Sport Sciences and Health Research

University of Tehran
Faculty of
Physical Education and Sport Science

The Effect of Virtual Reality Exercises on Balance and Strength of Selected Lower Limb Muscles in Children with Attention Deficit Hyperactivity Disorder

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Article Info

Article type:

Original Article

Article history:

Received: 13 May 2025

Revised: 20 June 2025

Accepted: 06 July 2025

Published online: 01 January 2026

Abstract

Background: Attention Deficit Hyperactivity Disorder (ADHD) is one of the most common developmental disorders in children, associated with balance issues and muscle strength deficits.

Aim: This study aimed to investigate the effect of six weeks of virtual reality (VR) exercises on static balance, dynamic balance, and lower limb muscle strength in 8- to 12-year-old children with ADHD.

Materials and Methods: In this quasi-experimental study with a pre-test and post-test design, 30 boys with ADHD were randomly assigned to experimental (n=15) and control (n=15) groups. The experimental group underwent VR exercises using the Nintendo Wii Fit Plus console for 6 weeks, 3 sessions per week, 25–30 minutes each, while the control group received no intervention. Static balance (Modified Stork Test), dynamic balance (Y-Balance Test), and muscle strength (quadriceps, hamstrings, dorsiflexors, and plantar flexors; handheld dynamometer) were assessed. Data were analyzed using ANCOVA ($p<0.05$).

Results: The experimental group showed significant improvements in static balance ($p=0.001$, effect size=0.67), dynamic balance ($p=0.001$, effect size=0.36), and muscle strength (quadriceps, hamstrings, plantar flexors, and dorsiflexors; $p<0.003$ for all measured muscles) compared to the control group. Effect sizes for quadriceps, hamstrings, and plantar flexors were large (0.43–0.45), while for dorsiflexors, it was moderate (0.28).

Conclusion: VR exercises are an effective and engaging method for improving balance and muscle strength in children with ADHD, likely due to their motivational and interactive nature, and should be considered for inclusion in rehabilitation programs.

Keywords: Attention Deficit Hyperactivity Disorder, Virtual Reality, Static Balance, Dynamic Balance, Muscle Strength

Cite this article: Nikravesh, M., Karimizadeh Ardakani, M., Tabrizi, Y. M., & Sabzi, M. (2026). The Effect of Virtual Reality Exercises on Balance and Strength of Selected Lower Limb Muscles in Children with Attention Deficit Hyperactivity Disorder. *Sport Sciences and Health Research*, 18(1), 33-43.

1. Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most prevalent neurodevelopmental disorders in children, characterized by inattention, impulsive behaviors, and hyperactivity inappropriate for the child's age (1). Its global prevalence in children ranges from 5–7% (2), and in Iran, it varies between 5.8–20%, with a higher prevalence in boys (2–9 times higher than girls) (3, 4). ADHD not only affects cognitive functions, such as attention and executive control, and social interactions, but also leads to physical and motor impairments. Approximately 50% of children with ADHD exhibit Developmental Coordination Disorder (DCD), a condition resulting in deficits in motor skills, balance, and coordination (5). These issues significantly impair participation in daily activities, academic performance, and quality of life (6, 7).

Balance, a critical component of motor function, is categorized into static (maintaining a stable posture) and dynamic (maintaining equilibrium during movement) types (8, 9). Static balance is essential for stability in stationary positions, such as standing, while dynamic balance is crucial for activities like walking or running. Children with ADHD often struggle with both types of balance due to deficits in sensory-motor integration and weaknesses in vestibular, visual, and proprioceptive systems (7-10). Studies indicate that these children perform poorly in balance tests, such as single-leg standing or dynamic movement tasks, compared to their healthy peers (3, 10).

Muscle strength, particularly in lower limb muscles (e.g., quadriceps, hamstrings, dorsiflexors, and plantar flexors), plays a vital role in maintaining balance and performing daily movements (11). Muscle weakness in children with ADHD can increase the risk of falls and reduce their ability to perform independent activities (n (12).

Common treatments for ADHD include pharmacotherapy (e.g., methylphenidate) and behavioral interventions, but these approaches often have side effects and may not fully address motor deficits (13). In recent years, non-pharmacological interventions, such as exercise therapy, have gained attention for their effectiveness and appeal to children (14). Virtual reality (VR) provides an interactive and motivating environment that enhances children's attention and engagement (15, 16). By simulating real-world settings and offering immediate feedback, VR enables the practice of balance and strength exercises through engaging games (17). VR systems, particularly more accessible 2D systems (e.g., Wii Fit), are suitable for motor interventions in children with special needs due to their interactive nature and lower cost (16).

