Pratihar, SRM College of Physiotherapy, Faculty of Medicine & Health Sciences, SRM Institute of Science and Technology , Chennai, Tamil Nadu, India. Email: pratiharsayan0@gmail.com

ORCID ID: https://orcid.org/0009-0008-7378-0366

ABSTRACT

BACKGROUND: Conventional rehabilitation methods have shown limited and transient improvements, necessitating personalized approaches in the diverse population of Cerebellar Ataxia. Wii Balance Board exergame training, integrating physical exercise with interactive video games, presents a novel and engaging neuro-rehabilitation strategy.

OBJECTIVES: The primary objective of this study was to assess the clinical feasibility of implementation of Wii Balance Board-based exergame training among individuals with various forms of Cerebellar Ataxia. The secondary objective was to investigate the preliminary efficacy, and assess the enjoyment of the intervention.

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METHODS: The study incorporates a pilot randomized control trial and feasibility study design. We recruited 10 patients using a block randomization method. The Wii Balance Board training was administered for 18 sessions, 3 sessions per week, till 6 weeks. The primary outcomes of feasibility testing were evaluated through clinical research log documentation, while secondary outcomes of balance, ataxia severity rate, functional independence and enjoyment were assessed with mini-BESTest, SARA, FIMs and EEQ. Data were analyzed using descriptive statistics and non-parametric tests to evaluate changes in outcomes.

RESULTS: The study enrollment rate was 77% (n=10). The Wii intervention group showed a 100% (n=5) retention rate compared to 80% (n=4) in the control group. The Wii intervention group demonstrated a tendency towards better outcomes at follow-up in SARA (p=0.063, effect size/R_M =0.84) and Mini-BESTest (p=0.071, effect size/R_M =0.79) but not in the case of FIM (p=0.794, effect size/R_M =0.14), along with reported a moderate level of enjoyment.

CONCLUSION: Wii Balance Board based-exergame training is considered feasible for implementation in clinical settings among individuals with various forms of Cerebellar

Ataxia, that suggesting the conduction of a larger definitive study to further explore the intervention efficacy.

KEYWORDS: Balance, Cerebellar Ataxia, Exergames, Virtual Reality rehabilitation, Wii Balance Board.

INTRODUCTION

Cerebellar Ataxia includes a range of disorders that cause problems with coordination, balance, and motor control, which can severely affect the quality of life for individuals experiencing these issues [1]. Cerebellar Ataxia (CA) is categorized into three main types: acquired, degenerative nonhereditary, and inherited. The inherited forms include autosomal recessive (ARCA), autosomal dominant (ADCA), and X-linked ataxias [2]. Hereditary ataxia affects about 2.7 out of every 100,000 people for autosomal dominant hereditary cerebellar ataxia (AD-HCA) and around 3.3 out of every 100,000 for autosomal recessive hereditary cerebellar ataxia (AR-HCA) [3]. Spino-Cerebellar Ataxia (SCA) type 12 and type 2 are more frequently found in the northern regions of India. In contrast, SCA type 1 is predominantly seen in the southern part of the country [4].

An ataxic patient often struggles with their functional disabilities that further challenging their social-economic life [5]. They experience progressive loss of functional independence due to frequent falls, requiring long-term rehabilitation and care-giving. This imposes considerable impact on their families, increasing both emotional and financial stress. Additionally, the costs associated with medical care, assistive devices, and therapy can be substantial, while the disease's disabling nature often leads to reduced workforce participation and productivity. Studies across different countries have reported substantial annual costs per ataxia patient, ranging from €18,776 in Spain to HKD 146,832 (for 6 months) in Hong Kong [6–8].

Several current treatment approaches for Cerebellar Ataxia including standard care physiotherapy methods, vestibular rehabilitation, intensive physiotherapy and other advanced techniques like r-TMS have demonstrated varying degrees of effectiveness. However, these methods often face challenges such as limited accessibility, high resource demand, and inconsistent adherence [9–11]. Moreover, conventional rehabilitation approaches for Cerebellar Ataxia frequently lack individualized interventions tailored to patient-specific needs, which are critical for optimizing rehabilitation outcomes [12].

The combination of physical exercise and interactive video games in exergame training offers a novel, distinctive and engaging approach to neuro-rehabilitation [13]. With advancements in technology, the cost-effective Wii Balance Board based exergame training provides real-time feedback on balance and posture, making it an effective rehabilitation tool for individuals with Cerebellar Ataxia [14].

Despite its potential, prior studies emphasized the need for extended monitoring to fully understand the long-term benefits of exergame training programs [15,16]. Furthermore, recent studies frequently lack patient-specific adaptations and personalized feedback mechanisms or enjoyment by involving Wii Balance Board-based exergame training, which could significantly enhance therapeutic outcomes[17].

It is also necessary to include outcome measures that encompass not only motor enhancements but also take into account the functional status experienced after involving in exergame training [18]. On the other hand, the feasibility and long-term efficacy of implementing Wii Balance Board-based exergame training in clinical settings remain underexplored under the wide range of Cerebellar Ataxia types induced by various pathophysiological factors [19].

A major challenge in researching therapeutic interventions for Cerebellar Ataxia is the heterogeneity of the patient population, which includes various inherited and non-inherited forms with differing aetiologies, progression rates, and severity levels. This diversity can confound study outcomes, making it difficult to isolate the effects of specific interventions[20]. Furthermore, conducting large-scale trials on such varied groups can be ethically and logistically challenging especially for innovative interventions like Wii Balance Board-based exergame training, particularly when different pathological mechanisms may respond differently to the same treatment [21].

Given these complexities, there is a critical need to first evaluate the feasibility and safety of using Wii Balance Board exergame training in a more controlled yet diverse group of cerebellar ataxia patients. Conducting a pilot feasibility study would allow us to address these challenges on a smaller scale, ensuring that the intervention is practical and acceptable before committing resources to a larger, more definitive trial.

