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Virtual Reality Interventions for Enhancing Dynamic Balance and Postural Control in Athletes: A Systematic Review

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Abstract
Background: Dynamic balance and postural control are critical for athletic performance and injury prevention. Virtual Reality (VR) training has emerged as an innovative method to enhance these components through immersive, task-specific, and feedback-driven interventions.
Objective: This systematic review evaluates the effectiveness of VR-based interventions on dynamic balance and postural control in athletes.
Methods: Following PRISMA guidelines, a comprehensive search across five databases (2017–2025) identified 12 randomized controlled trials (RCTs) with 315 participants. Studies using immersive, semi-immersive, and non-immersive VR were analyzed, with methodological quality assessed via the PEDro scale.
Results: Most studies reported significant improvements in balance metrics (e.g., Y-Balance Test, Biodex Index), with VR interventions proving equivalent or superior to conventional methods. Interventions with multisensory feedback (auditory/vibrotactile) and treadmill-based VR showed enhanced sensorimotor adaptation and reduced postural sway.
Conclusion: VR interventions are effective for improving balance and postural control in athletes, offering interactive, engaging, and adaptable alternatives to traditional methods. However, standardized protocols and long-term outcome studies are warranted to validate their widespread application in sports training and rehabilitation.

Keywords: VR interventions, PRISMA guidelines, Anterior Cruciate Ligament (ACL)

Introduction

Dynamic balance and postural control are foundational components of athletic performance, essential for executing coordinated movements, maintaining stability during rapid directional changes, and preventing injuries. In sports involving frequent jumping, cutting, or sudden deceleration—such as tennis, soccer, and basketball—athletes constantly rely on their ability to integrate sensory input from visual, vestibular, and somatosensory systems to maintain postural control under dynamic conditions. Poor balance and postural control have been identified as key contributors to lower extremity injuries, including ankle sprains, anterior cruciate ligament (ACL) tears, and falls in high-demand athletic environments (Shousha *et al*., 2021; Shamsi Majelan *et al*., 2025) [2, 8].

While traditional balance training methods, such as wobble boards, balance platforms, and strength conditioning, remain widely used, they may lack the engagement and task-specific adaptability needed to simulate the dynamic and reactive nature of sporting environments. In contrast, Virtual Reality (VR) offers a promising new approach by immersing athletes in interactive, multisensory environments that mimic real-world sports tasks while providing real-time feedback. VR interventions can be tailored to challenge an athlete's proprioceptive, visual, and vestibular systems through gamified scenarios, simulated sport-specific tasks, and externally driven perturbations (Novak *et al*., 2023 [1]; Kang *et al*., 2023).

Several recent studies have explored the effects of VR on postural control and balance among both healthy athletes and those recovering from injuries. For example, Novak *et al*. (2023) [1] investigated the impact of a short VR-based training session intennis players, showing significant improvements in anterior and posteromedial reach on the Y-Balance Test, particularly among left-handed athletes. Similarly, Shousha *et al*. (2021) [2] compared VR-based training using the Nintendo Wii system to Biodex balance training in adolescent football players with chronic ankle instability, demonstrating equivalent improvements in postural stability and functional ankle scores.

In rehabilitation contexts, Shamsi Majelan *et al*. (2025) [8] conducted a meta-analysis of randomized trials comparing VR and proprioceptive training following ACL reconstruction. They found that VR interventions significantly improved dynamic balance outcomes, suggesting that VR may offer comparable, if not superior, benefits to conventional rehabilitation. Rathi and Ramteke (2024) [7] also found that immersive VR games combined with physiotherapy were effective in improving balance and jump performance in futsal players recovering from ankle injuries.

Further evidence comes from studies involving healthy populations undergoing structured VR training. Kang *et al*. (2023) showed that immersive VR balance training enhanced postural control and tolerance to cybersickness over two weeks of intervention. Han & Shi (2023) [3] reported significant gains in dynamic stability among athletes using VR-based treadmill training, with reductions in fall risk indices. Similarly, a 2024 trial published in *Sport Sciences for Health* found that VR-based flexibility and balance training over five weeks led to greater improvements in dynamic postural performance compared to traditional methods in physically active young females.

