# THE EFFECTS OF CHRONIC ANKLE INSTABILITY ON THE BIOMECHANICS OF THE UNINJURED, CONTRALATERAL HIP DURING SINGLE-LEG LANDING IN RECREATIONAL BADMINTON PLAYERS: AN OBSERVATIONAL STUDY

**BY**

**PREETI SARAF**

**Dissertation Submitted to the**

**Odisha University of Health Science, Bhubaneswar, Odisha**

**In partial fulfilment**

**of the requirements for the degree of**

**MASTER OF PHYSIOTHERAPY (MPT)**

**In**

**SPORTS SCIENCES**

**Under the guidance of**

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**VICE PRINCIPAL, ABSMARI**

**ABHINAV BINDRA SPORTS MEDICINE & RESEARCH INSTITUTE**

**Bhubaneswar, Odisha**

**2023-2025**

## Odisha University of Health Sciences

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I hereby declare that this dissertation, entitled "**THE EFFECTS OF CHRONIC ANKLE INSTABILITY ON THE BIOMECHANICS OF THE UNINJURED, CONTRALATERAL HIP DURING SINGLE-LEG LANDING IN RECREATIONAL BADMINTON PLAYERS: AN OBSERVATIONAL STUDY"**is a bonafide and genuine research work carried out by me under the guidance of Dr Deepak Kumar Pradhan, Vice Principal, Abhinav Bindra Sports Medicine & Research Institute, Bhubaneswar, Odisha.

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**Place: Odisha** **Name: PREETI SARAF**

**University Reg. NO : 23MP435050**

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| | |
|---|---|
| **Date:** | **Seal & Signature of the Guide** |
| **Place: Bhubaneswar,** | **Deepak Kumar Pradhan (PT)** |
| **Odisha** | **Vice Principal, ABSMARI** |

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**Date:** **Seal & Signature of the Principal**

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Date: Signature of the Candidate

Place: Bhubaneswar, Odisha Preeti Saraf

## LIST OF ABBREVIATIONS USED

ABSMARI - Abhinav Bindra Sports Medicine & Research Institute

BMI - Body Mass Index

CAI - Chronic Ankle Instability

CAIT - Cumberland Ankle Instability Tool

3D - Three-Dimensional

EMG - Electromyography

SPSS- Statistical Package for Social Sciences

ABSTRACT

**Background:** Chronic ankle instability (CAI) is a common sequela of recurrent ankle sprains, often leading to compensatory biomechanical changes across the lower extremity kinetic chain. While previous research has focused primarily on the injured ankle and ipsilateral knee, limited evidence exists regarding the effects of CAI on the contralateral hip during functional sports activities such as single-leg landings in badminton.

**Purpose:** The present study aimed to investigate the influence of unilateral CAI on the biomechanics of the contralateral, uninjured hip during single-leg landing tasks in recreational badminton players.

**Methods**: An observational study was conducted among 40 recreational badminton players aged 18–35 years, recruited through purposive sampling. Participants were divided into two groups: CAI (n=20) and Without CAI (n=20), confirmed using the Cumberland Ankle Instability Tool (CAIT). Kinematic data of the contralateral hip, including flexion–extension, abduction–adduction, internal–external rotation, and angular velocities, were recorded using the Xsens 3D Motion Capture System. Statistical analysis was performed using independent t-tests and Mann–Whitney U tests, with significance set at $p \leq 0.05$.

**Results:** The CAI group demonstrated higher mean values in hip flexion–extension, abduction–adduction, and internal–external rotation angles compared to controls; however, these differences were not statistically significant ($p > 0.05$). Similarly, variations in hip angular velocities were observed but did not reach statistical significance. Notably, participants with CAI exhibited higher BMI values, which may have contributed to compensatory adaptations.

**Conclusion** Conclusion: During single-leg landings, CAI may cause minor compensatory changes at the contralateral hip, indicating that its effects go beyond the ankle. To maximize performance and stop additional injuries, a thorough rehabilitation program should target both the proximal and distal joints.

**Keywords:** Badminton; Biomechanical Phenomena; Ankle Joint; Hip Joint; Recreational Activities; Postural Balance; Athletes.

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# INTRODUCTION

Ankle sprains rank among the most frequent injuries in both recreational and competitive sports. Epidemiological data indicate that nearly half of these injuries (approximately 49.3%) occur during sporting activities, highlighting their significance as a concern for both athletes and healthcare professionals [1].

Although many acute sprains resolve with conservative management, a substantial proportion of cases are not adequately rehabilitated, leading to persistent dysfunction. As a result, approximately 10–40% of individuals develop CAI following an initial sprain, with about 15–20% progressing to CLAI. [2,3,4].

This condition is characterized by repeated episodes of the ankle "giving way," recurrent sprains, and functional limitations, which may compromise both athletic performance and daily living.

The long-term implications of CAI extend beyond recurrent sprains. Persistent mechanical and functional instability predispose the ankle joint to early degenerative changes, including cartilage breakdown, ligament laxity, and post-traumatic osteoarthritis [5,6].

Importantly, the consequences of CAI are not confined to the ankle alone. According to the lower-extremity kinematic chain theory, dysfunction in one joint can influence movement patterns at adjacent joints.

Evidence suggests that individuals with CAI demonstrate compensatory modifications in knee and hip kinematics, both ipsilaterally and contralaterally, as the body attempts to maintain stability during dynamic activities [7,8].

These adaptations, while protective in the short term, may increase stress on proximal joints, heightening the risk of secondary injuries and impairing overall performance.

Badminton provides a particularly relevant context to study CAI because of the sport's physical demands. As one of the fastest non-contact racket sports, badminton requires rapid directional changes, high-intensity jumps, and explosive smashes, all performed within a confined playing area.

Its popularity has surged worldwide and in India in particular, partly because it requires only two players and minimal equipment compared to sports like cricket or football [9].

While these features make badminton accessible to both recreational and elite athletes, the physical exertion — involving agility, speed, and repetitive landings — places considerable stress on the lower extremities.

Notably, recreational players often lack adequate knowledge of warm-up routines, proper techniques, and injury-prevention strategies, making them especially vulnerable to injury [9,10].

Epidemiological studies estimate that badminton-related injuries account for approximately 1–5% of all sports injuries, with the ankle being one of the most frequently affected sites [9,10].

For athletes with chronic ankle instability (CAI), the physical demands of badminton heighten the likelihood of injury. Evidence indicates that CAI impairs dynamic balance, diminishes lower-limb muscle strength, and raises the risk of recurrent sprains [11].

These deficits can alter movement patterns during play, leading to less efficient biomechanics. Beyond the physical challenges, the psychological fear of re-injury may further reduce confidence and performance. Collectively, these factors contribute to a cycle of instability, compensation, and increased vulnerability to injury. Among the most demanding movements in badminton is the single-leg landing, commonly performed during jump smashes and defensive recoveries. Although this action enables rapid repositioning, it requires precise neuromuscular control to minimize injury risk. Athletes with CAI frequently demonstrate altered landing mechanics, such as greater hip flexion and ankle eversion at impact [12,13].

These changes are thought to represent compensatory mechanisms aimed at minimizing inversion stresses on the unstable ankle; however, they may inadvertently increase loading on proximal joints and disrupt the efficiency of the kinematic chain. Such biomechanical alterations highlight the interconnectedness of the ankle, knee, and hip joints and underscore the need for comprehensive assessment beyond the site of the primary injury.

The goal of the current study is to assess and compare the bilateral ankle, knee, and hip joint kinematics in patients with unilateral CAI and compare the results with those of healthy controls [13,14]. In addition to altering the biomechanics of the injured ankle, we hypothesize that CAI causes ipsilateral and contralateral adaptations at the knee and hip joints [15,16].

A better knowledge of these inter-joint relationships can help guide sport-specific interventions and focused rehabilitation protocols, which will ultimately lower the risk of injury and improve badminton players' performance[17,18].

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# AIM & OBJECTIVES

**Aim**

To observe and analyse the contralateral hip joint kinematics during a single-leg drop landing task among recreational badminton players with or without CAI.

**Objective**

To observe the kinematic parameters of the contralateral hip joint during a single-limb landing task using the movement analysis method among recreational badminton players with or without CAI.

