

# INPLASY

## Application and Effectiveness of Virtual Reality Technology in Ankle Rehabilitation: Meta-Analysis

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### ADMINISTRATIVE INFORMATION

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**Review Stage at time of this submission** - Preliminary searches.

**Conflicts of interest** - None declared.

**INPLASY registration number:** INPLASY202510021

**Amendments** - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 7 January 2025 and was last updated on 7 January 2025.

### INTRODUCTION

**Review question / Objective** This meta-analysis aims to evaluate the effectiveness of virtual reality (VR) technology in the rehabilitation of ankle injuries compared to conventional rehabilitation methods or no intervention. Specifically, the review focuses on assessing the impact of VR interventions on balance, functional performance, and muscle strength.

#### PICOS Framework:

- Population (P): Individuals with ankle injuries, including lateral ankle sprains (LAS), chronic ankle instability (CAI), and functional ankle instability (FAI).
- Intervention (I): Virtual reality (VR)-based rehabilitation programs, including immersive and non-immersive systems.
- Comparator (C): Conventional rehabilitation methods or no intervention.

- Outcome (O): Primary outcomes include balance, functional performance, and muscle strength. Secondary outcomes include proprioception, pain reduction, and re-injury prevention.
- Study Design (S): Randomized controlled trials (RCTs) and quasi-experimental studies.

**Rationale** Ankle injuries, particularly lateral ankle sprains (LAS), chronic ankle instability (CAI), and functional ankle instability (FAI), are among the most common musculoskeletal injuries worldwide. These conditions can lead to long-term functional impairments, decreased balance, and increased risk of re-injury. Despite the effectiveness of traditional rehabilitation methods, such as physical therapy and balance training, these approaches often face limitations in terms of patient engagement, individualized feedback, and long-term adherence.

In recent years, virtual reality (VR) technology has emerged as a promising tool for rehabilitation. VR

interventions provide immersive, interactive environments that can enhance patient engagement, deliver real-time feedback, and offer personalized rehabilitation strategies. Preliminary studies suggest that VR-based rehabilitation may improve outcomes such as balance, functional performance, and muscle strength while potentially reducing pain and re-injury rates. However, the effectiveness of VR interventions in ankle rehabilitation remains underexplored, with limited systematic evidence to support their widespread implementation.

This meta-analysis aims to address this gap by synthesizing existing research on VR-based rehabilitation for ankle injuries. By comparing VR interventions to conventional rehabilitation methods, the study seeks to provide robust evidence on the clinical and functional outcomes of VR in this context. The findings will offer valuable insights into the potential of VR technology to revolutionize ankle rehabilitation, improve patient outcomes, and reduce healthcare costs.

**Condition being studied** The condition being studied in this review includes ankle injuries, specifically lateral ankle sprains (LAS), chronic ankle instability (CAI), and functional ankle instability (FAI). Ankle injuries are among the most common musculoskeletal injuries globally, with an annual incidence rate of 2.15 per 1,000 people and significantly higher rates among athletes. These injuries often occur during physical activity, particularly in high-impact sports such as basketball, soccer, and track and field.

Ankle injuries can lead to long-term functional impairments, including reduced balance, weakened muscle strength, and compromised proprioception. Recurrent injuries are common, with rates as high as 34%, and can result in chronic conditions such as CAI, characterized by pain, instability, and reduced quality of life. Traditional rehabilitation methods, such as balance and strength training, aim to restore function and prevent re-injury. However, these approaches face challenges in delivering individualized feedback, maintaining patient adherence, and providing engaging rehabilitation environments.

This review focuses on the effectiveness of virtual reality (VR)-based rehabilitation as a novel approach to address these challenges. VR interventions offer immersive, interactive environments that may enhance recovery outcomes by improving balance, functional

performance, and muscle strength, while potentially reducing re-injury rates.

## METHODS

**Participant or population** This review will include individuals diagnosed with ankle injuries, specifically lateral ankle sprains (LAS), chronic ankle instability (CAI), and functional ankle instability (FAI). Eligible participants may be athletes or non-athletes, with no restrictions on gender or ethnicity. The review will focus on adult participants aged 18 years or older, who are undergoing rehabilitation interventions for ankle injuries.

