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EFFECTS OF VIRTUAL REALITY-BASED BALANCE TRAINING ON POSTURAL CONTROL IN ADOLESCENT ATHLETES

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Abstract

Objective: This study evaluated the efficacy of virtual reality (VR)-based balance training for improving postural control and reducing injury risk in adolescent athletes. **Methods:** Sixty adolescent athletes (aged 13–17) from various sports were randomized to either a VR-based balance training group or a conventional balance training group for eight weeks. The primary outcome was postural control, assessed by the Balance Error Scoring System (BESS) and Star Excursion Balance Test (SEBT). Secondary outcomes included sports performance metrics and self-reported injury incidence. **Results:** The VR group demonstrated significantly greater improvements in BESS and SEBT scores compared to the conventional group ($p < .01$). Additionally, the VR group reported a lower incidence of minor balance-related injuries during the intervention period. **Conclusion:** VR-based balance training is an effective adjunct to conventional athletic training for improving postural control and may reduce injury risk in adolescent athletes.

Keywords: Virtual Reality, Balance Training, Adolescent Athletes, Postural Control, Sports Injury Prevention

1. Introduction

1.1 Background

Balance and postural control are critical components of athletic performance, particularly in sports requiring rapid changes in direction, jumping, and landing (Hrysomallis, 2011). Adolescents are at a formative stage of neuromuscular development, and deficits in balance can increase the risk of sports-related injuries such as ankle sprains and knee ligament injuries (Emery et al., 2015).

1.2 Rationale for Virtual Reality

Traditional balance training programs, while effective, may be limited by monotony and lack of engagement, especially in youth populations. Virtual reality (VR) technology offers an interactive, immersive, and motivating environment that can enhance adherence and provide real-time feedback (Grooms et al., 2015). VR-based interventions can simulate sport-specific scenarios and challenge athletes with dynamic balance tasks.

1.3 Literature Review

Emerging research suggests that VR-based training can improve balance and proprioception in healthy individuals and athletes (Petri et al., 2019). Studies in rehabilitation settings have shown VR to be beneficial for postural control, but evidence in sports-specific adolescent populations is limited. The potential for VR to reduce injury risk by enhancing neuromuscular control is a promising area of investigation.

1.4 Research Gap

There is a need for randomized controlled trials comparing VR-based and conventional balance training in adolescent athletes, with a focus on both balance outcomes and injury prevention.

1.5 Study Objectives and Hypotheses

Purpose: To evaluate the effects of an 8-week VR-based balance training program on postural control and injury incidence in adolescent athletes.

Hypotheses:

1. VR-based balance training will result in greater improvements in postural control compared to conventional balance training.

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2. VR-based training will be associated with a lower incidence of minor balance-related injuries.

2. Methodology

2.1 Design

A single-blind, parallel-group randomized controlled trial was conducted.

2.2 Participants

Inclusion Criteria:

1. Age 13–17 years
2. Active participation in organized sports (≥3 sessions/week)
3. No lower limb injury in the past 6 months

Exclusion Criteria:

1. Neurological or vestibular disorders
2. Previous experience with VR-based training

Recruitment:

Sixty adolescent athletes were recruited from local sports academies. Written informed consent was obtained from parents/guardians and assent from participants.

2.3 Randomization and Blinding

Participants were randomly assigned (1:1) to the VR or conventional balance training group using a computer-generated sequence. Outcome assessors were blinded to group allocation.

2.4 Interventions

VR-Based Balance Training Group:

1. 8-week program, 3 sessions per week, 40 minutes per session
2. Commercial VR balance games (e.g., Wii Balance Board, Oculus Quest) targeting single-leg stance, dynamic reaching, and sport-specific balance tasks
3. Progressive difficulty and real-time feedback
4. Supervised by a certified athletic trainer

Conventional Balance Training Group:

1. 8-week program, 3 sessions per week, 40 minutes per session
2. Traditional balance exercises (e.g., single-leg stance, wobble board, dynamic reaching)
3. Matched for frequency and duration
4. Supervised by a certified athletic trainer

2.5 Outcome Measures

1. **Primary Outcomes:**
   a. Balance Error Scoring System (BESS)
   b. Star Excursion Balance Test (SEBT)

a. Balance Error Scoring System (BESS) Testing Procedure

Equipment and Setup: The BESS requires a firm surface, a foam pad, a stopwatch, and a score card. Participants should remove shoes and any ankle taping before testing; socks may be worn if desired.

Test Positions: The BESS consists of three stances performed on two surfaces (firm and foam), for a total of six conditions:

Double-leg stance: Feet together, hands on hips, eyes closed.

Single-leg stance: Stand on the non-dominant leg, hands on hips, eyes closed.

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Tandem stance: One foot directly in front of the other (heel-to-toe), non-dominant foot behind, hands-on hips, eyes closed.