Previous studies have demonstrated the effectiveness of VR-based exercises in improving balance and motor function in various populations, including older adults, stroke patients, and children with cerebral palsy (17-20). For instance, Ghasemi et al. (2018) showed that rebound therapy improved balance and muscle strength in children with ADHD (14). However, compared to traditional interventions like rebound therapy or pharmacotherapy, VR protocols offer unique and attractive features for children with ADHD, including interactive gameplay, immediate visual and auditory feedback, and a motivating virtual environment that enhance engagement and adherence, particularly in a population prone to inattention and impulsivity (15, 16). These features make VR more acceptable and enjoyable for children with ADHD, addressing their challenges with sustained focus and motivation often encountered in conventional exercise programs (21). Despite these advantages, limited research has explored the impact of VR exercises on balance and muscle strength in children with ADHD specifically, highlighting a research gap.

Thus, this study aimed to examine the effect of six weeks of VR exercises on static balance, dynamic balance, and muscle strength (quadriceps, hamstrings, dorsiflexors, and plantar flexors) in 8- to 12-year-old children with ADHD. It was hypothesized that the interactive and engaging nature of VR environments would enhance motor performance in these children.

2. Methods and Materials

This quasi-experimental study with a pre-test and post-test design was conducted at the Bonyad Sports Complex in Tehran from November 2023 to February 2024.

2.1. Participation

The study population consisted of 8- to 12-year-old boys with ADHD referred to pediatric psychiatry clinics in Tehran with medical records. Participants were selected based on inclusion criteria, including no concurrent psychiatric or physical conditions (except ADHD), a score above 34 on the Conners' Parent Rating Scale, and no regular exercise in the past six months. Exclusion criteria included the use of medications other than Ritalin during the study and missing more than three training sessions.

Using G*Power 3.1.9.4 software, with a test power of 0.80, a significance level of 0.05, and a large effect size (1.02) based on prior studies (e.g., (14, 22)), a sample size of 30 was calculated. Ultimately, 30 eligible children were randomly assigned to experimental (n=15) and control (n=15) groups.

2.2. Instrument

1. **Conners' Parent Rating Scale** Designed by Keith Conners, this 26-item questionnaire uses a Likert scale (0=never to 3=very much) to assess attention deficits in children. Scores range from 26 to 104, with a score above 34 indicating ADHD. The scale has shown high reliability (0.9) (23) and validity (0.85, Institute of Cognitive Sciences) (24).

2. **Y-Balance Test (Dynamic Balance)** The Y-Balance Test evaluates dynamic balance, requiring strength, flexibility, neuromuscular control, core stability, balance, and proprioception (25). Participants stand on one leg at the center of a Y-shaped marker and reach as far as possible in three directions (anterior, posteromedial, and posterolateral) with the other leg while maintaining balance. Errors, such as moving the support leg or losing balance, require retesting. After six practice trials to minimize learning effects, the main test is conducted, and the overall balance score is calculated as the average reach distance in the three directions.
3. **Modified Stork Test (Static Balance)** The Modified Stork Test assesses static balance. Participants stand on their dominant leg, place the non-dominant foot against the knee of the dominant leg, and keep their hands on their hips. The test ends if the hands move from the hips or the non-dominant foot moves from the knee. Each participant performs the test three times, and the average duration is recorded as the final score (8).
4. **Handheld Dynamometer (Muscle Strength)** Lower limb muscle strength (quadriceps, hamstrings, dorsiflexors, and plantar flexors) was measured using a handheld dynamometer. For each muscle, participants performed three trials, and the highest force produced was recorded.
   - **Quadriceps**: Participants sat on the edge of a chair, with the dynamometer placed under a strap 2 cm above the ankle. They extended their knee.
   - **Hamstrings**: The dynamometer was placed under a strap 2 cm above the ankle, and participants flexed their knee.
   - **Plantar Flexors and Dorsiflexors**: The dynamometer was positioned to measure downward (plantar flexors) or upward (dorsiflexors) ankle movements. Each test included three trials with 15-second rest intervals, and the highest score was recorded (26-28).

2.3. Procedure

The experimental group participated in VR exercises using the Nintendo Wii Fit Plus console for 6 weeks, with 3 sessions per week lasting 25–30 minutes. The exercises included balance tasks (e.g., Balance Bubble, Ski Slalom) and strength tasks (e.g., squats), designed progressively to increase difficulty and motor challenges. Detailed training protocols are provided in Appendix 1.