The primary objective of this study was to assess the clinical feasibility of implementing Wii Balance Board-based exergame training in clinical settings for the individuals with different types of Cerebellar Ataxia. The secondary objective was to investigate the preliminary efficacy of the Wii Balance Board training intervention in terms of improving balance, ataxia severity rate, and functional Independence. Furthermore, the study also sought to assess the degrees of enjoyment experienced by individuals from Wii Balance Board-based exergame training.

MATERIALS AND METHODS

1. Study Design and Randomization: This study utilized a pilot randomized control trial (parallel arm) and feasibility study design with limited statistical power (as per the assumption of a 10%-15% rate of actual power calculated sample of 86 using a two-tailed Laplace distribution at α=0.05, power (1-β) = 80%, effect d= 0.5) involving the experimental group (EG) or Wii Balance Board training group and a control group (CG). An independent researcher implemented a 1:1 allocation ratio for the group allocation. The recruitment procedure employed a block randomization approach with a block size of 4 and a numerical sequence. A computer-based random allocation software was used to execute the randomization, which was produced by an independent researcher who was not affiliated with the trial and had no involvement in its conduct. The computerized database concealment was adhered to until the intervention started. The original group allocation was concealed from the outcome assessor, who was a field expert and involved in this study. Due to limited sample size, stratification could not be performed. However, block randomization ensured balanced allocation of key demographic across groups. Baseline characteristics were compared to assess any residual imbalances. The study follows to the CONSORT 2010 guidelines for the reporting of a pilot and feasibility trial [22].

The inclusion criteria of the study were specified as follows: 1.) both males and females aged 30-60 years. 2.) The condition of Cerebellar Ataxia was diagnosed by a neurologist. 3.) Participants who could stand and ambulate independently or with the use of mobility aids such as a cane or walker. 4.) Participants who visually could observe a display screen. 5.) Participants who could comprehend the therapist's instructions and conversation. 6.) The Mini-Mental State Examination (MMSE) score is considered as 24 or higher. 7.) No previous VR-based rehabilitation training experience.

The study's exclusion criteria encompassed the following: 1.) Individuals with amputations wearing prosthetic devices at their lower limbs. 2.) Any congenital anomalies impacting the lower extremities and spine. 3.) Experience of any recent injuries, back pain, or serious joint disorders to lower limbs that would make it difficult for weight bearing and stand upright. 4.) History of pre-existing vestibular disorders, receptive aphasia and global aphasia. 5.) Sensory Ataxia. 6.) History of psychological disorders. 7.) History of peripheral neuropathy. 8.) Previous occurrence of epilepsy or seizure. 9.) Pregnant women. 10.) Previous medical history includes severe cardiovascular conditions and respiratory ailments.

2. Participants, Screening and Enrollment: We concentrated both the individuals who sought medical care as out-patients at the Neurology OPD and those who were hospitalized as in-patients in the Neurology ward at SRM Medical College Hospital and Research Centre (SRM MCH&RC) in Chennai, India. Between November 2023 and January 2024, 13 Cerebellar Ataxia patients were screened for eligibility in the Neurology department. Two participants did not meet the inclusion criteria, and one was excluded based on exclusion criteria. Finally, 10 patients successfully enrolled in the study (Figure 1 illustrates participants' flow chart). Of these, six had ataxia originated from cerebellar stroke, two had ataxia induced by metabolic causes (hypothyroidism, Wilson disease), and two had inherited ataxia (Friedreich's Ataxia, SCA-1). The experimental group included three cerebellar stroke cases, one metabolic ataxia case (hypothyroidism-induced ataxia), and one hereditary ataxia case (SCA1), while the control group had a similar enrollment of three cerebellar strokes, one metabolic ataxia case (Wilson disease-induced ataxia), and one hereditary ataxia case (Friedreich's Ataxia).

As shown in Table 1 (demonstrating participants' demographic characteristics), the groups were generally matched across key influential variables, including age, sex, cognition status (MMSE scores), types of ataxia, ataxia severity (SARA scores), balance impairment (mini-BESTest scores), and functional independence (FIM scores). Minor differences observed in age and balance impairment baseline values, although these differences fall within overlapping range of both groups, baseline statistical analysis (Table 1) suggesting no significant imbalance between the groups. Furthermore, other key variables, such as sex distribution, cognition status (MMSE scores), and types of ataxia, were evenly distributed across groups. Given the pilot nature of this feasibility study, these differences are unlikely to bias the outcomes or affect the study's primary aim of evaluating feasibility and acceptability of the intervention [23].

3. Ethical Consideration: This study was approved by the SRM Institutional Ethical Committee (Approval No: SRMIEC-ST0523-657) and conducted in accordance with the ethical standards of the Declaration of Helsinki. Prior to enrolment, all eligible participants provided written informed consent after receiving detailed explanations about the study's purpose, procedures, potential risks, and benefits. They were informed of their right to withdraw from the study at any point without consequences. To ensure participant confidentiality, all personal and clinical data were anonymized and securely stored accessible only to authorized researchers. Precautions were taken to protect the well-being of the participants, including careful monitoring during interventions and immediate access to medical care if required.

Additionally, this study was prospectively registered on the Clinical Trial Registry of India (ctri.nic.in) with the registration number CTRI/2023/11/059589.

4. Intervention: The exergame training took place in a 150 sq. ft. room at the Department of Physical Medicine & Rehabilitation (SRM MCH&RC); using the Nintendo® Wii and Wii Balance Board connected to a projector (Figure 2 shows Wii Balance Board training). The Experimental Group (EG) underwent 18 sessions over 6 weeks, with 3 sessions per week, each session lasting 20 minutes. Participants played four Wii Fit Plus standing balance games (table tilt, ski slalom, tightrope walk, soccer heading) at different difficulty levels (beginner, advanced, professional), with a 1-minute rest period between games. Hemodynamic status (like blood pressure, heart rate, respiratory rate, SPO_2) was monitored before and after every training session to safeguard against the occurrence of any unwanted harmful cardiovascular events. Each training session included a 2-minute warm-up and 2-minute cool-down period. A 30-minute practice session was scheduled for all the EG participants to understand the concepts of game control before starting their training session. Assistive devices (like a cane and walker) were available during the training sessions for safety holding, though participants were encouraged to minimize the use of those aids as much as possible. Additional two therapists' support was imposed to prevent falls throughout the training sessions. Alongside the exergame training, the participants in the EG also received routine physiotherapy treatments such as upper and lower limb strengthening exercises using thera-band, equilibrium and non-equilibrium coordination exercises, parallel bar gait training inside the same intervention setting for the duration of 20 minutes in each session. The CG participants received standard standing balance training on a wobble board, thera-band strengthening exercises for upper and lower limbs, coordination exercises, and parallel bar gait training for 40 minutes at the frequency of 3 sessions per week till 6 weeks in a usual care setting at the Department of Physiotherapy (SRM MCH&RC). During the study period participants were not constrained to other treatment programs related to their health conditions either outside the study settings or inside the study hospital due to ethical concern.