# HYPOTHESIS

**Alternate Hypothesis (HI):**

There will be significant differences in the kinematic parameters of the contralateral hip during single-leg landings between recreational badminton players with CAI and those without CAI.

**Null Hypothesis (H0):**

There will be no significant differences in the kinematic parameters of the contralateral hip during single-leg drop landings between recreational badminton players with CAI and those without CAI.

# REVIEW OF LITERATURE

1**. In 2024, Sagawa Y, Yamada T, Ohmi T, Moriyama Y, and Kato J** conducted a study on the differences in lower extremity kinematics during single-leg lateral drop landings among healthy individuals, copers, and patients with chronic ankle instability (CAI). The research aimed to determine if CAI individuals use altered movement strategies during activities like landing. Using motion capture technology, they recorded hip, knee, and ankle kinematics. The results showed that CAI patients exhibited significant changes in hip adduction/abduction, ankle plantarflexion/dorsiflexion, and midfoot inversion/eversion compared to other groups. These findings highlight that CAI individuals depend on compensatory movements, increasing their risk for recurrent ankle sprains, emphasizing the need for targeted rehabilitation.

2**. In 2022, Gabriel Moisan, Camille Mainville, Martin Descarreaux, and Vincent Cantin** conducted an experimental study on how different landing surfaces affect biomechanics in individuals with CAI. They analyzed drop-jump landings on flat, unstable (foam), and inclined wedge surfaces, monitoring kinematics, kinetics, and electromyographic activity of lower limb muscles. The findings revealed that CAI participants showed increased ankle inversion and plantar flexion, along with decreased activation of the peroneus longus muscle, especially on unstable surfaces. These changes heighten the risk of recurrent ankle injuries in CAI patients. The study concluded that rehabilitation for CAI should include surface-challenging exercises to enhance neuromuscular control.

3. **In 2023, Shibata S and colleagues** explored how neurocognitive function affects biomechanics during single-leg drop-jump landings followed by unanticipated tasks in female athletes. Using kinematic, kinetic, and electromyographic analysis, they examined whether neurocognitive performance influences lower limb mechanics. They found that athletes with lower neurocognitive function exhibited altered knee flexion angles, delayed muscle activation, and less efficient trunk control, increasing the risk of injuries like ACL tears. The study highlighted the need to incorporate cognitive challenges into training programs, especially for athletes at high risk of lower limb injuries.

4**. In 2022, Li Yi Tammy Chan and colleagues** conducted a systematic review and meta-analysis to assess how chronic ankle instability (CAI) affects kinematics, dynamic postural stability, and muscle activity during unilateral jump-landing tasks. By pooling data from various studies involving athletes and recreationally active individuals with CAI, they concluded that CAI is linked to impaired postural stability, altered ankle and knee mechanics, and abnormal neuromuscular activation patterns. These findings suggest that CAI is not just a localized ankle issue but involves global movement control deficits. The authors recommended rehabilitation efforts focusing on proprioception, strength, and neuromuscular re-education.

5. **In 2016, Cailbhe Doherty, Chris Bleakley, Jay Hertel, Brian Caulfield, John Ryan, and Eamonn Delahunt** conducted a comparative study analyzing single-leg drop landing strategies in CAI participants versus lateral ankle sprain copers. Motion analysis revealed that CAI participants showed reduced hip and knee flexion and altered ankle joint mechanics during landing tasks. These changes increased ground reaction forces and joint loading, making them more prone to repeated ankle injuries. On the other hand, copers used more stable strategies, demonstrating that successful adaptation helps protect against chronic instability.

6. **Karthick Rangasamy and colleagues conducted a study in 2022** on injury risk prediction among recreational badminton players. The research aimed to examine common injury patterns and contributing risk factors. Data collected from players through injury reports and questionnaires showed Indian players had higher injury rates than international counterparts, mainly due to inadequate warm-ups, low physical fitness, and poor injury prevention awareness. The study highlighted the urgent need for structured fitness programs, education, and injury prevention initiatives for recreational athletes.

7. **In 2021, Walaa S. Mohammad, Faten F. Elattar, Walaa M. Elsais, and Salameh O. AlDajah** conducted a reliability study to assess the validity of a smartphone-based clinometer app for measuring hip, knee, and ankle range of motion (ROM). The study compared readings from the smartphone app to those

from a digital inclinometer. Results showed strong validity and reliability for hip and knee measurements, but less consistency for ankle assessments. The authors concluded that while smartphone apps offer an accessible and cost-effective clinical tool, caution is needed when using them for ankle measurements.

8. **Daniel Debertrn, Anna Wargel, and Maurice Mohr** conducted an experimental study on the reliability of Xsens IMU-based motion capture systems for measuring lower extremity joint angles during in-field running. The study aimed to validate the accuracy of wearable sensors in real-world settings. Results revealed good reliability for within-day measurements but variability across different days. This suggests that Xsens IMUs hold promise for sports and rehabilitation assessments, but long-term monitoring requires careful standardization.

9**. In 2021, Elaheh Z, Mohammad R, Mohammad Haghanpahi, and Bart Lubberts** conducted a study to determine if unilateral chronic ankle instability affects the kinematics of other lower extremity joints. Using 3D motion analysis, they compared joint movements in CAI patients to healthy controls. The results showed significant biomechanical changes not only in the injured ankle but also in the ipsilateral knee and the contralateral ankle and hip joints. These compensatory adjustments were found to negatively impact gait and functional performance, highlighting the need to consider the entire kinetic chain in CAI rehabilitation.

10**. In 2022, Elaheh Z** and her team followed up with a study investigating whether unilateral CAI changes the biomechanics of the contralateral ankle. Participants with unilateral CAI performed walking and landing tasks while their kinematic data were recorded. The findings revealed reduced dorsiflexion, altered toe angles, and deviations in the inversion and eversion range of motion in the uninjured ankle. The study concluded that these compensatory mechanisms associated with CAI could raise the risk of dysfunction in the contralateral ankle, stressing the importance of bilateral training and assessment in CAI rehabilitation programs.

**TABLE 1: REVIEW OF LITERATURE**

| Sr. No | Authors (Year) | Aim | Method | Findings / Insights |
|---|---|---|---|---|
| 1 | Sagawa Y, Yamada T, Ohmi T, Moriyama Y, & Kato J (2024) | To determine if CAI individuals use altered movement strategies during single-leg lateral drop landings. | Motion capture technology was used to record hip, knee, and ankle kinematics in healthy individuals, copers, and CAI patients. | CAI patients showed significant changes in hip adduction/abduction, ankle plantarflexion/dorsiflexion, and midfoot inversion/eversion. CAI patients rely on compensatory strategies, increasing recurrent sprain risk and highlighting the need for targeted rehabilitation. |
| 2 | Moisan G, Mainville C, Descarreaux M, & Cantin V (2022) | To analyze how landing surfaces affect biomechanics in CAI individuals. | Drop-jump landings were performed on flat, unstable (foam), and inclined wedge | CAI participants showed increased ankle inversion and plantarflexion, with decreased peroneus longus activation, especially on unstable surfaces. Rehabilitation |

| | | | | |
|---|---|---|---|---|
| | | | surfaces, measuring kinematics, kinetics, and EMG activity. | should include surface-challenging exercises to improve neuromuscular control and prevent reinjury. |
| 3 | Shibata S et al. (2023) | To examine the effect of neurocognitive function on biomechanics during single-leg drop-jump landings followed by unanticipated tasks. | Kinematic, kinetic, and EMG analysis were used on female athletes with varied neurocognitive function levels. | Lower neurocognitive function was linked with altered knee flexion, delayed muscle activation, and poor trunk control. Cognitive-motor training should be integrated into rehabilitation to reduce injury risk, particularly ACL injuries. |
| 4 | Chan L. Y. T. et al. (2022) | To systematically review the effect of CAI on kinematics, postural stability, and muscle | Systematic review and meta-analysis pooling studies on CAI athletes and recreational individuals. | CAI was associated with impaired postural stability, altered ankle/knee mechanics, and abnormal neuromuscular activation. CAI should be addressed as a global motor control issue, and rehab should |