Each session began with 10–15 minutes of warm-up and general stretching, followed by 30–40 minutes of selected balance and strength exercises tailored to improve balance, muscle strength, and postural control. Sessions were supervised by the researcher and two experienced trainers to ensure proper execution. To ensure consistency in exercise delivery, the researcher and trainers underwent a standardized training program prior to the study. This training included a 2-day workshop covering the operation of the Nintendo Wii Fit Plus console, detailed protocols for each exercise, safety considerations, and strategies for maintaining participant engagement and correct form. Regular calibration meetings were held weekly during the intervention to review exercise execution, address challenges, and ensure adherence to the protocol. The control group received standard treatment but did not participate in VR exercises.

2.4. Statistic

Data were analyzed using SPSS version 20. Normality was assessed with the Shapiro-Wilk test, homogeneity of variances with Levene's test, and between-group differences with ANCOVA at a significance level of 0.05.

3. Results

Analysis of anthropometric characteristics (age, height, weight, and BMI) showed that the groups were homogeneous ($p>0.05$ for all variables). The Shapiro-Wilk test confirmed normal distribution for all variables ($p>0.05$), and Levene's test verified homogeneity of variances ($p>0.05$).

Table 1. Anthropometric Characteristics (Mean ± SD, n=15 per group)

Variable	VR Exercise Group	Control Group	P-Value
Age (years)	10.19±1.14	10.38 ± 0.91	0.31
Height (m)	1.38 ± 0.23	1.37 ± 0.12	0.67
Weight (kg)	35.26 ± 4.23	34.71 ± 3.05	0.29
BMI (kg/m²)	23.82 ±1.39	24.41 ± 1.27	0.41

Table 2. Descriptive Statistics of Variables in Pre- and Post-Tests

Variable	Group	Pre-Test (Mean ± SD)	Post-Test (Mean ± SD)
Static Balance (s)	Experimental	2.13±0.54	2.76±0.50
	Control	1.93±0.35	1.93±0.33
Dynamic Balance (cm)	Experimental	51.13±5.55	54.66±4.46
	Control	54.20±4.52	54.20±4.44
Quadriceps Strength (N/m²)	Experimental	5.96±1.36	6.46±1.45
	Control	5.22±1.32	5.17±1.33
Hamstring Strength (N/m²)	Experimental	5.56±1.37	5.89±1.22
	Control	5.21±1.02	5.23±1.02
Plantar Flexor Strength (N/m²)	Experimental	4.61±1.13	4.93±1.08
	Control	4.44±0.71	4.47±0.77
Dorsiflexor Strength (N/m²)	Experimental	4.77±1.60	5.11±1.52
	Control	4.20±0.97	4.22±0.92

Table 3. Paired t-Test, ANCOVA, and Effect Size Results

Variable	Paired t-Test (Experimental)	Paired t-Test (Control)	ANCOVA (Between-Group)	Effect Size (η²)
Static Balance	p=0.001, t=9.47	p=0.33, t=-1.00	p=0.001, F=56.67	0.67
Dynamic Balance	p=0.002, t=5.24	p=0.09, t=0.65	p=0.001, F=15.31	0.36
Quadriceps Strength	p=0.01, t=9.63	p=0.71, t=0.45	p=0.001, F=22.30	0.45
Hamstring Strength	p=0.02, t=11.18	p=0.91, t=-0.09	p=0.001, F=21.06	0.43
Plantar Flexor Strength	p=0.002, t=5.24	p=0.09, t=0.65	p=0.001, F=21.95	0.44

Dorsiflexor Strength	p=0.001, t=8.58	p=0.35, t=0.36	p=0.003, F=10.77	0.28

Statistical Results Explanation

- **Descriptive Statistics**: Means and standard deviations indicate significant improvements in all measured variables in the experimental group compared to the control group, as confirmed by paired t-tests and ANCOVA (p≤0.003).
- **Paired t-Test**: Significant improvements were observed in all variables from pre- to post-test in the experimental group (p<0.05), while the control group showed no significant changes (p>0.05).
- **ANCOVA**: After controlling for pre-test effects, between-group differences in post-test were significant for all variables (p≤0.003).
- **Effect Size (η²)**: Large effect sizes were observed for static balance and strength of quadriceps, hamstrings, and plantar flexors (≥0.43), while moderate effect sizes were noted for dynamic balance and dorsiflexor strength (0.28–0.36).

For further clarity, Figures 1 and 2 compare the pre- and post-test means of the variables in the experimental and control groups.