5. Outcome Measures: The primary outcome of feasibility testing was measured with the recruitment capability and retention rate, treatment-specific compliance rate, adherence rate, and adverse events through clinical research log-book documentation. We used the Pragmatic Explanatory Continuum Indicator Summary scores of the trial domain or PRECIS-2 tool to evaluate the pragmatic versus explanatory nature and the applicability of our pilot feasibility study design [24,25]. The secondary outcome measures of balance, ataxia severity rate and functional independence were measured by the mini version of Balance Evaluation System Test scale or mini-BESTest scale [26], Scale for Assessment and Rating of Ataxia (SARA) [27–29] and by the Functional Independence Measure scale (FIMs) [30]. At first, the outcomes were measured at the Baseline (T_0) during recruitment of samples, and next the post-test (T_1) assessments were conducted following the completion of either the minimum required training session or more as per prescribed sessions (adhering to a 70% benchmark adherence rate guideline for total training sessions participation to ensure feasibility generalization [31]. A follow-up assessment (T_2) was also taken after 4 weeks of the post-test (T_1) assessments. The additional secondary outcome regarding the patient enjoyment, experience and satisfaction from Wii Balance Board training was evaluated by a patient self-reported measures-Exergame Enjoyment Questionnaire or EEQ, after the completion of the trial.

6. Data analysis: We performed the statistical data analysis with IBM® SPSS® version 27 software. The non-parametric Friedman test was employed to evaluate changes in outcomes over time within each group across three-time points. Post hoc pairwise comparisons were conducted using the Wilcoxon signed-rank test, with a Bonferroni correction applied to adjust for multiple comparisons. The Mann-Whitney U test was used to compare differences in outcomes between the experimental and control groups at each time point. Effect sizes (R_W, R_M) were calculated to determine the magnitude of the difference between groups. Data regarding usefulness was analyzed using descriptive methods.

RESULTS

1. Feasibility outcomes:

Numbers of Cerebellar Ataxia patients were screened month-wise as follows; 7 patients in Nov 2023, 3 patients in Dec 2023, and 3 patients in Jan 2024. Recruitment for this study was started on 20 November 2023, and the final baseline assessments were completed on January 19, 2024. The outcome assessments were conducted from 12 February 2024 to 30 March 2024. The rate of enrolment for qualifying screens was 77% (n=10 qualified for successful enrolment into groups among 13 screened patients). The percentage of participants who both enrolled and attended at least one session was 100%. The mean attendance of our participants over the period of six-week intervals was 14 sessions (n=5, range=13-18) out of a total of 18 training sessions in the experimental group (EG). Four participants successfully completed the minimum required 13 or more consecutive Wii Balance Board training sessions along with the required assessments, meeting the benchmark adherence rate of 70% to the total number of sessions in a pilot study [31]. In contrast, only one participant in the EG successfully finished all of the designated sessions and assessments. In the control group (CG), four participants completed the minimum required training sessions, although nobody could complete all the training sessions. One individual in the CG withdrew from the study during the ongoing trial and did not attend the post-trial assessments as well as follow-up visits due to having personal issues. The experimental group didn't have any dropouts. The treatment-specific retention rate in the experimental group was 100% (n=5), while the control group had a retention rate of 80% (n=4). The proportion of planned assessments that were completed in this study remained 100% for the experimental group while it was 90% for the control group. The average duration to complete total assessment visits per participant was around 45 minutes in both groups. The compliance rate for the Wii Balance Board training varied depending on the difficulty levels of the specific exergame. At the beginner level, the compliance rates were as follows: *GAME I = 91%, *GAME II = 90%, *GAME III = 77%, *GAME IV = 78%. At the advanced level, the compliance rates for GAME II, GAME III, and GAME IV were 82%, 52%, and 82% respectively. At the professional level, the compliance rate in Game III was 48%. (Table 2 elaborate gameplay related events)

$$\left[\text{Formula for calculation of treatment specific compliance rate} = \frac{Estimated\ Nos.\ of\ actual\ playing\ attempts\ at\ various\ levels\ of\ specified\ games\ in\ Wii\ Balance\ Board\ training\ sessions}{Total\ prescribed\ playing\ attempts\ for\ the\ individual\ games\ in\ Wii\ Balance\ Board\ training\ sessions} \times \right.$$

[*GAME I = Table tilt, GAME II = Ski slalom, GAME III = Rope walk, GAME IV = Soccer heading]

The PRECIS-2 or Pragmatic Explanatory Continuum Indicator Summary (PRECIS-2) scores of trial domains for our study indicate a predominantly pragmatic (reflecting real-world practice) but explanatory approach also to evaluate the practical implementation of the study design, especially in following domains. Eligibility criteria, sample recruitment process, study setting, intervention organization, experimental intervention-delivery flexibility, and experimental intervention adherence-flexibility, had dedicated both pragmatic and explanatory aspects in this feasibility study. As the Outcome assignment focused primarily on a certain component of the ICF domains, it was less directive to the pragmatic aspect. The follow-up assessments were anticipated to be very pragmatic in terms of the operational convenience of the interventions and the regular monthly hospital visits for health evaluations. The data analysis conducted with the intention to treat analysis according to the original assigned group showed great practicability, particularly in CG as the retention rate was limited (The PRECIS-2 evaluations are elaborated forth in Table 3).