Studies involving participants with other lower limb injuries, neurological disorders, or systemic conditions affecting balance and mobility will be excluded to ensure the homogeneity of the population studied.

**Intervention** The intervention evaluated in this review is virtual reality (VR)-based rehabilitation for ankle injuries, including lateral ankle sprains (LAS), chronic ankle instability (CAI), and functional ankle instability (FAI). VR interventions may involve immersive systems (e.g., head-mounted displays) or non-immersive systems (e.g., screen-based systems, motion-sensing consoles like Nintendo Wii or Xbox Kinect).

These interventions aim to provide balance training, proprioceptive exercises, and functional rehabilitation in an engaging, interactive environment. VR technology enables real-time feedback, personalized training programs, and simulated scenarios that mimic real-life conditions, potentially enhancing patient adherence and rehabilitation outcomes.

Studies where VR is used solely for educational purposes or as a diagnostic tool without active rehabilitation will be excluded.

**Comparator** The comparator interventions in this review include conventional rehabilitation methods or no intervention. Conventional rehabilitation methods may involve physical therapy, balance training, proprioceptive exercises, or strength training delivered without the use of virtual reality (VR) technology. These methods are widely recognized as standard practices for ankle injury rehabilitation.

Studies comparing VR-based rehabilitation to placebo interventions, sham therapy, or alternative therapies that do not specifically target ankle

rehabilitation will also be considered. However, interventions targeting injuries outside the ankle joint will be excluded.

**Study designs to be included** This review will include randomized controlled trials (RCTs) and quasi-experimental studies that evaluate the effectiveness of virtual reality (VR)-based rehabilitation for ankle injuries. Eligible studies must provide quantitative data on primary outcomes such as balance, functional performance, or muscle strength. Observational studies, case series, case reports, and qualitative studies will be excluded to maintain methodological rigor.

#### Eligibility criteria

- Additional Inclusion Criteria:
  - Studies published in peer-reviewed journals.
  - Studies available in English or Chinese.
  - Studies reporting sufficient data to calculate effect sizes for meta-analysis.
  - Interventions conducted in clinical, rehabilitation, or sports settings.
- Additional Exclusion Criteria:
  - Studies with participants who have neurological disorders or systemic conditions affecting balance and mobility.
  - Studies using VR interventions solely for educational purposes or diagnostics without active rehabilitation.
  - Conference abstracts, theses, dissertations, and unpublished studies.
  - Studies lacking a comparator group or relevant outcome data.

**Information sources** The primary information sources for this review will include electronic databases such as PubMed, Cochrane Library, Embase, Web of Science, and Scopus. These databases will be systematically searched using predefined keywords and Boolean operators to identify relevant studies.

In addition, the reference lists of included studies and related systematic reviews will be manually searched to identify additional eligible studies. Grey literature, such as conference proceedings and dissertations, will not be included. If necessary, authors of selected studies may be contacted to clarify missing data or obtain supplementary information.

#### Main outcome(s)

The primary outcomes of this review are:

1. Balance: Measured using standardized tests such as the single-leg stance test or Biodex

Balance System. Timing: baseline and post-intervention.

2. Functional Performance: Assessed through tasks like the timed up-and-go test and hopping tests. Timing: baseline and post-intervention.

3. Muscle Strength: Measured using isokinetic dynamometry or manual muscle tests. Timing: baseline and post-intervention.

Effect measures will include mean differences (MD) or standardized mean differences (SMD) for continuous outcomes, with 95% confidence intervals.