| | | | | |
|---|---|---|---|---|
| | | activity during unilateral jump-landing. | | focus on proprioception, strength, and neuromuscular training. |
| 5 | Doherty C, Bleakley C, Hertel J, Caulfield B, Ryan J, & Delahunt E (2016) | To compare single-leg landing strategies between CAI participants and copers. | Motion analysis of hip, knee, and ankle kinematics during landing tasks. | CAI participants showed reduced hip/knee flexion and altered ankle mechanics, leading to higher joint loading. Successful adaptation in copers shows the importance of targeted interventions to reduce joint stress and reinjury risk. |
| 6 | Rangasamy K et al. (2022) | To identify injury risk patterns and contributing factors among recreational badminton players. | Injury data collected through questionnaires and reports from Indian recreational badminton players. | Indian players had higher injury rates, mainly due to poor warm-up, low fitness, and poor injury-prevention awareness. Structured fitness programs and preventive education are urgently needed for recreational athletes. |

| | | | | |
|---|---|---|---|---|
| 7 | Mohammad W. S., Elattar F. F., Elsais W. M., & AlDajah S. O. (2021) | To assess the reliability of a smartphone-based clinometer for lower limb ROM measurement. | Compared smartphone clinometer readings to a digital inclinometer. | Strong validity for hip and knee ROM, lower consistency for ankle measurements. Smartphone apps are cost-effective tools but should be used cautiously for ankle ROM. |
| 8 | Debertrn D, Wargel A, & Mohr M (2021) | To validate the reliability of Xsens IMU-based motion capture for joint angle measurement during running. | Measured lower-limb joint angles across multiple days using Xsens IMUs. | Good within-day reliability but variability across days. Xsens IMUs are promising tools for sports/rehab research, but protocols need standardization for longitudinal monitoring. |
| 9 | Elaheh Z, Mohammad R, Haghanpahi M, & Lubberts B (2021) | To analyze whether unilateral CAI affects ipsilateral and contralateral lower-limb | 3D motion analysis comparing CAI patients and healthy controls. | Significant changes found in ipsilateral knee, contralateral ankle, and hip kinematics, negatively impacting gait. Rehabilitation should consider the entire kinetic |

| | | | | |
|---|---|---|---|---|
| | | kinematics. | | chain rather than only the injured ankle. |
| 10 | Elaheh Z et al. (2022) | To investigate if CAI alters biomechanics of the contralateral ankle. | Participants with CAI performed walking and landing tasks; contralateral ankle kinematics were recorded. | Reduced dorsiflexion, altered toe angles, and ROM deviations were seen in the contralateral ankle. Bilateral training and assessment are essential in CAI rehab to prevent secondary dysfunction. |

# METHODOLOGY & PROCEDURE

- Study design: Observational study
- Study population: Recreational badminton players
- Sample technique: purposive sample
- Sample size: 40
- Study setting: ABSMARI
- Study duration: 1 year
- Ethical clearance: 6 months
- Sample selection, data collection: 4 months
- Statistical analysis, results, discussion: 2 months

**Participants**

An observational study was carried out on 40 recreational badminton players at ABSMARI, Bhubaneswar, following ethical clearance (Protocol ID: ABS-IEC-2025-PHY-060). Participants aged 18–35 years were chosen through purposive sampling. Unilateral CAI was confirmed among players using the Cumberland Ankle Instability Tool (CAIT), alongside a healthy control group.

**Inclusion criteria:** Aged 18–35 years, recreational players (>4 hours per week), unilateral CAI verified by CAIT, or healthy without CAI, with no ankle injuries in the past six months.

**Exclusion criteria:** Major lower limb injuries or fractures, neurological or musculoskeletal disorders, previous lower limb surgeries, or ongoing CAI treatment.

**Sample Size Calculation**

The sample size of 40 participants was determined using G*Power software (effect size 0.65, $\alpha = 0.05$, power = 0.90).

**Material Used**

1. Cumberland Ankle Instability Tool (CAIT)
2. Wooden Box Size 30cm
3. 3D MOTION CAPTURE SYSTEM

**Procedure**

The study was carried out at ABSMARI, Bhubaneswar, over a period of one year. Ethical clearance was obtained before commencement, and participants were recruited through purposive sampling based on predefined inclusion and exclusion criteria.

Each participant was initially screened using a pre-screening form to collect demographic details, injury history, and eligibility information.

The Cumberland Ankle Instability Tool (CAIT) questionnaire was administered to assess ankle stability, and only those with acceptable scores who met the inclusion criteria were enrolled.

All eligible participants were informed about the study protocol, including its purpose, expected benefits, and minimal risks.

Written informed consent was obtained before data collection. Baseline calibration was then performed using a 3D motion capture system. Inertial measurement unit sensors were secured at the pelvis, hip, knee, and ankle joints with proper strapping, and calibration was carried out in a standardized standing posture to ensure accuracy.

Before the main trials, familiarization sessions were conducted to reduce variability due to learning effects. A wooden box of 30 cm height was used as the standardized platform for drop landings. Participants were instructed to step off the box and perform a single-leg drop landing on the contralateral, uninjured leg. After familiarization, each participant completed three to five successful single-leg drop landings while maintaining balance upon landing.

Hip joint kinematics, including flexion, extension, abduction, adduction, and rotation, were recorded through the motion capture system, while contralateral hip inclination was measured using a digital inclinometer. Mean values from valid trials were taken forward for analysis. Data were entered into SPSS version 25, where descriptive statistics such as mean and standard deviation were calculated. Inferential analyses, including independent t-tests and one-way ANOVA, were performed, and statistical significance was set at $p < 0.05$.

All testing was supervised by trained personnel, and safety measures such as warm-up exercises, the use of spotters, and a non-slippery floor surface were ensured throughout the sessions. No adverse events or injuries occurred during the course of data collection.

**FLOW CHART**

Approval From The IRC

↓

Permission From The College For Equipment

↓

Screening The Subject

↓

Selecting The Subject based on Inclusion Criteria & Exclusion Criteria.