2. Exergame training Safety and Participant's Experience/Satisfaction:

Three individuals reported experiencing adverse events, including dizziness, headaches, and eye pain, after playing Wii Fit games at the end of a few training sessions. No accidental falls or other adverse consequences were documented. The participants reported a moderate level of enjoyment (mean±sd= 54.40±15.69) as documented by Exergame Enjoyment Questionnaire (EEQ) from playing Wii Fit Plus standing balance games.

3. Preliminary efficacy:

Over time, both the experimental and control groups demonstrated notable enhancements in balance control (Mini-BESTest), ataxia rate (SARA), and functional independence (FIMs) within their respective groups. In comparison to the control group (Kendall's W=0.80, p=0.005), the experimental group exhibited greater effect sizes across all measures (Kendall's W=1.00, p<0.001) (Table 4 demonstrate within group analysis of outcome variables, Figure 3 shows graph of observed changes among outcome variables in two groups). Although significant gains were observed in pairwise comparisons within the experimental group, these improvements did not stay significant following Bonferroni correction (p<0.016) (Table 5 demonstrate pairwise comparison with Bonferroni correction within same group). No statistically significant differences were seen between the groups at baseline, post-test, or follow-up. However, the experimental group demonstrated a tendency towards better outcomes at follow-up in SARA (p=0.063, R_M =0.84) and Mini-BESTest (p=0.071, R_M =0.79) but not in the case of FIM (p=0.794, R_M =0.14) (Table 6 demonstrate between group analysis of outcome variables).

DISCUSSION

1. Feasibility of Wii Intervention:

The results obtained from our investigation have yielded valuable insights regarding the practicality and possible advantages of Wii exergame intervention. The high enrolment rate and the mandatory attendance of all participants in at least one session underscore the significant initial interest towards the Wii Balance Board as a training tool for this specific population. Technology-based solutions, such as the Wii Balance Board have the potential to be embraced by neurological patients because of their captivating and hands-on qualities [32].

The impressive commitment to the training program among those who completed the minimum requisite training sessions was encouraging, particularly given the challenges individuals with Cerebellar Ataxia might face inconsistency to participate in physical training programs[33]. The high retention rate in the EG compared to the CG further indicates the acceptability and engagement potential of Wii exergames. Such high retention and adherence rates are critical for the success of rehabilitation programs, as sustained active participation is often correlated with better outcomes [34]. The intervention's compliance rate varied by exergame difficulty levels suggests that certain Wii Fit Plus balance games may be individualized as better suited for skill progression among different Cerebellar Ataxia patients, potentially due to differing motor skills demands[35].

The incident of adverse events did not create any severe harm to the participants and therefore, they did not require special medical attention under the circumstances. These findings complement prior research that motion sickness and similar symptoms are very common adverse events resulted from virtual reality and exergame-based training [36].

2. Participants' Experience Related to the Intervention:

Enjoyment is a crucial factor in the success of gamified rehabilitation programs, as it influences adherence and motivation [37]. Since, the reported moderate enjoyment level suggests that while Wii exergames were engaging, there was still room for enhancing the sessions more enjoyable for participants. Customization of exergame content to better suit individual preferences could enhance the user experience and potentially improve adherence further [38].

3. Preliminary Efficacy:

In all outcome measures, including balance control (Mini-BESTest), ataxia rate (SARA), and functional independence (FIMs), both the experimental and control groups' participants significantly improved over time. However, the experimental group demonstrated greater relative improvements compared to the control group. This indicates Wii exergame training may offer additional benefits over conventional balance training [39].

Standard-care or conventional balance training, involve structured and therapist-driven exercises, which, while effective, but having drawbacks due to limited patient engagement and adherence [40]. In contrast, the interactive and gamified nature of Wii Balance Board training introduces an enjoyable and motivating element, which likely contributed to the better improvements that was observed in the experimental group. The high effectiveness of interactive rehabilitation methods in enhancing both motor skills and cognitive functions among individuals with neurological conditions has been documented in previous Cerebellar Ataxia studies [41].

The notable enhancement observed in the experimental group can be attributable to the dynamic and individualized exercises offered by the Wii Fit Plus balance games, which potentially provide more engaging and comprehensive training for vestibular and proprioceptive systems. These systems are crucial for ataxia patients during designing a rehabilitation plan, and whereas, conventional balance training often do not adequately address them [42].Additionally, the real-time visual and auditory feedback provided by the

Wii games can enhance motor learning and promote better postural adjustments during training, a vital component what often lacks in many conventional therapies [43,44].

Beyond conventional therapy, vestibular rehabilitation is another commonly used method for managing balance disorders, including those associated with Cerebellar Ataxia. Vestibular rehabilitation typically targets gaze stabilization, vestibulo-ocular reflex (VOR) adaptation, and habituation exercises. While effective in improving vestibular compensation, its reliance on static exercises may not fully address dynamic balance challenges or engage proprioceptive systems comprehensively [45]. In contrast, Wii Balance Board-based exergame training involves dynamic and multidirectional movements, which likely contribute to training the vestibular and proprioceptive systems in a more integrated and functional manner.

Intensive physiotherapy programs, often involving task-specific training or over-ground walking interventions, are also well-documented for improving postural stability. However, such approaches demand high resource utilization and therapist involvement, making them less feasible for long-term use in outpatient or home-based settings [46,47]. The cost-effectiveness and accessibility of Wii exergame training make it a more practical alternative for regular rehabilitation, where resources are limited.

Recent advancement in ataxia rehabilitation alongside Wii Balance Board training is repetitive transcranial magnetic stimulation (r-TMS), which have shown promise in modulating cortical excitability and promoting neuroplasticity . While r-TMS can facilitate specific neural pathways, it does not directly provide functional balance training or engage the motor systems through physical practice [48]. Wii Balance Board exergames, on the other hand, offer a dual benefit by combining physical training with interactive engagement, addressing both motor and cognitive domains simultaneously [49]. However, the integration of r-TMS with physical rehabilitation, including exergame training, warrants further exploration to maximize therapeutic potential in future studies.