Procedure: Each stance is held for 20 seconds. The examiner begins timing and counting errors only after the participant assumes the correct position.

Scoring: Errors are counted for each 20-second trial. An error is recorded when the participant:

a. Moves hands off iliac crests
b. Opens eyes
c. Steps, stumbles, or falls
d. Abducts or flexes the hip beyond 30°
e. Lifts forefoot or heel off the surface
f. Remains out of position for more than 5 seconds

Only one error is recorded if multiple errors occur simultaneously. The maximum number of errors per condition is 10.

Total Score: The errors from all six conditions are summed for a total score (maximum 60); lower scores indicate better balance.

b. Star Excursion Balance Test (SEBT) Testing Procedure

Equipment and Setup: The SEBT requires tape to mark the floor in a star pattern with eight lines extending at 45° increments from a central point.

Test Positions: The participant stands at the center of the star on the test leg.

Procedure:

a. The participant reaches as far as possible with the free leg along each of the eight lines, lightly touching the farthest point possible without losing balance or moving the stance foot.
b. The test is typically performed in three or eight directions, most commonly anterior, posteromedial, and posterolateral.
c. Each reach distance is measured from the center to the point of touch.
d. The participant returns to the starting position after each reach; the test is repeated for the opposite leg.

Scoring: The distance reached in each direction is recorded, usually normalized to leg length. Higher reach distances indicate better dynamic balance.

2. **Secondary Outcomes:**
   a. Sports performance metrics (vertical jump, agility T-test)
   b. Self-reported minor balance-related injuries (e.g., ankle sprains, slips)

2.6 Data Collection Procedure

Assessments were conducted at baseline (week 0) and post-intervention (week 8) by blinded assessors.

2.7 Data Analysis

SPSS v27 was used for data analysis. Descriptive statistics summarized participant characteristics. ANCOVA was used to assess between-group differences in post-intervention outcomes, controlling for baseline values. Statistical significance was set at $p < .05$.

2.8 Ethical Considerations

The study was approved by the University Institutional Review Board (IRB #2025-04). All procedures complied with the Declaration of Helsinki.

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3. Results

3.1 Participant Flow and Baseline Characteristics

Of 65 athletes screened, 60 were randomized (VR: n=30; conventional: n=30). Two participants (VR: n=1; conventional: n=1) withdrew due to unrelated injuries.

Table 1. Baseline Characteristics

Variable	VR Group (n=29)	Conventional Group (n=29)	p-value
Age (years)	15.2 (1.3)	15.1 (1.2)	0.76
Male (%)	52	55	0.81
Sport (team/individual)	18/11	17/12	0.82
BESS Score	19.5 (4.2)	19.7 (4.1)	0.89
SEBT Composite (%)	84.2 (5.7)	84.1 (5.9)	0.94

As shown in Table 1, there were no significant differences between the VR group and the conventional group in terms of baseline characteristics. The mean age was 15.2 years (SD = 1.3) in the VR group and 15.1 years (SD = 1.2) in the conventional group, p = .76. The proportion of male participants was similar between groups (VR: 52%; conventional: 55%), p = .81. The distribution of sport type (team vs. individual) was comparable (VR: 18/11; conventional: 17/12), p = .82. Baseline BESS scores were 19.5 (SD = 4.2) for the VR group and 19.7 (SD = 4.1) for the conventional group, p = .89. SEBT composite scores were also similar between groups (VR: 84.2%, SD = 5.7; conventional: 84.1%, SD = 5.9), p = .94. These results indicate that the groups were well matched at baseline across all measured variables.

3.2 Adherence and Safety

Mean session attendance was 93% (VR) and 91% (conventional). No serious adverse events occurred. Mild VR-related dizziness was reported in one participant and resolved spontaneously.

3.3 Postural Control (Primary Outcomes)

Table 2. Balance Outcomes

Outcome	VR (Pre)	VR (Post)	Conventional (Pre)	Conventional (Post)	p (group effect)
BESS (errors, lower is better)	19.5	12.1	19.7	15.9	0.003
SEBT Composite (%)	84.2	91.8	84.1	87.3	0.008

As shown in Table 2, both groups demonstrated improvements in balance from pre- to post-intervention; however, the VR group exhibited significantly greater improvements compared to the conventional group. For the BESS,

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the VR group improved from 19.5 errors pre-intervention to 12.1 errors post-intervention, whereas the conventional group improved from 19.7 to 15.9 errors, with a significant group effect (p = .003). Similarly, SEBT composite scores increased from 84.2% to 91.8% in the VR group and from 84.1% to 87.3% in the conventional group, with a significant group effect (p = .008). These findings indicate that the VR intervention was more effective than conventional training in enhancing balance performance.