**Quality assessment / Risk of bias analysis** The quality of included studies will be assessed using the Cochrane Risk of Bias (RoB 2.0) tool for randomized controlled trials and the ROBINS-I tool for quasi-experimental studies. The following domains will be evaluated:

1. Cochrane Risk of Bias Tool (RoB 2.0):
  - Random sequence generation (selection bias)
  - Allocation concealment (selection bias)
  - Blinding of participants and personnel (performance bias)
  - Blinding of outcome assessment (detection bias)
  - Incomplete outcome data (attrition bias)
  - Selective reporting (reporting bias)
  - Other potential sources of bias
2. ROBINS-I Tool:
  - Bias due to confounding
  - Bias in selection of participants
  - Bias in classification of interventions
  - Bias due to deviations from intended interventions
  - Bias due to missing data
  - Bias in measurement of outcomes
  - Bias in selection of the reported result

Two independent reviewers will perform the quality assessment. Discrepancies will be resolved through discussion or by consulting a third reviewer. Results of the risk of bias assessment will be presented in tabular form and included in the interpretation of the findings to ensure the robustness of conclusions.

**Strategy of data synthesis** The data will be synthesized using a meta-analysis approach where appropriate. For continuous outcomes such as balance, functional performance, and muscle strength, the effect sizes will be calculated as mean differences (MD) or standardized mean differences (SMD) with 95% confidence intervals (CI). Heterogeneity among studies will be assessed using the  $I^2$  statistic and Cochran's Q test, with  $I^2$  values above 50% indicating substantial heterogeneity.

A random-effects model will be applied to account for between-study variability. Subgroup analyses will be conducted to explore potential sources of heterogeneity, such as type of VR intervention (immersive vs. non-immersive), participant characteristics (e.g., age or type of ankle injury), and intervention duration. Sensitivity analyses will be performed by excluding studies with a high risk of bias to evaluate the robustness of the results.

When meta-analysis is not feasible due to insufficient or highly heterogeneous data, a narrative synthesis will be conducted to summarize the findings. All analyses will be performed using RevMan or Comprehensive Meta-Analysis (CMA) software. The results will be presented as forest plots for quantitative outcomes and descriptive summaries for narrative findings.

**Subgroup analysis** Subgroup analyses will be conducted to explore potential sources of heterogeneity and provide a deeper understanding of the effects of virtual reality (VR)-based rehabilitation for ankle injuries. The planned subgroups include:

1. Type of Ankle Injury:
  - Lateral ankle sprains (LAS) vs. chronic ankle instability (CAI) vs. functional ankle instability (FAI).
2. Type of VR Intervention:
  - Immersive VR systems (e.g., head-mounted displays) vs. non-immersive systems (e.g., screen-based or motion-sensing consoles).
3. Participant Age Group:
  - Younger adults (18–35 years) vs. older adults (36+ years).
4. Intervention Duration:
  - Short-term interventions (<6 weeks) vs. long-term interventions (≥6 weeks).

The analyses will be conducted using a random-effects model to account for between-study variability. Interaction tests will be performed to assess statistical differences between subgroups. The results will help identify which populations or intervention types benefit the most from VR-based rehabilitation.

**Sensitivity analysis** Sensitivity analyses will be conducted to assess the robustness and reliability of the meta-analysis results. These analyses will involve:

1. Excluding Studies with High Risk of Bias:
  - Studies assessed as having a high risk of bias in the quality assessment will be excluded to evaluate their impact on the overall results.
2. Varying Effect Models:

- The results will be compared using both fixed-effects and random-effects models to assess the influence of model selection.

### 3. Excluding Small Sample Studies:

- Studies with a small sample size (e.g., <30 participants) will be excluded to determine their contribution to heterogeneity and overall effect size.

### 4. Alternative Outcome Metrics:

- Sensitivity analyses will assess the influence of using different metrics for the same outcome (e.g., mean differences vs. standardized mean differences).

The results of sensitivity analyses will be reported in detail to provide insights into the stability of the findings and ensure the reliability of the conclusions.

**Language restriction** The search will be limited to studies published in English and Chinese.

**Country(ies) involved** The search will be limited to studies published in English and Chinese.

**Keywords** Virtual reality; Ankle rehabilitation; Ankle injuries; Chronic ankle instability; Functional ankle instability; Balance training; Muscle strength; Meta-analysis.

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