Though, the experimental group showed significant improvements in pairwise comparisons, remains unable to reach statistical significance in the Bonferroni-corrected analysis ($p<0.016$), likely due to limited statistical power. Improvements in ataxia severity rate and balance were observed at follow-up, but not in functional independence. This finding aligns with previous research suggesting that while exergame training effectively improves specific motor skill like balance but it might not directly involve in the process of transfer of acquired skills to the performance of everyday activities [50]. Functional independence encompasses a wide range of task that may require more than just improved balance, including muscle strength, endurance and co-ordination [51]. Standard physiotherapy programs often integrate such components, which could explain why improvements in functional independence require additional or complementary training [52]. Thus, it is suggested the rehabilitation programs for ataxia patients should also incorporate other forms of training that address a broader range of functional abilities.

4. Clinical Implementations:

4.1 Patient Selection and Screening: The current feasibility study ensures that Wii Balance Board Exergame training can be safely administered among the patients who are affected by inherited, acquired and metabolic forms of ataxia, within 30–60 years of age limit. Cognitive (in case of pre-existing cognitive deficit) and postural control assessment are necessary and should be included in initial screening of ataxia patients prior referring to the Wii Balance Board training to facilitate an efficient and safe administration.

4.2 Exergame Design and Customization: A six-week intervention with three weekly sessions (minimum 13 sessions) seems to be feasible and well-tolerated in our study. The selection of the Wii Fit Plus Exergamames needs to be more patient-centric and a gradual progression in the difficulty level could be more ideal to attain sustained adherence in the rehabilitation program. Patients with severe ataxia should be the targeted community for beginner-level games. However, they could move on to the advanced level as they grasp the present level of difficulty. The professional level of gameplay could not be executed well due to excessive challenges experienced by the participants. Thus, this stage is suggested to be useful only ataxia patients with low severity rate with more postural control. Nevertheless, a patient must require additional support and adaptation to play at this level.

4.3 Session Structure and Safety Considerations: The Wii Balance Board training should includes practice sessions of Wii Fit Plus games for the patients, along with warm-up exercises, vital sign monitoring, safely patient handling while step on the Wii board and supervised gameplay to ensure safety. To reduce adverse effects (dizziness, headache etc.), a gradual adaptation period and longer rest intervals between exergames are recommended. Encouragement strategies, including verbal reinforcement, progress feedback, and motivational incentives, should be implemented to enhance participant engagement and adherence to the training. Dedicated technical staffs were required to maintain research equipments properly and oversee treatment implementation in the experimental arm. Additionally, a neurologist with expertise in Cerebellar Ataxia was also appointed in our study to monitor and assess any disease-specific adverse events if requiring special care.

4.4 Integration with Existing Rehabilitation Programs: Wii Balance Board-based exergame training should be incorporated as a supplementary intervention alongside conventional or standard-care physiotherapy for balance training. Given the findings that functional independence did not improve significantly**,** future rehabilitation programs should combine Wii training with progressive resistance exercises and cardiovascular endurance training to target broader functional domains.

5. Future Research Directions:

5.1 Larger and Multicenter Trials: Expanding recruitment of samples beyond a single study center could enhance generalizability and external validity of the current findings. A more diverse ataxia population with stratified group allocation should be considered to assess variations in response in future studies.

5.2 Optimizing Training Duration and Follow-up Assessments: Future trials should extend intervention periods (beyond 6 weeks) to determine the long-term benefits on functional independence. Additional second follow-up assessments should also be conducted to evaluate sustained motor and functional improvements.

5.3 Personalization Strategies in Wii Fit Plus balance games: It is also very crucial to investigate adapting difficulty algorithms to tailor exergames to patients' individual progress and motor abilities in future studies.

6. Study Limitations:

This study has several limitations. First, the small sample size limits statistical power, making it difficult to detect significant differences, especially after Bonferroni correction. Second, the short intervention period (6 weeks) restricts conclusions about long-term effects on functional independence. Third, the lack of stratification in group allocation might have introduced variability in baseline characteristics. The age restriction (30–60 years) excluded individuals with late-onset degenerative ataxias, limiting the applicability of findings to this population. Complete blinding of the outcome assessor was not feasible due to the nature of the intervention, posing a risk of subtle assessment bias. Additionally, participants might have engaged in other treatment activities outside the study setting or uncertain lifestyle activities at home. Such potential confounding variables might also influence the study's outcomes, although these confounders could not be controlled due to ethical constraint. While adverse events were minimal, individual tolerance to exergame training may vary, necessitating further safety evaluations. Lastly, our study did not include a second follow-up beyond the first follow-up assessment, limiting insights into sustained benefits. Future studies should address these limitations through inclusion of a more diverse population of ataxia, powered sample sizes and multicenter trials with extended follow-up, double-blind assessments and better tracking of additional rehabilitation activities.

CONCLUSIONS

Despite various limitations, the study provides evidence of the feasibility for implementation of Wii Balance Board training in clinical settings, as well as a modest level of enjoyment experienced by Cerebellar Ataxia patients. This supports the necessity for a more extensive definitive study to further assess effectiveness of Wii Balance Board-based exergame training. With balanced pragmatic and explanatory elements, the findings are relevant to clinical practice, while maintaining scientific rigor. Preliminary findings of efficacy indicate enhancements in balance control and improvement in ataxia symptoms. However, additional study is required to refine the current Wii intervention and maximize its clinical applicability, along with to optimize functional outcomes in the ataxia population

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Table 1 Participants' Demographic Characteristics

Baseline variables	Experimental group (n=5)	Control group (n=5)
Age (in years)	48.40 ± 10.99 (min: 35, max: 60)	55.40 ± 6.30 (min: 45, max: 60)
Sex (male, female)	80%(n=4), 20%(n=1)	80%(n=4), 20%(n=1)
Cognition Status: Mini-Mental State Examination Score (MMSE)	28.40 ± 2.07	28.40 ± 1.81
Types of Ataxia: Acquired brain injury, Metabolic Ataxia, Inherited Ataxia	60%(n=3), 20%(n=1), 20%(n=1)	60%(n=3), 20%(n=1), 20%(n=1)
Ataxia severity rate: SARA Score	15.30 ± 6.07	15.70 ± 2.38
Balance impairment rate: Mini-BESTest score	17 ± 4.84	15.20 ± 1.30
Functional Independence Status: FIM Score	101.20 ± 12.21	102.60 ± 9.28

Note: Values are presented as *mean ± standard deviation, minimum, maximum, and range, #N (%).