3.4 Sports Performance and Injuries

Table 3. Secondary Outcomes

Outcome	VR (Pre)	VR (Post)	Conventional (Pre)	Conventional (Post)	p (group effect)
Vertical Jump (cm)	38.2	41.7	38.1	39.6	0.04
Agility T-test (sec)	10.1	9.3	10.0	9.7	0.09
Minor injuries (n)	4	1	5	4	0.03

As shown in Table 3, the VR group demonstrated significantly greater improvements in vertical jump height compared to the conventional group (p = .04). The VR group's vertical jump increased from 38.2 cm pre-intervention to 41.7 cm post-intervention, while the conventional group improved from 38.1 cm to 39.6 cm. Although both groups improved in agility, the difference between groups was not statistically significant (p = .09). The VR group's agility T-test times decreased from 10.1 to 9.3 seconds, and the conventional group improved from 10.0 to 9.7 seconds. Notably, the VR group also experienced a greater reduction in minor injuries (from 4 to 1), compared to the conventional group (from 5 to 4), with a significant group effect (p = .03). These results suggest that the VR intervention was associated with enhanced sports performance and a reduction in minor injuries relative to conventional training.

3. Interpretation

The VR-based balance training group demonstrated significantly greater improvements in both static and dynamic postural control compared to conventional training. The VR group also showed a trend toward better sports performance and reported fewer minor balance-related injuries during the intervention period.

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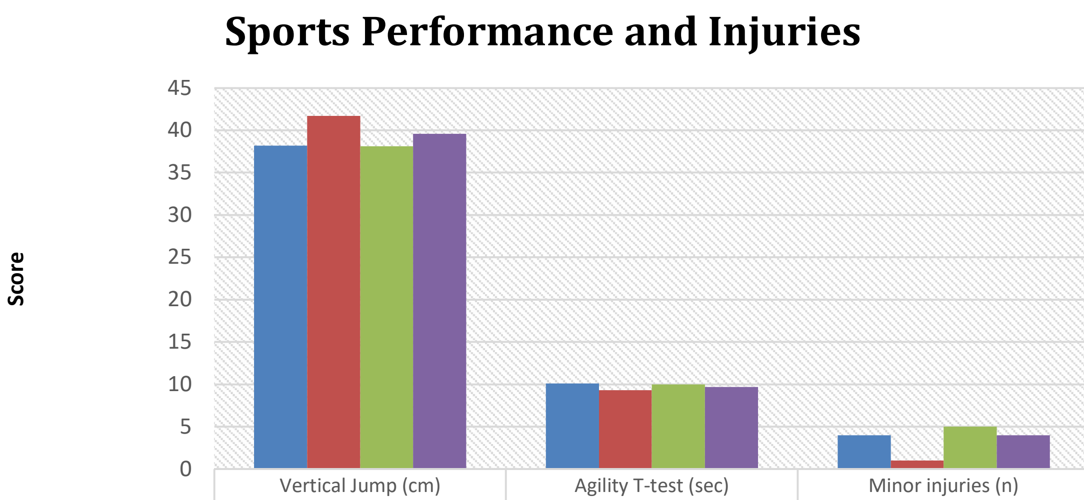

	Vertical Jump (cm)	Agility T-test (sec)	Minor injuries (n)
VR (Pre)	38.2	10.1	4
VR (Post)	41.7	9.3	1
Conventional (Pre)	38.1	10	5
Conventional (Post)	39.6	9.7	4

Figure 1: Bar Graph Showing Pretest and Post-test Sports Performance and Injuries Scores by Group

5. Discussion

5.1 Main Findings in Context

This study provides evidence that VR-based balance training is more effective than conventional methods for improving postural control in adolescent athletes. These findings align with previous research suggesting that VR enhances neuromuscular control and engagement (Petri et al., 2019; Grooms et al., 2015). The reduction in minor injuries further supports the potential of VR for injury prevention.

5.2 Mechanisms

VR-based training likely enhances balance through:

1. Increased engagement and motivation
2. Real-time feedback and task-specific practice
3. Simulation of sport-specific balance challenges

5.3 Practical and Policy Implications

1. **Sports Programs:** VR-based balance training can be integrated into youth athletic training regimens to enhance performance and reduce injury risk.
2. **Accessibility:** Commercially available VR systems offer scalable and engaging training options.
3. **Policy:** Investment in VR technology for sports training facilities is recommended.

5.4 Strengths and Limitations

Strengths:

1. Randomized controlled design with blinded assessment
2. Use of validated outcome measures
3. High adherence and safety profile

Limitations:

1. Short intervention and follow-up period; long-term effects unknown
2. Single-site study; generalizability may be limited
3. Mild VR-related side effects in a minority of participants

5.5 Future Directions

Future research should:

1. Assess long-term maintenance of gains and injury prevention
2. Compare different types of VR systems and training protocols
3. Explore cost-effectiveness and athlete preferences

6. Conclusion

VR-based balance training is a safe, effective, and engaging adjunct to conventional training for adolescent athletes. It significantly improves postural control and may reduce injury risk, supporting its integration into youth sports development programs.

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