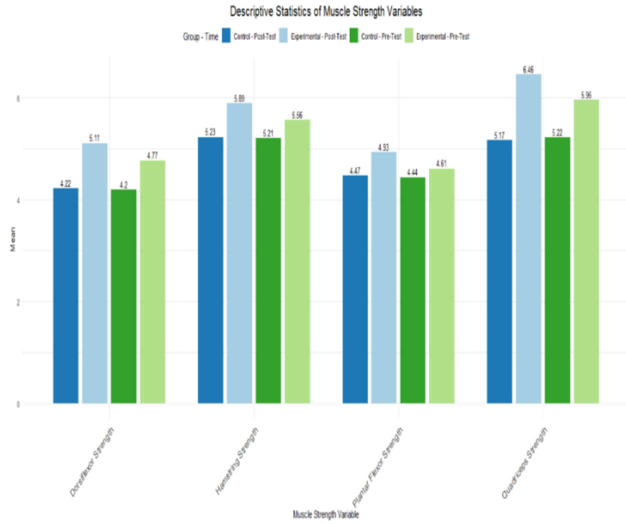

Figure 1. Comparison of Strength Variables

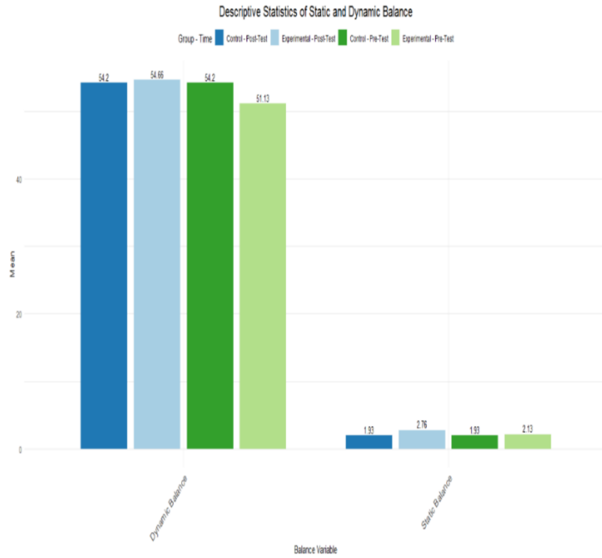

Figure 2. Comparison of Balance Variables

Figure Explanation:

- **Title**: Comparison of Balance and Muscle Strength Variables.
- **X-Axis**: Variables (static balance, dynamic balance, quadriceps, hamstrings, plantar flexors, dorsiflexors).

- **Y-Axis**: Mean values (seconds for static balance, centimeters for dynamic balance, N/m² for muscle strength).
- **Groups and Stages**: The figures include four bars per variable: experimental pre-test (light green), experimental post-test (light blue), control pre-test (dark green), and control post-test (dark blue).

Observations: The figures show significant improvements in the experimental group post-intervention, particularly in dynamic balance (from 51.13 to 54.66 cm). The control group exhibited minimal changes. The largest effect size was observed for static balance (η^2=0.67), and the smallest for dorsiflexor strength (η^2=0.28).

4. Discussion

This study aimed to investigate the effects of a six-week virtual reality (VR) exercise program on static balance, dynamic balance, and lower limb muscle strength in 8- to 12-year-old children with attention-deficit/hyperactivity disorder (ADHD). The results indicate that the VR intervention significantly improved static balance (η^2=0.67), dynamic balance (η^2=0.36), and lower limb muscle strength in this population. These findings are particularly relevant given the unique physiological, mental, and socio-cultural characteristics of children with ADHD, which influence their motor performance and response to interventions.

Children with ADHD often exhibit physiological challenges, including impaired sensory-motor integration and reduced efficiency in the vestibular, visual, and proprioceptive systems (21). These deficits can lead to difficulties in maintaining balance and coordinating movements, as the cerebellum and prefrontal cortex, which are critical for motor control, show altered activation patterns in this population. Additionally, children with ADHD may have lower baseline muscle strength and motor coordination due to reduced physical activity levels, often resulting from inattention and impulsivity. These physiological characteristics make interventions like VR exercises, which target sensory integration and motor coordination, particularly effective for this group. The VR protocol in this study, involving exercises like Ski Slalom and squats, likely stimulated proprioceptors and mechanoreceptors, facilitating neural adaptations and enhancing motor control (29).

Mentally, children with ADHD face challenges related to executive function deficits, including difficulties with attention, impulse control, and working memory. These cognitive impairments can hinder their ability to engage in traditional exercise programs, which often require sustained focus and adherence to complex instructions. The engaging and interactive nature of VR exercises, with immediate feedback and gamified elements, aligns well with the mental characteristics of children with ADHD, who respond positively to stimulating and rewarding environments (21). The simplicity of VR tasks, such as weight-shifting or balance challenges, reduces cognitive load while maintaining engagement, thereby supporting improvements in balance and strength (30). Furthermore, the motivational aspects of VR may enhance self-efficacy and sustained participation, addressing the motivational deficits often observed in this population.