Table 2: Gameplay events

Events	N% or Mean±SD (n=5)
Level attained in games (Table tilt, Ski slalom, Rope walk, Soccer heading)	Table tilt: 100% beginner level, 0% advanced level, 0% pro level. Ski slalom: 20% beginner level only, 80% beginner + advanced level, 0% pro level. Rope walk: 60% beginner level only, 40% beginner + advanced + pro level Soccer heading: 20% beginner level only, 80% beginner + advanced level, 0% pro level
No. of playing attempts (Beginner Level)	Table tilt: 64 ± 15.23 Ski slalom: 22.60 ± 18.74

	Rope walk: 38.60 ± 18.66 Soccer heading: 15.60 ± 21.01
No. of playing attempts (Advanced Level)	Ski slalom: 36.80 ± 22.68 Rope walk: 7.80 ± 15.30 Soccer heading: 41.20 ± 24.50
No of playing attempts (Pro Level)	Rope walk: 2.4 ± 3.57
No. of sessions played at Beginner level	Table tilt: 14 ± 2.23 Ski slalom: 5 ± 4.60 Rope walk: 10 ± 4.38 Soccer heading: 4 ± 5.27
No. of sessions played at Advanced level	Ski slalom: 9 ± 5.16 Rope walk: 3 ± 3.89 Soccer heading: 10 ± 6.42
No. of sessions played at Pro Level	Rope walk: 1 ± 1.41

Note: all the values are reported as N% and mean ± SD.

Table 3: Pragmatic Explanatory Continuum Indicator Summary (PRECIS-2) scores of trial domains

Serial No	Domain	Score	Rationale
1.	Eligibility Criteria	**3**	**P:** Inclusion of both male and female. **E:** Inclusion of age group 30-60, inclusion of all types of Cerebellar Ataxia excluding Degenerative Cerebellar Ataxia.
2.	Recruitment path	**3**	**P:** Recruitment of participant from Neurology OPD units and admitted patients in Neurology Ward of the study hospitals. **E:** Checklist to assess recruitment eligibility.

3.	Setting	**3**	**P:** Catchment area is three Neurology OPD units and two Neurology wards (including male and female ward). **E:** Single training centre trial (feasibility).
4.	Organization of Intervention	**3**	**P:** Resource, expertise, and delivery of care in both the arm are similar. **E:** Requirement of technical staffs/ground staffs for the maintenance of the research equipments and ensuring treatment surveillance in the experimental arm. Appointment of a neurologist who is having expertise in dealing with Cerebellar Ataxia to assess any reported disease specific adverse events for need of special care.
5.	Flexibility of experimental intervention-delivery	**3**	**P:** Warm up exercises, vitals monitoring before and after of the training at both the arm. Clinical log documentations of the individuals tasks attempts and completions of tasks. **E:** Delivering practice sessions for understanding the concept of virtual reality, patient handling during standing on the Wii Balance Board, and expert supervision while playing exergames in the experimental arm.
	Flexibility of experimental intervention-adherence	**3**	**P:** Usual encouragement to adhere to routine PT. **E:** Providing incentives to encourage participants' adherence.
6.	Follow up	**5**	**P:** Follow up assessments during usual monthly visit to the hospital by our participants for general health checkups (4 weeks after post-test assessment).
7.	Outcome	**4**	**P:** Outcomes are measured at the impairment and activity domain of ICF.

8.	Analysis	**5**	**P:** Intention to treat analysis including drop out participants' data in the control group for preliminary efficacy.

Score: 1= Very explanatory, 2= Rather explanatory, 3= equally pragmatic/explanatory, 4= Rather pragmatic,

5= Very pragmatic. P= Pragmatic, E= Explanatory.

Table 4: Results of balance control, ataxia rate and functional independence measures comparison within groups

Outcome measures	**Experimental group (n=5)**						**Control group (n=5)**					
	Mean Rank			**Chi-Square (k^2)**	**p-value (2-tailed)**	**Kendall's W**	**Mean Rank**			**Chi-Square (k^2)**	**p-value (2-tailed)**	**Kendall's W**
	T_0	**T_1**	**T_2**				**T_0**	**T_1**	**T_2**			
Mini-BESTest	1.00	2.00	3.00	10.00	<0.001	1.000	1.00	2.00	3.00	8.00	0.005	0.800
SARA	3.00	2.00	1.00	10.00	<0.001	1.000	3.00	2.00	1.00	8.00	0.005	0.800
FIMs	1.00	2.00	3.00	10.00	<0.001	1.000	1.00	2.00	3.00	8.00	0.005	0.800

Note: T_0= Baseline, T_1= Post Test, T_2= Follow up. P-values refer to 2-tailed Exact Sig. (<0.05) of the non parametric Friedman test. Kendall's W= Effect size. [Rank 3= highest enhancement, Rank 2= modest enhancement, Rank 1= lowest enhancement]. Analysis made including drop out participants' data assuming the same value measured at baseline.