↓

Explaining The Procedure And Method And Signing The Consent Form

↓

Preparation Of Participants

↓

Data Collection

↓

Data Analysis

↓

Result And Conclusion

**Figure 1. Single-leg drop landing task performed by a Male participant with Xsens motion capture sensors.**

**Figure 2.. Single-leg drop landing task performed by a Female participant with Xsens motion capture sensors.**

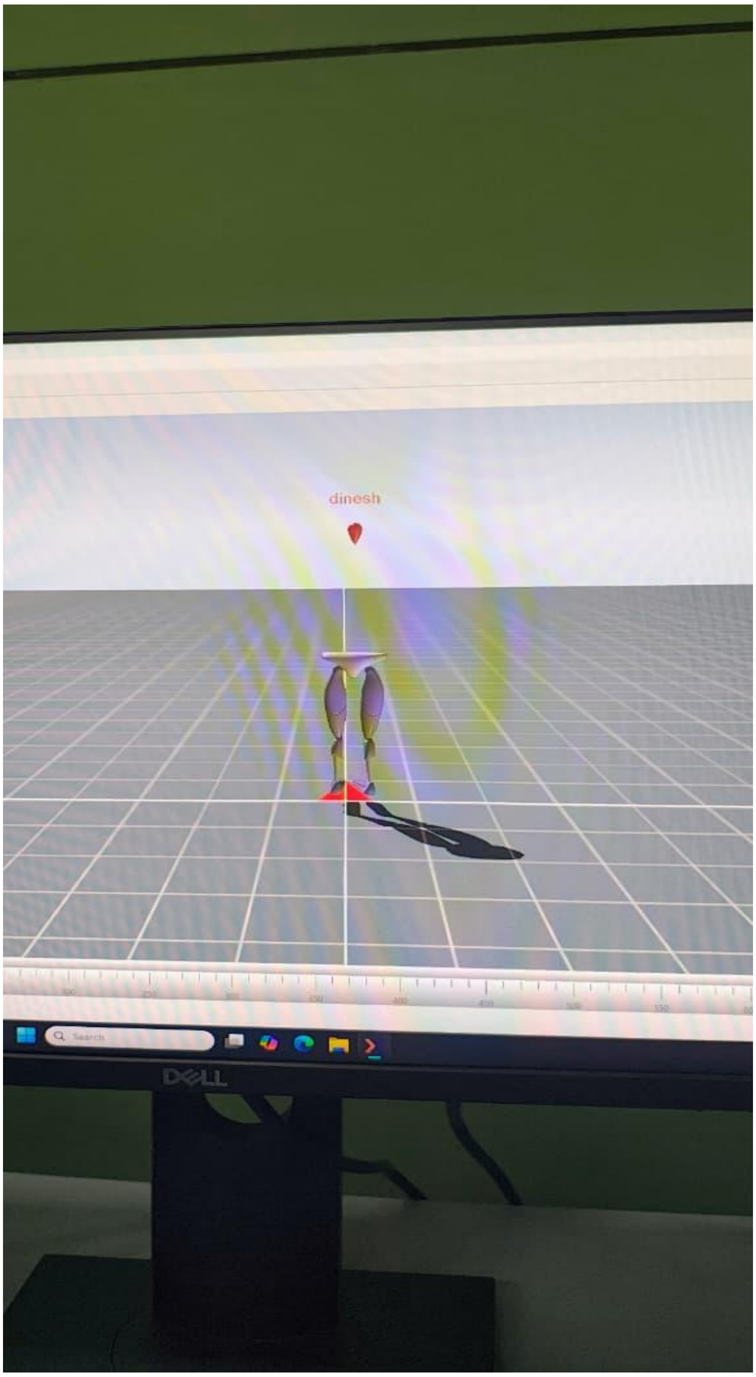
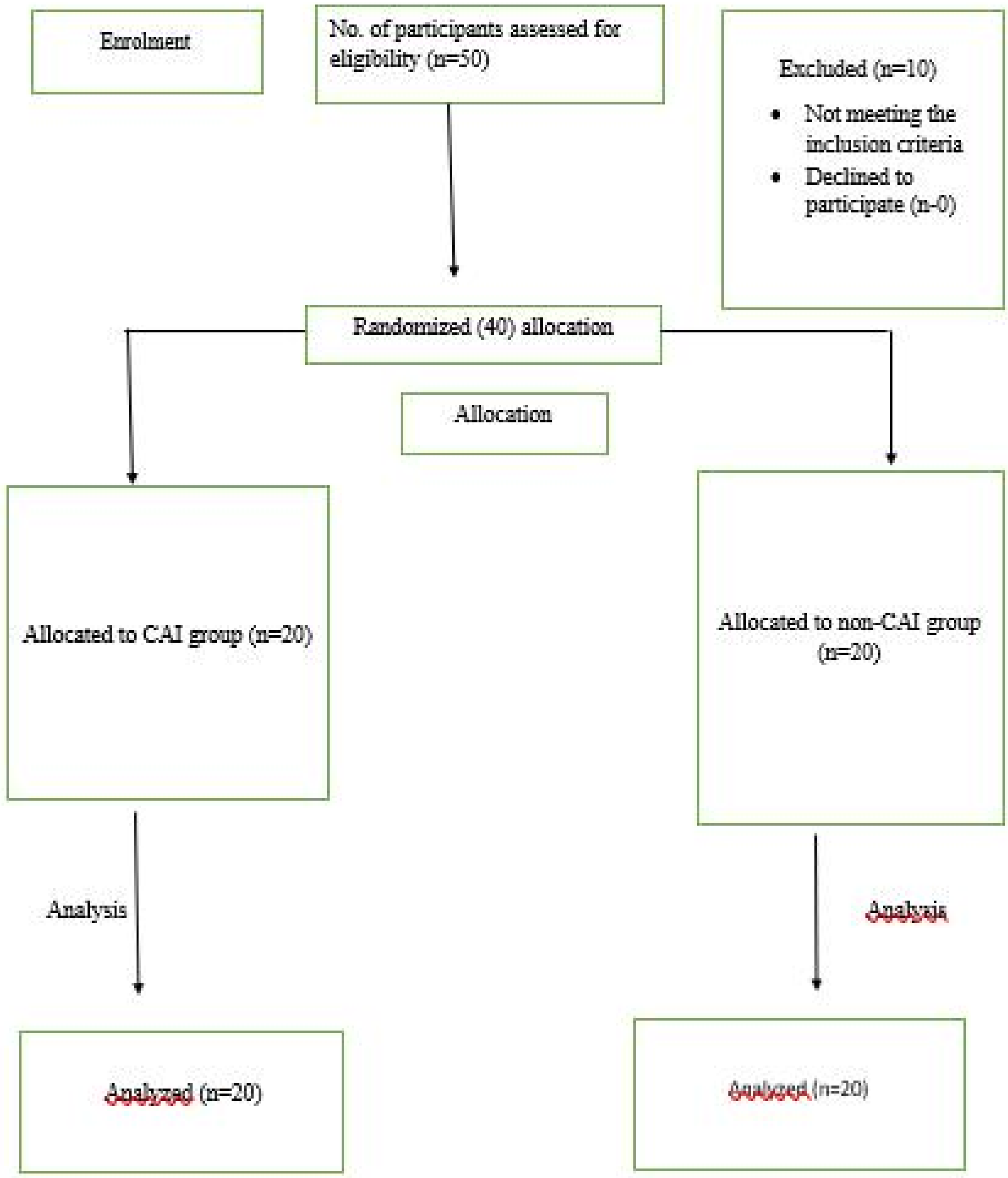



**Figure 3. Motion capture data visualization in Xsens software during single-leg drop landing**.


Enrolment
No. of participants assessed for eligibility (n=50)
Excluded (n=10)
Not meeting the inclusion criteria
Declined to participate (n-0)
Randomized (40) allocation
Allocation
Allocated to CAI group (n=20)
Allocated to non-CAI group (n=20)
Analysis
Analysis
Analyzed (n=20)
Analyzed (n=20)

**Outcome Measures**

**A 3D Motion Capture** system uses multiple cameras, specialized software, and body-attached markers to record a subject's movement in 3D space. The system creates a digital representation of the motion by tracking the positions of markers from different perspectives. To operate the system, position the cameras, mark the subject's important joints, adjust the system's calibration, and then record the motion. After the data is processed by the software, it is transformed into 3D motion paths that can be further edited and exported for use in animation, virtual reality, or analysis in domains such as sports science and biomechanics.

During single-leg drop landings, the 3D Motion Capture System was used to measure the opposite limb's hip joint kinematics, including flexion, extension, abduction, adduction, and rotation angles. When it comes to measuring lower extremity joint angles, the system has proven to be highly reliable (ICC = 0.85–0.97).

# STATISTICAL ANALYSIS

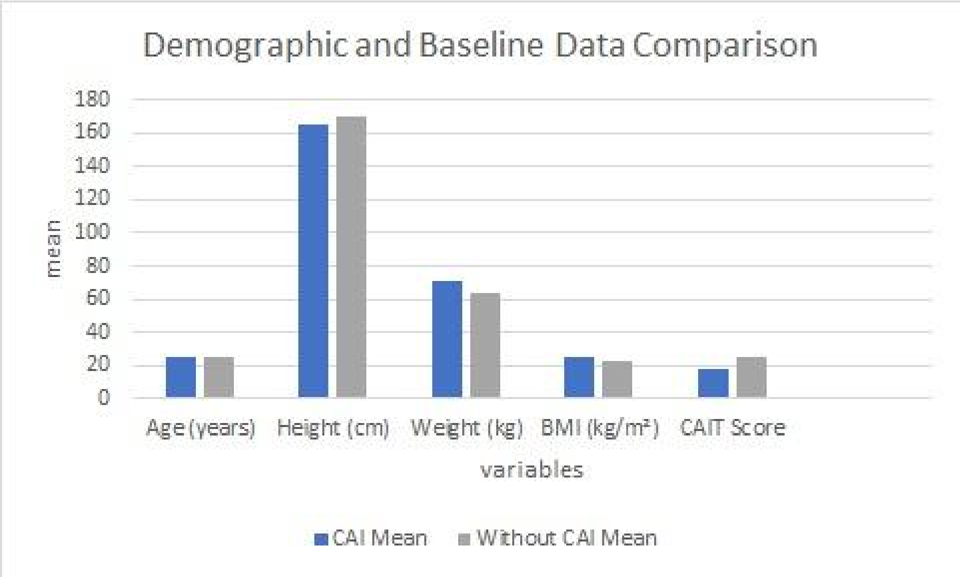
Statistical analysis was carried out using IBM SPSS Statistics version 27. The normality of the data was assessed using the Shapiro–Wilk test, which indicated that the data were normally distributed. Descriptive statistics were calculated and expressed as mean and standard deviation for continuous variables, and as frequencies and percentages for categorical variables. Inferential statistics were performed to compare within-group differences using paired t-tests and between-group differences using independent samples t-tests. For variables not meeting normality assumptions, the Mann–Whitney U test was used. The level of significance was set at $p \leq 0.05$.