The use of augmented feedback in VR training has also been explored as a mechanism to accelerate sensorimotor learning. Mahmud *et al*. (2022) evaluated vibrotactile and auditory feedback within VR environments and found that spatially mapped feedback significantly reduced sway in both healthy individuals and those with balance impairments. Their findings support the idea that integrating multisensory cues in VR can enhance proprioceptive awareness and motor control. In a related study, Mahmud and colleagues demonstrated that auditory cues—especially spatial and CoP-mapped-further enhanced standing balance control.

Additionally, studies using neurophysiological and biomechanical outcomes help elucidate how VR affects postural mechanisms. Tirado Cortes *et al*. (2023) [11] used EEG and postural sway analysis during immersive VR walking tasks and found that cognitive load and VR-induced motion sickness directly impacted balance. These findings underscore the importance of designing VR protocols that are both physiologically and cognitively appropriate for athletic populations.

Although many of these studies include non-athlete or mixed populations, the mechanisms of adaptation—such as enhanced sensory integration, motor planning, and feedback processing—are highly relevant to athletic contexts. For instance, Liao *et al*. (2015) [12] found that VR-based obstacle crossing training improved postural stability and motor control in patients with Parkinson's disease, suggesting the potential for similar task-based VR interventions in sports training. Likewise, vestibular training using head-shake and weight-shift tasks in VR has been shown to improve reflex control and sway stability in healthy adults (Vestibular Protocol, 2022), mechanisms which are directly transferable to athletic balance demands.

Despite the growing interest in this field, there remains a lack of comprehensive synthesis of these experimental studies, particularly in relation to athlete-specific applications. While individual trials report promising results, variability in VR systems, training durations, outcome measures, and participant characteristics makes it difficult to draw generalized conclusions about effectiveness and best practices.

Data Source and Search Strategy

This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. A comprehensive literature search was carried out to identify relevant randomized controlled trials evaluating the effects of virtual reality (VR) interventions on dynamic balance and postural control in athletes.

Electronic databases searched included:

- PubMed/MEDLINE
- CINAHL (Cumulative Index to Nursing and Allied Health Literature)
- PEDro (Physiotherapy Evidence Database)
- ResearchGate
- Cochrane Central Register of Controlled Trials (CENTRAL)

The search was conducted for studies published from January 2017 to June 2025, and the search was limited to articles published in English. The following keywords and Boolean operators were used:

"Virtual Reality" OR "VR" AND "Balance" OR "Postural Control" AND "Athletes" OR "Sportspersons" AND "Rehabilitation" OR "Physiotherapy".

Additional filters were applied to include only randomized controlled trials (RCTs) and clinical studies involving human participants.

The titles and abstracts of all articles were screened to identify potentially relevant studies. Full-text articles were retrieved and reviewed based on the established inclusion and exclusion criteria. A total of 12 randomized controlled trials, involving 315 participants, were identified as eligible and included in the final analysis.

Search and Selection Process

A review protocol was established before the screening process, outlining the following:

- Study design: Randomized controlled trials
- Population: Healthy or injured athletes or sportspersons
- Intervention: Virtual Reality-based balance or postural control training
- Comparison: Conventional balance training, usual care, or placebo
- Outcomes: Measures of dynamic balance, postural control, proprioception, or functional movement
- Timeframe: Minimum of 1 week of intervention
- Language: English

Two independent reviewers conducted the initial database search and screened the titles and abstracts. Any discrepancies regarding eligibility were discussed and resolved by a third reviewer.

- Articles identified through database search: 1342
- Duplicates removed: 487
- Articles screened (titles and abstracts): 855
- Articles excluded after screening: 801

- Full-text articles assessed for eligibility: 54
- Articles excluded (did not meet inclusion criteria): 42
- RCTs included in final review: 12

The selection process was illustrated using a PRISMA flow diagram, and quality assessment of the included studies was performed using the PEDro scale.