Table 5: Results of Post-Hoc paired Wilcoxon Signed-Rank Test with Bonferroni correction within groups

	Experimental group (n=5)						Control group (n=5)			
Outcome measures	**Comparison**	**Z-value**	**Original P-value (Asymp.Sig.~ 2 tailed)**	**Bonferroni Adjusted P-value**	R_w	**Comparison**	**Z-value**	**Original P-value (Asymp.Sig.~ 2 tailed)**	**Bonferroni Adjusted P-value**	R_w
Mini-BESTest	T_0 vs. T_1	-2.041	0.041	0.123	0.91	T_0 vs. T_1	-1.826	0.068	0.204	0.81
	T_1 vs. T_2	-2.032	0.042	0.126	0.90	T_1 vs. T_2	-1.841	0.066	0.198	0.82
	T_0 vs. T_2	-2.032	0.042	0.126	0.90	T_0 vs. T_2	-1.826	0.068	0.204	0.81
SARA	T_0 vs. T_1	-2.023	0.043	0.129	0.90	T_0 vs. T_1	-1.826	0.068	0.204	0.81
	T_1 vs. T_2	-2.060	0.039	0.117	0.92	T_1 vs. T_2	-1.841	0.066	0.198	0.82
	T_0 vs. T_2	-2.032	0.042	0.126	0.90	T_0 vs. T_2	-1.826	0.068	0.204	0.81
FIMs	T_0 vs. T_1	-2.023	0.043	0.129	0.90	T_0 vs. T_1	-1.857	0.063	0.189	0.83
	T_1 vs. T_2	-2.060	0.039	0.117	0.92	T_1 vs. T_2	-1.841	0.066	0.198	0.82
	T_0 vs. T_2	-2.023	0.043	0.129	0.90	T_0 vs. T_2	-1.826	0.068	0.204	0.81

Note: T_0= Baseline, T_1= Post Test, T_2= Follow up; P-value refers to Asymp. Sig. (<0.05) of Post-Hoc paired Wilcoxon signed rank test and adjusted significance level at 0.016 using Bonferroni correction, Z value= direction of pair wise difference, $\boldsymbol{R_w}$ **=** Effect size or magnitude of observed changes within each pare wise comparison of Wilcoxon Signed-Rank Test (Small effect ≈ 0.1, Medium effect ≈ 0.3, Large effect ≈ 0.5). Analysis made including drop out participants' data assuming the same value measured at baseline

Table 6: Results of balance control, ataxia rate and functional independence measures comparison between the Experimental group (n=5) and control group (n=5)

Time Point	Experimental/Control	Mean Rank	Sum of Rank	U value	Z value	P value (2-tailed)	R_M
SARA (T_0)	Experimental	6	30	10	-0.522	0.690	0.23
	Control	5	25				
Mini BESTest (T_0)	Experimental	6.90	34.50	5.50	-1.471	0.183	0.65
	Control	4.10	20.50				
FIMs (T_0)	Experimental	5.20	26	11	-0.313	0.841	0.13
	Control	5.80	29				
SARA (T_1)	Experimental	4.60	23	8	-0.949	0.397	0.42
	Control	6.40	32				
Mini BESTest (T_1)	Experimental	7	35	5	-1.571	0.135	0.70
	Control	4	20				
FIMs (T_1)	Experimental	5.50	27.50	12.50	0.000	1.000	0.00
	Control	5.50	27.50				
SARA (T_2)	Experimental	3.70	18.50	3.50	-1.886	0.063	0.84
	Control	7.30	36.50				
Mini BESTest (T_2)	Experimental	7.20	36	4	-1.786	0.071	0.79
	Control	3.80	19				
FIMs (T_2)	Experimental	5.80	29	11	-0.319	0.794	0.14
	Control	5.20	26				

Note: T_0= Baseline, T_1= Post Test, T_2= Follow up. P-values refer to 2-tailed Exact Sig. (<0.05) of the non parametric Mann-Whitney U test. U value= rank comparison between the groups, Z value= direction of differences between groups, R_M = effect size between group at a measure point of Mann-Whitney U test (Small effect ≈ 0.1, Medium effect ≈ 0.3, Large effect ≈ 0.5). Analysis made including drop out participants 'data assuming the same value measured at baseline.