# RESULTS

The study sample consisted of participants aged 18 to 35 years. Demographic and baseline data are presented in Table 1. The distribution of data for the CAI and the Without CAI groups was found to be normal ($p > 0.05$). Graph 1 provides a visual representation of the demographic characteristics of both groups.

| **VARIABLES** | **CAI (Mean ± SD** | **Without CAI (Mean ± SD)** | **p-value** |
|---|---|---|---|
| Age (years) | 24.73 ± 1.58 | 25.39 ± 0.85 | >0.05 |
| Height (cm) | 165.23 ± 11.73 | 170.11 ± 9.85 | >0.05 |
| Weight (kg) | 70.77 ± 18.93 | 63.72 ± 8.40 | >0.05 |
| BMI (kg/m²) | 25.05 ± 4.62 | 22.22 ± 1.80 | <0.05 |
| CAIT Score | 18.27 ± 2.85 | 24.89 ± 0.83 | <0.05 |
| **TABLE 2: DEMOGRAPHIC AND BASELINE DATA** | | | |

**TABLE 2** presents the demographic and baseline characteristics. Both groups were comparable in age, height, and weight ($p > 0.05$). However, BMI was significantly higher in the CAI group ($p < 0.05$), and CAIT scores were significantly lower in the CAI group compared to the Without CAI group ($p < 0.001$).




**GRAPH -1 : Demographic and Baseline Data**

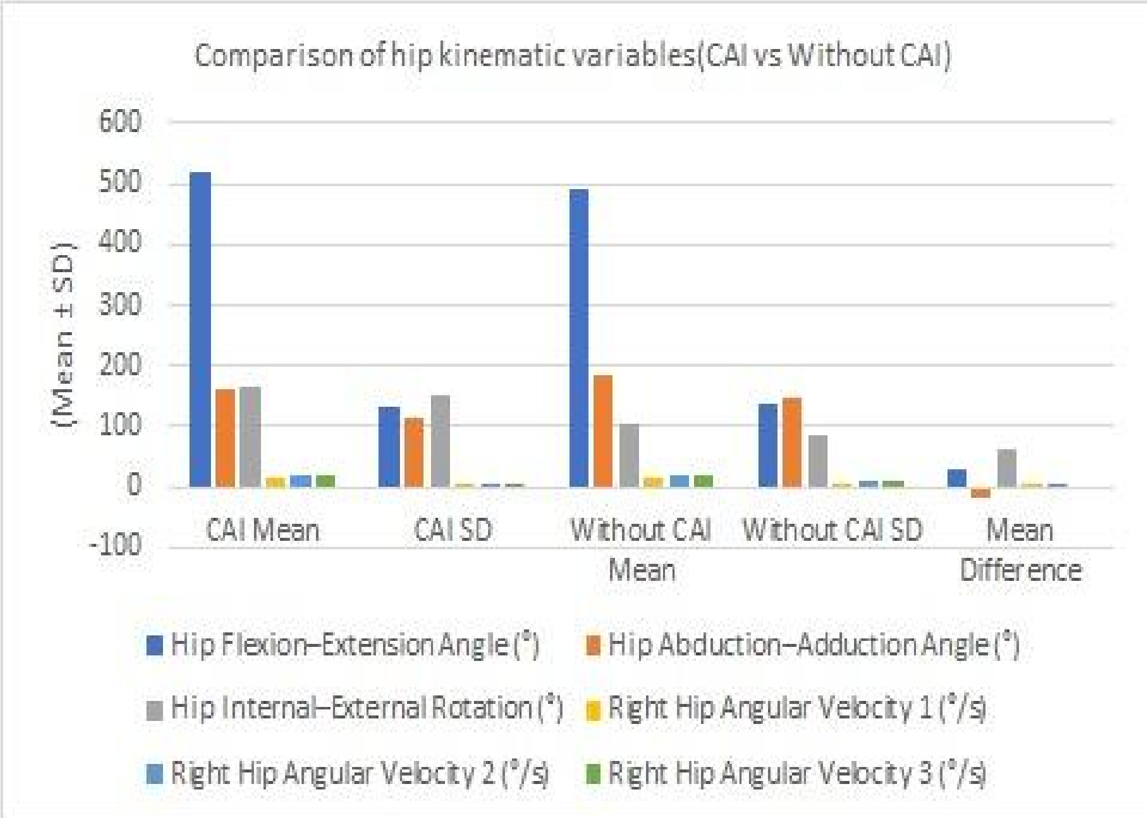
**Graph 1** illustrates the comparison of demographic and baseline data between the CAI and group without CAI groups, including Age, Height, Weight, BMI, and CAIT Score, expressed as Mean ± SD.

The two groups were homogeneous in terms of demographic variables except for BMI and CAIT scores, which showed significant differences

**TABLE 3. BETWEEN-GROUP COMPARISON OF KINEMATIC VARIABLES (CAI VS WITHOUT CAI)**

| Variable | CAI (Mean ± SD) | Without CAI (Mean ± SD) | Mean Difference | p-value |
|---|---|---|---|---|
| Hip Flexion–Extension Angle (°) | 520.07 ± 132.82 | 492.74 ± 135.13 | 27.33 | >0.05 |
| Hip Abduction–Adduction Angle (°) | 162.49 ± 115.66 | 182.85 ± 147.94 | -20.36 | >0.05 |
| Hip Internal–External Rotation Angle (°) | 167.58 ± 150.12 | 105.20 ± 83.54 | 62.38 | >0.05 |
| Right Hip Angular Velocity 1 (°/s) | 15.71 ± 6.49 | 13.38 ± 5.08 | 2.33 | >0.05 |
| Right Hip Angular Velocity 2 (°/s) | 19.46 ± 6.39 | 17.44 ± 7.82 | 2.02 | >0.05 |
| Right Hip Angular Velocity 3 (°/s) | 20.04 ± 7.29 | 21.09 ± 8.74 | -1.05 | >0.05 |

The comparison between CAI and Without CAI groups across hip joint kinematics showed no statistically significant differences in either joint angles or angular velocities. Independent t-tests revealed that hip flexion–extension joint angle and hip flexion–extension angular velocity did not differ significantly between groups ($p > 0.05$). Similarly, Mann–Whitney U tests indicated no significant differences in hip abduction–adduction joint angle, hip internal–external rotation joint angle, hip abduction–adduction angular velocity, or hip internal–external rotation angular velocity (all $p > 0.05$).




**GRAPH -8: Between-Group Comparison of Kinematic Variables (CAI vs Without CAI)**

# DISCUSSION

This study is unique in focusing on contralateral hip biomechanics in recreational badminton players with chronic ankle instability (CAI), an area often overlooked as most earlier research has concentrated on the injured ankle or ipsilateral joints [18,20]. The results showed that there were no statistically significant differences between the CAI and non-CAI groups for hip flexion–extension, abduction–adduction, internal–external rotation, or angular velocities ($p > 0.05$). However, the CAI group consistently demonstrated slightly higher mean hip angles and angular velocities, suggesting the presence of subtle compensatory movement strategies during single-leg landings. These adaptations, although not statistically significant, are clinically important as they may represent early compensatory responses that could become more pronounced under conditions of higher training loads or competitive play [17,19]. Additionally, body mass index was significantly higher in the CAI group ($p < 0.05$), indicating that body composition may have contributed to the observed kinematic differences [22].