Socio-cultural factors also play a significant role in the lives of children with ADHD. These children may experience social stigma, reduced peer acceptance, and lower participation in group physical activities due to their impulsive or hyperactive behaviors. Such social challenges can limit opportunities for motor skill development and physical fitness, further exacerbating motor deficits. VR exercises, conducted in a controlled and non-judgmental virtual environment, provide a safe space for these children to practice motor tasks without fear of social evaluation (21). This aspect likely contributed to the significant improvements observed in this study, as the VR setting minimized social pressures and allowed children to focus on motor performance.

The observed improvements in static and dynamic balance in the experimental group are likely attributable to the physiological and neurological mechanisms enhanced by VR exercises. By presenting balance challenges in virtual environments (e.g., tightrope walking or skiing), these exercises encourage precise center-of-gravity adjustments and activation of stabilizing muscles (21). This process improves sensory-motor integration, addressing the physiological deficits common in children with ADHD (31). Previous studies, such as Welsch et al. (2021), have shown that interactive motor interventions improve executive function and balance in children with ADHD (22). Heirani et al. (2017) reported enhanced balance and mobility in patients with brain injuries through VR-based motor exercises (22). Unlike Eskandarnezhad et al. (2017), who reported limited improvements in static balance, this study found significant improvements in both balance types, likely due to the engaging nature of VR, which aligns with the mental and socio-cultural needs of children with ADHD (21).

From a neurological perspective, VR exercises stimulate proprioceptors and mechanoreceptors, facilitating central nervous system reorganization (29). This process may activate the primary motor cortex and enhance motor planning, which is often impaired in children with ADHD (32). The multifaceted nature of balance (involving strength, proprioception, and coordination) and the combination of balance and strength exercises in the VR protocol likely amplified its effectiveness (32). For instance, exercises like Ski Slalom require coordination between lower limb muscles and sensory systems, improving these functions in children with ADHD (30).

Improvements in muscle strength, measured as force per unit area (N/m^2), in the quadriceps, hamstrings, and plantar flexors (large effect sizes, $\eta^2 \geq 0.43$) and dorsiflexors (moderate effect size, $\eta^2 = 0.28$) align with prior studies (33, 34). Sadeghi et al. (2021) reported enhanced lower limb muscle strength in older adults through VR and combined exercises (33), and Wehner et al. (2021) found that Tai Chi, similar to VR balance exercises, increased muscle strength (34). These improvements are likely due to bodyweight resistance exercises (e.g., squats) in the VR protocol, which stimulate fast-twitch motor units and enhance muscle coordination (35, 36). The significant improvements in muscle strength may be partly due to the participants' relatively low baseline fitness levels, as individuals with less training experience often show stronger responses to resistance exercises (35). The moderate effect size for dorsiflexor strength may be due to the protocol's limited focus on this muscle. Exercises like squats and Ski Slalom primarily engage proximal muscles (quadriceps, hamstrings) and plantar flexors, with dorsiflexors playing a lesser role. This suggests that future protocols should include more targeted dorsiflexor exercises.

Physiologically, VR exercises improved cerebral blood flow and the efficiency of pyramidal cells and the cerebellum, contributing to enhanced strength and balance (37). Additionally, stimulation of muscle spindles and reduced inhibition from Golgi tendon organs improved joint position sense, further supporting strength and balance gains. These physiological adaptations are particularly beneficial for children with ADHD, given their baseline motor and neurological deficits.

Study limitations include challenges in implementing interventions with ADHD children due to inattention and impulsivity, as well as the small sample size, which limits generalizability. Additionally, uncontrolled variables such as participants' physical activity levels outside the study or potential effects of ADHD medications may have influenced the results.

5. Conclusion

Six weeks of VR exercises significantly improved static balance, dynamic balance, and lower limb muscle strength in 8- to 12-year-old children with ADHD. Due to their engaging and interactive nature, these exercises are an effective rehabilitation method for this population. It is recommended that clinicians and trainers incorporate VR exercises alongside other training protocols. Future research should involve larger samples, comparisons with other training methods, and exploration of effects on variables like attention and focus to complement these findings.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed equally to the conceptualization, study design, and preparation of the manuscript.

Ethical considerations

All participants were enrolled, Trained, And tested at a single site after reading and signing the informed consent from that was approved by the university of Tehran Institutional Review Board, which also approved the study.

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

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