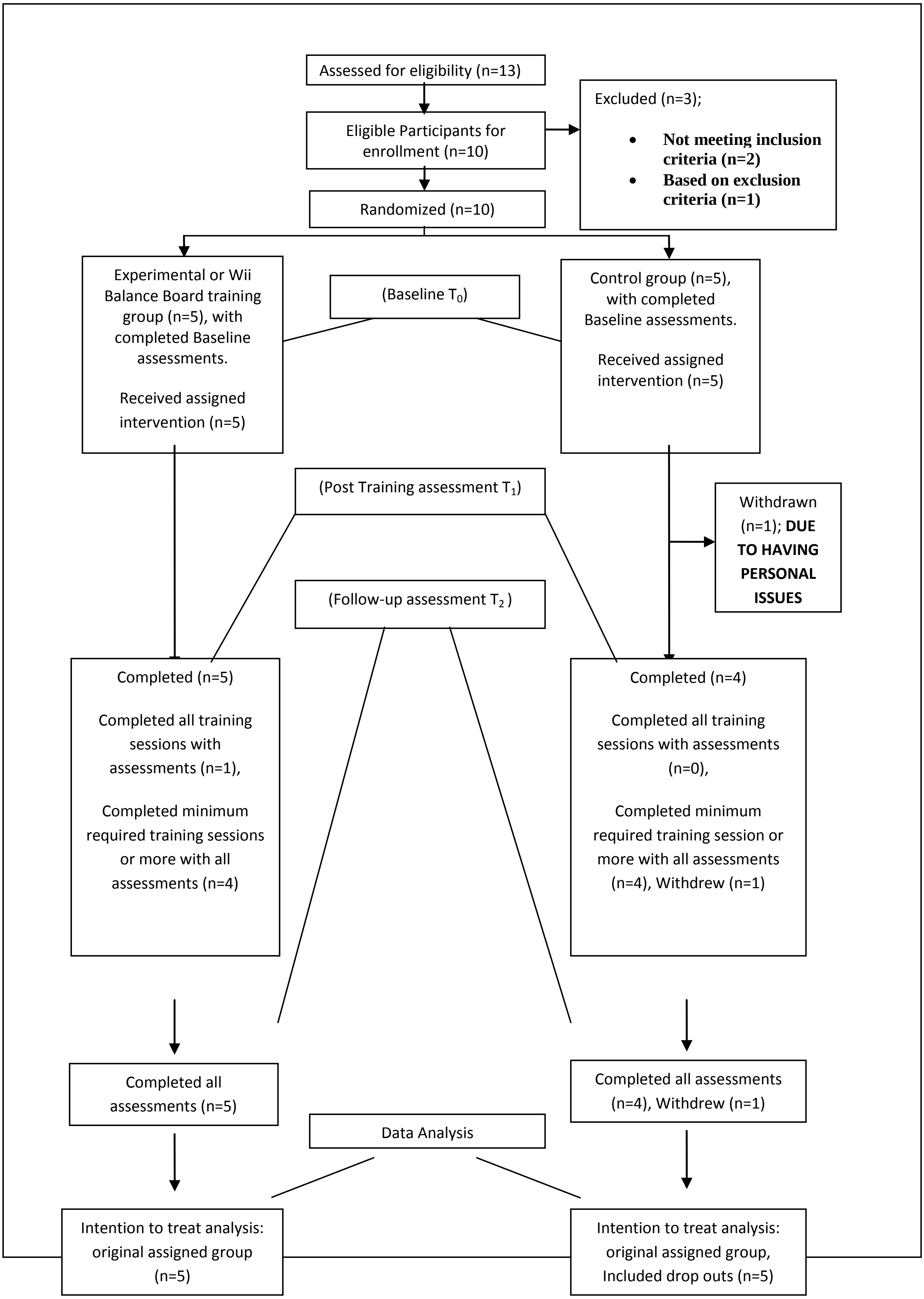
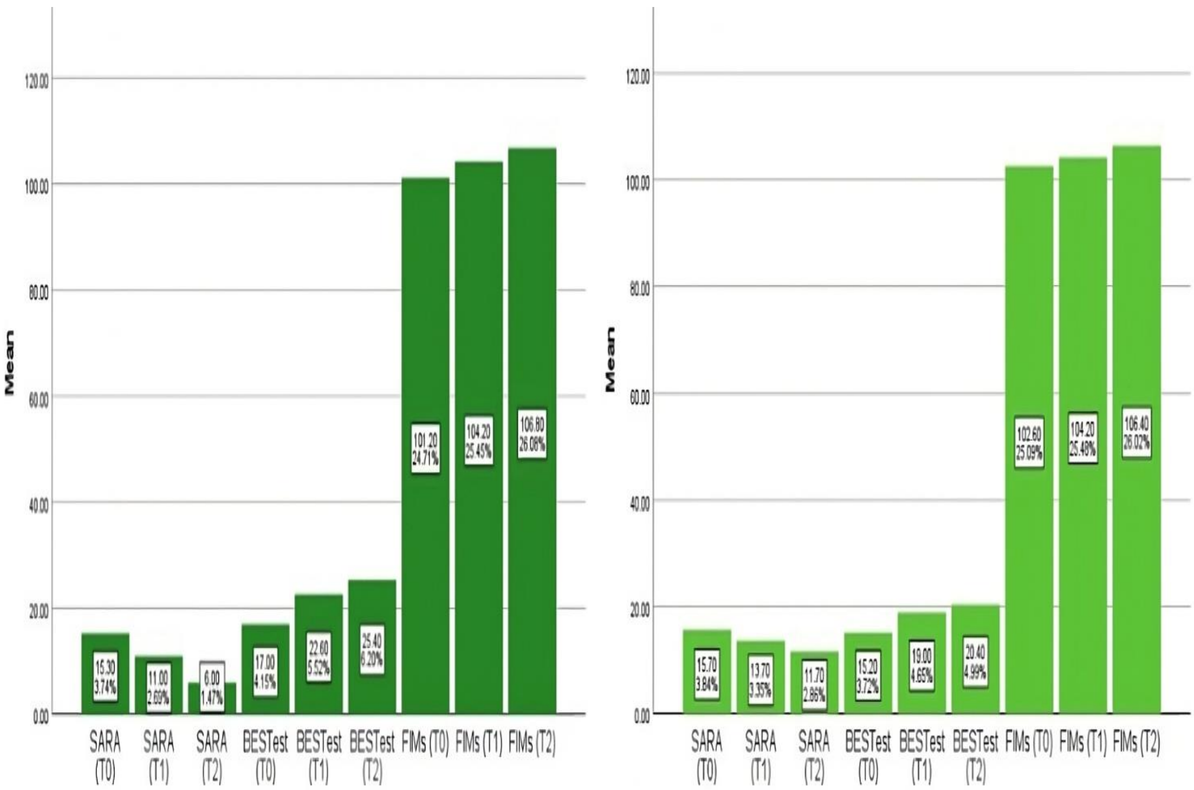

Assessed for eligibility (n=13)
Eligible Participants for enrollment (n=10)
Excluded (n=3);
Not meeting inclusion criteria (n=2)
Based on exclusion criteria (n=1)
Randomized (n=10)
Experimental or Wii Balance Board training group (n=5), with completed Baseline assessments.
Received assigned intervention (n=5)
(Baseline T0)
Control group (n=5), with completed Baseline assessments.
Received assigned intervention (n=5)
(Post Training assessment T1)
Withdrawn (n=1); DUE TO HAVING PERSONAL ISSUES
(Follow-up assessment T2)
Completed (n=5)
Completed all training sessions with assessments (n=1),
Completed minimum required training sessions or more with all assessments (n=4)
Completed (n=4)
Completed all training sessions with assessments (n=0),
Completed minimum required training session or more with all assessments (n=4), Withdrew (n=1)
Completed all assessments (n=5)
Completed all assessments (n=4), Withdrew (n=1)
Data Analysis
Intention to treat analysis: original assigned group (n=5)
Intention to treat analysis: original assigned group, Included drop outs (n=5)

Figure 1: Participants' flow chart

Figure 2: Wii Balance Board training



Experimental Group

Control Group

Figure 3: Observed Changes in Outcome variables over time in Experimental Group and Control Group