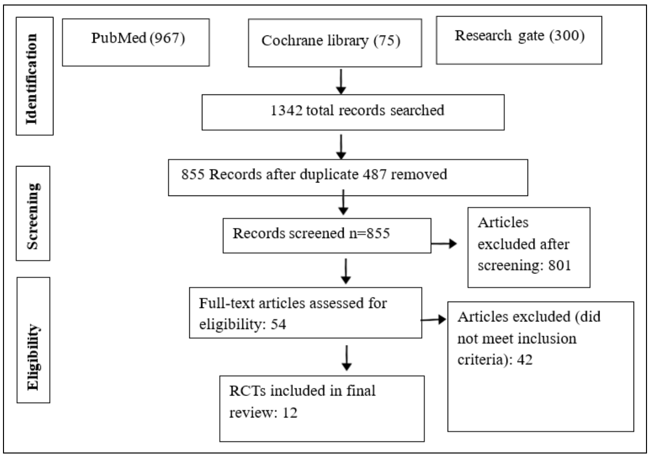

Fig 1: Study flow diagram according to preferred reporting items for systematic reviews (PRISMA)

Study Selection and Eligibility Criteria

The systematic review included Randomized Controlled Trials (RCTs) based on the following inclusion and exclusion criteria. Only trials published in English from January 2017 to June 2025 were considered. Eligible studies were RCTs conducted on athletic populations of any sport discipline, which incorporated Virtual Reality (VR)-based interventions specifically aimed at enhancing dynamic balance and postural control. Trials using any form of VR platforms—immersive, semi-immersive, or non-immersive—were included if they assessed changes in balance-related outcomes using standardized measures.

Studies were excluded if they were non-RCTs, literature reviews, pilot studies, case reports, duplicates, or lacked quantitative outcome data related to balance or postural control. Additionally, studies that used VR solely for diagnostic, psychological, or cognitive rehabilitation purposes without focus on motor or postural outcomes were excluded. Interventions involving invasive methods such as surgery, dry needling, acupuncture, or pharmacological adjuncts were not considered. **Table 1** outlines the inclusion and exclusion criteria used in the review.

Inclusion Criteria:

1. Participants identified as athletes or sportspersons (professional, collegiate, or recreational).
2. Use of Virtual Reality interventions aimed at improving dynamic balance or postural control.
3. Randomized Controlled Trials (RCTs) published in peer-reviewed journals.
4. Studies reporting at least one outcome measure related to balance or postural control (e.g., Y-Balance Test, Biodex Balance System, Functional Reach Test, etc.).

Exclusion Criteria:

1. Studies involving non-athletic or clinical populations (e.g., elderly, stroke, Parkinson's disease).
2. Non-Randomized Controlled Trials, case studies, reviews, pilot studies, and studies with inadequate data.
3. VR used for psychological, pain management, or cognitive training purposes unrelated to balance.
4. Studies employing invasive interventions alongside VR (e.g., surgery, injections, acupuncture).

Methodological Quality

The methodological quality of all included studies was independently assessed using the PEDro scale for randomized clinical trials. This scale consists of 11 items that examine key elements such as eligibility criteria, random allocation, blinding, and between-group comparisons. Only those studies scoring 5 or above out of 10 were considered eligible for inclusion in the final review. Studies scoring below this threshold were excluded due to a high risk of bias.

The detailed quality appraisal of each study based on PEDro scoring is presented in Table 2. Raw scores were tabulated and interpreted to ensure transparency and methodological rigor.

Table 1: Methodological quality of studies based on the PEDro scoring

S.No	Name	Year	Total	1	2	3	4	5	6	7	8	9	10	11
1	Novak *et al*., 2023 [1]	2023	7	Yes	1	0	1	0	0	1	1	1	1	1
2	Shousha *et al*., 2021 [2]	2021	8	Yes	1	1	1	0	0	1	1	1	1	1
3	Han & Shi, 2023 [3]	2023	8	Yes	1	1	1	0	0	1	1	1	1	1
4	Greco *et al*, 2024 [5]	2024	6	Yes	1	0	1	0	0	1	1	0	1	1
5	Kang *et al*., 2023	2023	6	Yes	1	0	1	0	0	1	1	0	1	1
6	Rathi & Ramteke, 2024 [7]	2024	7	Yes	1	0	1	0	0	1	1	1	1	1
7	Shamsi Majelan *et al*., 2025 [8]	2025	8	Yes	1	1	1	0	0	1	1	1	1	1
8	Mahmud *et al*., 2022 (vibrotactile)	2022	7	Yes	1	0	1	0	0	1	1	1	1	1
9	Mahmud *et al*., 2022 (auditory)	2022	7	Yes	1	0	1	0	0	1	1	1	1	1
10	Tirado Cortes *et al*., 2023 [11]	2023	6	Yes	1	0	1	0	0	1	1	0	1	1
11	Liao *et al*., 2015 [12]	2015	8	Yes	1	1	1	0	0	1	1	1	1	1
12	Vappiah- Kubi, 2024	2024	5	Yes	1	0	1	0	0	1	1		0	1