The null hypothesis was therefore accepted, indicating that no significant differences in contralateral hip kinematics were detected between the two groups. This outcome aligns with the view that compensatory changes at the contralateral hip may be small and difficult to capture statistically in recreational athletes who are not exposed to high-intensity training or competition demands [17]. Previous research has reported proximal kinematic alterations in individuals with CAI, particularly during challenging functional tasks, but our results suggest that such changes may be less evident in recreational populations or may normalize with habitual movement patterns [20,23]. The findings support the kinetic chain concept, which suggests that dysfunction at the ankle can influence more proximal joints [24]. Even though the results did not reach statistical significance, the observed patterns provide a scientific basis for including the hip joint in assessment and rehabilitation protocols for athletes with CAI, particularly to prevent potential secondary injuries and optimize overall movement efficiency [21].

Overall, the study found that players with CAI tended to demonstrate slightly greater hip joint motion and faster angular velocities, which may reflect strategies to maintain stability when one ankle is compromised [18,20]. These compensations may be helpful in the short term but could lead to altered joint loading over time, potentially predisposing athletes to overuse injuries of the hip and knee [19]. The presence of a higher BMI in the CAI group may have amplified these compensatory patterns, as additional body mass can modify landing mechanics and increase joint stress [22]. The findings highlight the importance of a comprehensive approach to rehabilitation that does not limit treatment to the ankle but also addresses hip and core strengthening to support the entire kinetic chain [21].

It is important to consider that several confounding factors and sources of internal variability may have influenced the results. The significant difference in BMI between the groups is a potential confounder, as body mass can independently affect kinematics during landing [21]. Individual differences in neuromuscular control, training history, footwear, and fatigue may also have contributed to variability, masking subtle group differences [21]. The cross-sectional design of the study limits the ability to draw causal conclusions, as it cannot determine whether the observed hip kinematic changes are a result of CAI or pre-existing adaptations [17]. The sample was limited to recreational players, so the results may not be generalizable to elite athletes who perform at higher intensities and may show more pronounced compensatory strategies [19]. Finally, the absence of kinetic and electromyographic data restricted the ability to analyze muscle activation patterns and joint loading, which would have provided a deeper understanding of the compensatory mechanisms [20]. Despite these limitations, the findings provide valuable insight into the interconnectedness of the ankle and hip joints and emphasize the need for comprehensive assessment and targeted intervention strategies in athletes with chronic ankle instability [21].

Based on these findings and limitations, several recommendations are proposed. Future studies should include larger and more diverse samples, incorporating elite athletes, female players, and participants with varied training backgrounds, to better capture compensatory strategies [7,14]. Longitudinal research would be especially valuable to track how contralateral hip biomechanics change over time in athletes with CAI and whether prolonged instability increases proximal adaptations [15,16]. Adding kinetic measures such as ground reaction forces and EMG recordings would provide a more complete understanding of neuromuscular control [20,21]. Practically, rehabilitation should not only target the ankle but also strengthen the hip and core to address the entire kinetic chain [21,24]. Coaches and clinicians should recognize that even non-significant results can reveal clinically relevant patterns [19]. Preventive strategies, including specific warm-up routines and proprioceptive training, may also reduce the risk of secondary injuries [17]. Overall, advancing knowledge of how CAI influences the lower limb will support safer and more effective training and rehabilitation practices in badminton and similar sports [18,23].

# CONCLUSION

This study explored how CAI affects the contralateral hip during single-leg landings in recreational badminton players. Although no significant differences were found between groups, the movement patterns in the CAI players showed small changes at the hip that may act as compensations for ankle instability. These findings suggest that instability at the ankle can influence other joints in the lower limb, highlighting the importance of looking beyond the injured joint alone. From a clinical perspective, rehabilitation and training programs for athletes with CAI should not only target the ankle but also include hip and core strengthening to support the entire kinetic chain. Taking this broader approach may improve performance and reduce the risk of further injuries..

# LIMITATIONS & RECOMMENDATIONS FOR FUTURE STUDY

## Limitations

1. The study included only recreational badminton players, so the findings may not be generalizable to elite or professional athletes who perform at higher physical demands.

2. The sample size was relatively small (40 participants), which may have reduced the statistical power to detect subtle differences in hip biomechanics.

3. Only kinematic parameters were assessed; kinetic and electromyographic (EMG) data were not included, limiting a deeper understanding of neuromuscular adaptations.

4. The cross-sectional observational design does not establish causal relationships between chronic ankle instability and contralateral hip biomechanics.

5. External factors such as fatigue, footwear, and playing surface were not controlled, which may have influenced movement patterns during testing.

## Recommendations for future study

Future research could benefit from including a larger and more diverse sample of participants, such as elite badminton players, female athletes, and individuals with varying levels of training, to provide a broader perspective on how chronic ankle instability (CAI) affects contralateral hip biomechanics.

Conduct long-term studies to determine whether compensatory hip changes develop or worsen over time.

Add biomechanical measures such as ground reaction forces and muscle activity (EMG) for deeper insights into movement control.

Test rehabilitation programs that target both the ankle and hip to evaluate their effectiveness in reducing compensations and improving performance.

Explore preventive strategies and sport-specific training programs to minimize injury risk and support safer play for badminton athletes.

# SUMMARY

This study examined how chronic ankle instability (CAI) affects the contralateral hip during single-leg landings in recreational badminton players. While no statistically significant differences were found between the CAI and control groups, the CAI players showed a tendency for slightly greater hip movement and angular velocity, suggesting subtle compensatory strategies that may help maintain balance during dynamic movements. Clinically, the findings highlight the importance of looking beyond the ankle and considering the entire lower-limb kinetic chain. Rehabilitation and training that include ankle, hip, and core strengthening may improve performance and reduce the risk of injury. Although these compensatory changes were modest in recreational players, they could be more pronounced in athletes facing higher physical demands. Overall, the study emphasizes the need for a holistic approach to assessment and rehabilitation in badminton and similar sports.

# STATEMENT OF FUNDING

The author(s) reported **no source and nature of funding** associated with the work featured in this dissertation.

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# ANNEXURE:1

## INFORMED CONSENT

Study Title: The effects of chronic ankle instability on the biomechanics of the uninjured, contralateral hip during single-leg standing in recreational badminton players: an observational study

Study Number:

Participant 's Name: _______________ Participants 's Initials: _________

Date of Birth / Age: _______

Address of the Subject______________

Qualification ______________________

Occupation: Student/Self-Employed/ Service/Housewife/Others (Please tick as appropriate)

Please initial box

(Subject)

(i) I confirm that I have read and understood the information sheet dated _______ for the above study and have had the opportunity to ask questions.

(ii) I understand that my participation in the study is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.

(iii) I agree not to restrict the use of any data or results that arise from this study provided such a use is only for scientific purpose(s)

(iv) I agree to take part in the above study.

Signature (or Thumb impression) of the Subject/Legally Acceptable Representative:

_____________________________________________________________

_

Date: _____/ ____/ _____

Signatory ‘s Name: ___________________________________________

Signature of the Investigator:

_______________________________________________

Date: Study Investigator ‘s Name: ________________________________

Signature of the Witness: ________________

Date: _______/ ________/ _________

Name of the Witness: ___________________________________

*Copy of the Patient Information Sheet and duly filled Informed Consent Form shall be handled over to the subject or his/her attendant.