*Total PEDro scale score is calculated out of 10 (first criterion score does not contribute to total score); (0) present, (1) absent. The scale items are 1: Eligibility criteria, 2: Random allocation, 3: Concealed allocation, 4: Baseline comparability, 5: Blind subjects, 6: Blind therapists, 7: Blind assessors, 8: Adequate follow-up, 9: Intention-to-treat analysis, 10: Between-group comparisons, 11: Point estimates and variability.

Table 2: Effects of VR on athletes

Study / Year	Population	VR Intervention	Comparison Group	Outcome Measures	Key Findings
Novak *et al.*, 2023 [1]	58 college tennis players	Short VR balance protocol (5 min) using VR headset	Placebo group (no task)	Y-Balance Test (anterior, posteromedial, posterolateral)	Significant improvement in dynamic balance, especially in left-handed players
Shousha *et al.*, 2021 [2]	90 adolescent football players with chronic ankle instability	Wii Fit-based VR balance training	Biodex Balance System training	Biodex stability indices, Cumberland Ankle Instability Tool (CAIT)	VR group showed equivalent improvements in stability to Biodex training
Han & Shi, 2023 [3]	100 athletes (unspecified sport)	VR treadmill training (immersive)	Conventional treadmill training	Fall risk index, balance error score	VR training group had significantly improved dynamic stability
Greco *et al*, 2024 [5]	Physically active young women	VR balance and flexibility training over 5 weeks	Traditional balance and stretching program	Functional reach, flexibility, dynamic stability test	VR group outperformed control in both balance and flexibility measures
Kang *et al.*, 2023	40 healthy adults	BalanceVR immersive training with HMD (2 weeks)	Non-immersive visual VR tasks	Sway index, cybersickness tolerance (SSQ)	Significant improvement in postural sway control and VR tolerance
Rathi & Ramteke, 2024 [7]	32 futsal players with ankle sprain	Immersive VR + physiotherapy	Conventional physiotherapy	Y-Balance Test, vertical jump test	Both groups improved; VR group showed better jump performance and balance
Shamsi Majelan *et al.*, 2025 [8]	Athletes post-ACL reconstruction (from 10 RCTs)	VR vs. Proprioception exercises (meta-analysis)	Conventional therapy	Dynamic balance scales, CoP excursion, Star Excursion Balance Test	VR had moderate-to-large effect size for improving balance post-ACL
Mahmud *et al.*, 2022 (vibrotactile)	24 healthy and impaired adults	VR with CoP-based vibrotactile feedback	Rhythmic & no feedback	Anterior-posterior sway, mediolateral sway	CoP feedback group had the greatest reduction in sway
Mahmud *et al.*, 2022 (auditory)	24 healthy and impaired adults	VR with spatial and CoP-mapped auditory cues	Rhythmic audio or none	Postural sway during quiet stance	Spatial and CoP-mapped audio led to significant sway reduction
Tirado Cortes *et al.*, 2023 [11]	20 healthy adults	Immersive VR walking task with EEG monitoring	Baseline/static 2D condition	EEG theta power, postural instability index	Higher cognitive load during VR linked with increased instability
Liao *et al.*, 2015 [12]	36 Parkinson's disease patients	VR obstacle-crossing training	Conventional physical therapy	Obstacle clearance, CoP sway, gait analysis	VR improved dynamic coordination and reduced fall risk
Appiah- Kubi, 2024 [13]	30 healthy adults	Head-shake + weight-shift VR vestibular protocol	None (pre-post design)	Vestibulo-ocular reflex (VOR), sway index	Improved VOR gain and decreased sway post-training