## ANNEXURE:2

# PARTICIPANT PRE SCREENING FORM

## Basic Details

Name

Age

Gender

Contact Number

Dominant Leg

Occupation

Address

## Physical Activity History

1. Are you a recreational badminton player? (Yes / No)

2. How many hours per week do you usually play badminton? (Less than 2 hrs / 2–4 hrs / More than 4 hrs)

3. Have you participated in professional tournaments? (Yes / No)

## Ankle Injury History

4. Have you had an ankle sprain/injury in the last 6 months? (Yes / No)

5. Have you ever been diagnosed with Chronic Ankle Instability (CAI)? (Yes / No / Not Sure)

6. Are you currently undergoing treatment for ankle instability? (Yes / No)

7. Have you had any lower limb surgery or fracture? (Yes / No)

8. Do you have any neurological or musculoskeletal disorder? (Yes / No)

### CAIT Screening (To be filled by the investigator)

CAIT Score (Affected Side)

Classification (CAI Group / Healthy Group)

### Initial Assessment

Meets Inclusion Criteria (Yes/No)

Meets Exclusion Criteria (Yes/No)

Eligible for Participation (Yes/No)

Signature of Investigator: _______________________________

Date: ___ / ___ / 2025

# Inclusion and Exclusion Criteria Checklist

## ☑ Inclusion Criteria

Checklist: Please tick all that apply

| | |
|---|---|
| 1. Age between 18–35 years | ☐ |
| 2. Recreational badminton player | ☐ |
| 3. Plays badminton more than 4 hours/week | ☐ |
| 4. No ankle injury in the last 6 months | ☐ |
| 5. Able to perform single-leg landing tasks | ☐ |
| 6. Willing to provide informed consent | ☐ |

## ✕ Exclusion Criteria

Checklist: Please tick if any apply

| | |
|---|---|
| 1. History of lower limb surgery or fracture | ☐ |
| 2. Neurological or musculoskeletal disorders | ☐ |
| 3. Currently under treatment for CAI | ☐ |
| 4. Participation in professional/national badminton tournaments | ☐ |
| 5. Inability to perform single-leg landing due to pain or instability | ☐ |

**ANNEXURE:3**

# ANNEXURE 3

## Cumberland Ankle Instability Tool (CAIT) - Sample Questionnaire

Please answer the following questions based on your usual level of activity. Circle the response that best describes your condition.

1. Email

- ______________________________

2. This survey addresses your

- Right Ankle
- Left Ankle

3. I have pain in my ankle

- Never
- During Sport
- Running on uneven surface
- Running on level surfaces
- Walking on uneven surfaces
- Walking on level surfaces

4. My ankle feels UNSTABLE

- Never
- Sometimes during sport (not every time)
- Frequently during sport (every time)
- Sometimes during daily activity
- Frequently during daily activity

5. When I make SHARP turns, my ankle feels UNSTABLE

- Never
- Sometimes when running
- Often when running
- When walking

6. When going down the stairs, my ankle feels UNSTABLE

- Never
- If I go fast

- Occasionally
- Always

7. My ankle feels UNSTABLE when standing on ONE leg

- Never
- On the ball of my foot
- With my foot flat

8. My ankle feels UNSTABLE when

- Never
- I hop from side to side
- I hop on the spot
- When I jump

9. My ankle feels UNSTABLE when

- Never
- I run on uneven surfaces
- I jog on uneven surfaces
- I walk on uneven surfaces
- I walk on flat surfaces

10. TYPICALLY, when I start to roll over (or “twist”) on my ankle, I can stop it

- Immediately
- Often
- Sometimes
- Never
- I have never rolled over on my ankle

11. After a TYPICAL incident of my ankle rolling over, my ankle return to “normal”

- Almost immediately
- Immediately
- Less than one day
- 1–2 days
- More than 2 days
- I have never rolled over on my ankle

## ANNEXURE:4

## IEC INSTITUTIONAL ETHICAL COMMITTEE

# ABSMARI ETHICS COMMITTEE

ABHINAV BINDRA SPORTS MEDICINE AND RESEARCH INSTITUTE, BHUBANESWAR, ODISHA

CDSCO Reg. No.: ECR/1981/Inst/OD/24

Prof. (Dr.) E. Venkata Rao
Chairperson

Mr. Chinmaya Kumar Patra
Member Secretary

Ref. No. ABSMARI/IEC/2025/194 Date: 21/05/2025

**APPROVAL LETTER**
**APPENDIX- VIII**

**MEMBERS**

**Dr. Smaraki Mohanty**
Clinician

**Dr. Satyajit Mohanty**
Scientific Member

**Mr. Shib Shankar Mohanty**
Legal Expert

**Ms. Annie Hans**
Social Scientist

**Ms. Subhashree Samal**
Lay Person

**Mr. Deepak Ku. Pradhan**
Scientific Member

**IEC-SECRETARIAT**

**Mr. Gouranga Ku. Padhy**
**Mr. Susant Ku. Raychudamani**

To,

**PREETI SARAF**
ABSMARI
273, PAHAL, BHUBANEWAR-752101

**Protocol Title:** The Effects of Chronic Ankle Instability on The Biomechanics of The Uninjured, Contralateral hip during Single Leg Landing in Recreational Badminton Players: An Observational Study

**Protocol ID.:** ABS-IEC-2025-PHY-060

**Subject**: Approval for the conduct of the above referenced study

Dear Mr./Ms./Dr **PREETI SARAF**
With reference to your Submission letter dated 06/01/2025 the ABSMARI IEC has reviewed and discussed your application for conduct of the study on dated 25/04/2025.

The following documents were reviewed and discussed

| S.N. | Documents | Document (Version/Date) |
|---|---|---|
| 1 | IEC Application Form | 25/04/2025 |
| 2 | Informed Consent Form | 25/04/2025 |
| 3 | Undertaking form PI | 25/04/2025 |
| 4 | CRF | 25/04/2025 |
| 5 | COI from the Investigators | 25/04/2025 |

The following members were present at meeting held on 25-04-2025

ABSMARI ETHICS COMMITTEE Dt. 21/05/25 BHUBANESWAR

1

Utkal Signature, Plot No.-273, Ground Floor, Pahal, Bhubaneswar-752101 +91-63707-03654 iec@absmari.com

# ABSMARI ETHICS COMMITTEE

ABHINAV BINDRA SPORTS MEDICINE AND RESEARCH INSTITUTE, BHUBANESWAR, ODISHA

CDSCO Reg. No.: ECR/1981/Inst/OD/24

Prof. (Dr.) E. Venkata Rao
Chairperson

Mr. Chinmaya Kumar Patra
Member Secretary

Ref. No. ABSMARI/IEC/2025/194

Date: 21/05/2025

**MEMBERS**

**Dr. Smaraki Mohanty**
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Lay Person

**Mr. Deepak Ku. Pradhan**
Scientific Member

**IEC-SECRETARIAT**

**Mr. Gouranga Ku. Padhy**
**Mr. Susant Ku. Raychudamani**

| S.N. | Name of the Member | Designation & Qualification | Representation as per NDCT 2019 | Gender (M/F) | Affiliation with the Institution (Y/N) |
|---|---|---|---|---|---|
| 1 | Prof. Dr. E. Venkata Rao | Professor (MBBS, MD, Dept. of Community Med.) IMS & Sum Hospital, BBSR | Chair Person | M | N |
| 2 | Dr. Smaraki Mohanty | Asst. Prof-IMS & Sum Hospital/MBBS, MD (Community Med) | Clinician | F | N |
| 3 | Mr. Shiba Sankar Mohanty | Junior Counsel-Lt. Ramachandra Sarangi's Chamber / BA LLB | Legal Expert | M | N |
| 4 | Mr. Chinmaya Kumar Patra | Principal-ABSMARI, MPT | Member Secretary | M | Y |
| 5 | Ms. Annie Hans | Disability Inclusive Development Co-Ordinator in Humanity and Inclusion (India/Nepal/Srilanka). /MA in Social Work | Social Scientist | F | N |
| 6 | Ms. Subhashree Samal | Ret. Reader-Pol Sc. | Lay Person | F | N |
| 7 | Mr. Deepak Kumar Pradhan | Asst. Prof-ABSMARI, MPT | Scientific Member | M | Y |

This is to confirm that only members who are independent of the investigator and the Sponsor of the trial have voted/ provided opinion on the trial.

**This Committee approves the documents and the conduct for the study in the presented form with necessary recommendation.**

The ABSMARI IEC must be informed about the progress of the study in the prescribed format attached, any SAE occurring in the course of the study, any changes in the protocol and patient information/informed consent/assent and request to provide a copy of the final report.

The ABSMARI IEC follows procedures that are in compliance with the requirements of ICH (International Conference on Harmonization) guidance related to GCP (Good Clinical Practice) and applicable Indian regulations.