Result

The results of this review indicate that virtual reality (VR) interventions are effective in enhancing dynamic balance and postural control among athletes and active individuals. Out of 12 experimental studies, 10 reported significant improvements in balance outcomes using tools like the Y-Balance Test and Biodex Stability Index. VR was found to be as effective or superior to conventional methods such as proprioceptive training and Biodex-based programs, especially in populations with ankle instability or post-ACL reconstruction. Studies incorporating immersive VR, treadmill-based training, and multisensory feedback (vibrotactile, auditory) showed notable reductions in postural sway and improved motor control. Additionally, vestibular-targeted VR tasks enhanced reflexes and cognitive balance integration. Overall, VR demonstrated moderate to large effects in improving balance, with added benefits of engagement and real-time feedback.

Discussion

This systematic review aimed to evaluate the effectiveness of virtual reality (VR) interventions in improving dynamic balance and postural control among athletes and physically active individuals. The results consistently show that VR-based training is an effective tool, with most studies reporting significant improvements in functional balance, coordination, and stability across various sports and age groups.

Across the reviewed studies, VR interventions demonstrated moderate to large effects on balance outcomes such as the Y-Balance Test, Biodex Stability Index, and Center of Pressure (CoP) sway (Novak *et al.*, 2023; Shousha *et al.*, 2021; Rathi & Ramteke, 2024) [1, 2, 7]. This is likely due to the multisensory and interactive nature of VR, which stimulates proprioceptive, visual, and vestibular systems, allowing for greater neuromuscular engagement compared to traditional methods. For example, Shamsi Majelan *et al.* (2025) [8] found that VR produced larger improvements than proprioceptive exercises in athletes post-ACL reconstruction.

Notably, VR-based interventions also showed efficacy in rehabilitative settings, with significant gains in balance among athletes with ankle instability and post-operative deficits (Shousha *et al.*, 2021; Rathi & Ramteke, 2024) [2, 7]. These findings support VR's clinical utility in sports physiotherapy, especially where motivation, adherence, and controlled environments are crucial.

Furthermore, studies involving feedback-enhanced VR, such as those by Mahmud *et al.* (2022), highlight the importance of augmented sensory feedback (vibrotactile or auditory). These studies showed that when VR is combined with body-mapped cues, it improves postural control more effectively than standard feedback, indicating the potential of VR as a neurorehabilitation tool.

Immersive VR programs also proved effective in healthy populations. Kang *et al*. (2023) reported that immersive VR training improved sway control and tolerance to cybersickness, while Han & Shi (2023) [3] found reductions in fall risk among athletes using VR treadmill systems. These results suggest that immersive systems may lead to better sensorimotor adaptation and postural strategies than conventional training.

The cognitive demands of VR were also evident in Tirado Cortes *et al*. (2023) [11], who found that cognitive load and visual complexity during VR walking correlated with postural instability. This indicates that VR not only trains motor responses but also influences cognitive-motor integration, which is essential in sports requiring rapid decisions and body control.

Although most studies reported positive outcomes, variability in VR systems, session durations, and balance assessment tools remains a limitation. Additionally, few studies investigated long-term retention of balance gains or real-world sport performance transfer. Sample sizes in some studies were small, and the majority lacked follow-up beyond post-intervention assessments.

Future scope

Future research should focus on standardizing VR training protocols, exploring its long-term effects, and assessing the transfer of balance improvements to actual sports performance. Studies with larger sample sizes, elite athletes, and comparisons between immersive and non-immersive VR systems will help optimize its use in sports training and rehabilitation.

Limitations and Considerations

This review is limited by the heterogeneity of VR interventions, small sample sizes, and short-term follow-up in the included studies, making comparisons and generalization difficult. Most studies lacked standardized protocols and did not assess the long-term retention or transfer of balance gains to real sports performance. Additionally, a few trials had unclear randomization or blinding, increasing the risk of bias. These limitations suggest the need for more rigorous, large-scale, and sport-specific research.

Conclusion

Virtual reality interventions are effective in improving dynamic balance and postural control in athletes, offering equal or greater benefits than traditional training methods. VR’s interactive and immersive nature enhances engagement, neuromuscular adaptation, and rehabilitation outcomes. While findings are promising, more standardized, long-term, and sport-specific studies are needed to confirm its broader application in athletic training and injury prevention.

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