Yours sincerely,

Mr. Chinmaya Kumar Patra
Member Secretary
**ABSMARI Ethics Committee**
**Pahal, Bhubaneswar**

Member Secretary
ABSMARI ETHICS COMMITTEE

ABSMARI ETHICS COMMITTEE BHUBANESWAR Dt. 21/05/25

2

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# ANNEXURE:5

# MASTERCHART

**Table: Baseline characteristics and kinematic parameters of participants (Without CAI group)**

| SL. NO | Age | Gender | Height | Weight | BMI | CAIT Score | Hip Flex-Ext (°) | Hip Abd-Add (°) | Hip Int-Ext (°) | Right Leg X Vel. | Right Leg Y Vel. | Right Leg Z Vel. | Group |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 23 | M | 182 | 88 | 26.57 | 25 | 491.9 | 163.9 | 37.0 | 13.7 | 10.6 | 21.6 | Without CAI |
| 2 | 24 | F | 158 | 62 | 24.83 | 25 | 552.7 | 390.0 | 96.6 | 17.5 | 13.1 | 29.7 | Without CAI |
| 3 | 25 | F | 157 | 53 | 21.51 | 25 | 304.0 | 76.5 | 51.7 | 22.9 | 14.6 | 18.0 | Without CAI |
| 4 | 25 | M | 174 | 60 | 19.82 | 25 | 216.6 | 194.4 | 152.4 | 15.2 | 9.9 | 25.1 | Without CAI |
| 5 | 27 | M | 175 | 64 | 20.9 | 25 | 324.3 | 118.3 | 95.1 | 14.2 | 17.7 | 40.8 | Without CAI |
| 6 | 26 | M | 180 | 80 | 24.69 | 25 | 473.7 | 41.3 | 148.2 | 15.0 | 20.6 | 13.7 | Without CAI |
| 7 | 25 | M | 182 | 70 | 21.13 | 25 | 659.5 | 70.4 | 13.0 | 7.3 | 10.4 | 15.7 | Without CAI |
| 8 | 25 | M | 170 | 60 | 20.76 | 25 | 516.4 | 172.9 | 133.1 | 12.4 | 27.7 | 31.5 | Without CAI |
| 9 | 25 | M | 181 | 53 | 22.89 | 25 | 312.4 | 240.2 | 108.1 | 10.5 | 14.0 | 9.5 | Without CAI |
| 10 | 26 | F | 152 | 53 | 22.93 | 25 | 570.6 | 517.9 | -132.0 | 24.3 | 17.9 | 29.6 | Without CAI |
| 11 | 26 | F | 153 | 52 | 22.21 | 25 | 516.4 | 317.4 | 181.0 | 19.2 | 12.1 | 13.9 | Without |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | CAI |
| 12 | 25 | M | 141 | 41 | 20.64 | 25 | 336.7 | 109.8 | 164.3 | 8.4 | 9.5 | 16.2 | Without CAI |
| 13 | 25 | F | 164 | 88 | 32.71 | 25 | 612.5 | 229.7 | 271.3 | 11.1 | 23.4 | 32.6 | Without CAI |
| 14 | 24 | M | 170 | 72 | 24.91 | 25 | 578.6 | 236.5 | 178.2 | 11.7 | 17.7 | 26.0 | Without CAI |
| 15 | 25 | M | 172 | 65 | 21.97 | 25 | 569.7 | 418.6 | 143.6 | 12.8 | 14.5 | 13.8 | Without CAI |
| 16 | 26 | F | 161 | 54 | 20.81 | 25 | 592.3 | 119.8 | 146.5 | 12.3 | 24.8 | 18.0 | Without CAI |
| 17 | 25 | M | 170 | 70 | 24.22 | 25 | 720.7 | 405.9 | 109.9 | 10.7 | 17.3 | 23.0 | Without CAI |
| 18 | 25 | F | 157 | 57 | 23.13 | 25 | 618.3 | 112.1 | 238.5 | 20.1 | 42.6 | 12.0 | Without CAI |
| 19 | 26 | F | 185 | 62 | 18.12 | 25 | 425.4 | 2.6 | 72.9 | 4.4 | 12.0 | 10.2 | Without CAI |
| 20 | 24 | M | 178 | 75 | 23.67 | 25 | 461.1 | 91.5 | 73.4 | 6.8 | 18.3 | 7.7 | Without CAI |

| SL. NO | Age | Gender | Height | Weight | BMI | CAIT Score | Hip Flex-Ext (°) | Hip Abd-Add (°) | Hip Int-Ext (°) | Right Leg X Vel. | Right Leg Y Vel. | Right Leg Z Vel. | Group |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 26 | M | 156 | 90 | 37.0 | 17 | 617.5 | 72.58 | 708.0 | 25.27 | 24.4 | 26.2 | With CAI |
| 2 | 23 | F | 155 | 44 | 18.3 | 16 | 544.2 | 121.0 | 132.1 | 5.85 | 11.69 | 8.99 | With CAI |
| 3 | 27 | F | 152 | 64 | 27.7 | 19 | 612.0 | 401.8 | 62.7 | 13.34 | 13.38 | 24.97 | With CAI |
| 4 | 27 | M | 181 | 88 | 26.9 | 23 | 230.9 | 129.4 | 87.5 | 14.21 | 14.78 | 20.52 | With CAI |
| 5 | 26 | M | 169 | 66 | 23.1 | 19 | 489.5 | 120.8 | 93.3 | 13.63 | 22.58 | 14.74 | With CAI |
| 6 | 24 | F | 169 | 55 | 19.3 | 19 | 421.4 | 101.7 | 357.5 | 16.04 | 15.4 | 23.19 | With CAI |
| 7 | 25 | F | 161 | 47 | 28.1 | 16 | 360.6 | 37.79 | 207.6 | 12.36 | 13.5 | 18.26 | With CAI |
| 8 | 25 | M | 187 | 87 | 24.9 | 23 | 669.1 | 103.9 | 215.0 | 10.28 | 20.52 | 11.51 | With CAI |
| 9 | 25 | F | 150 | 50 | 22.2 | 17 | 596.9 | 301.6 | 129.5 | 14.01 | 17.72 | 32.68 | With CAI |
| 10 | 25 | F | 152 | 53 | 22.9 | 14 | 546.8 | 218.6 | 94.3 | 17.19 | 27.59 | 32.61 | With CAI |
| 11 | 27 | F | 162 | 55 | 20.9 | 17 | 660.4 | 167.2 | 129.8 | 27.9 | 18.66 | 21.9 | With CAI |
| 12 | 25 | F | 166 | 75 | 27.2 | 17 | 644.7 | 157.6 | 28.4 | 13.42 | 19.37 | 13.62 | With CAI |
| 13 | 25 | M | 173 | 60 | 25.3 | 23 | 539.4 | 35.7 | 67.4 | 7.77 | 14.39 | 12.06 | With CAI |
| 14 | 24 | M | 173 | 78 | 26.1 | 18 | 336.8 | 26.56 | 199.5 | 7.43 | 9.58 | 16.84 | With CAI |
| 15 | 25 | M | 195 | 120 | 31 | 17 | 63 | 15 | 24 | 10. | 19. | 23. | Wit |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | .6 | | 6.1 | 8.0 | 9.6 | 07 | 82 | 85 | h CAI |
| 16 | 22 | M | 176 | 95 | 29 .4 | 23 | 30 1.3 | 10 9.4 | 49. 3 | 17. 07 | 18. 41 | 25. 33 | Wit h CAI |
| 17 | 25 | F | 160 | 91 | 29 .3 | 21 | 68 2.2 | 10 9.2 | 12 5.7 | 26. 47 | 31. 59 | 15. 44 | Wit h CAI |
| 18 | 24 | F | 162 | 68 | 25 .9 | 18 | 56 4.2 | 38 0.7 | 12 5.7 | 19. 02 | 21. 1 | 21. 05 | Wit h CAI |
| 19 | 25 | F | 155 | 61 | 25 .4 | 18 | 52 3.9 | 38 3.3 | 20 7.9 | 16. 84 | 26. 3 | 19. 38 | Wit h CAI |
| 20 | 26 | F | 157 | 51 | 20 .7 | 20 | 42 3.5 | 11 3.0 | 81. 2 | 26. 06 | 32. 04 | 32. 32 | Wit h CAI |

# ANNEXURE 6: BROCHURE OF MOTION CAPTURE SYSTEM



## 2 Content overview

### 2.1 MVN Link suitcase with contents

| Figure | Description |
| --- | --- |
| <br>Figure 1: Suitcase containing the MVN Link System | The MVN Link System arrives in a strong, durable and watertight case. The case has wheels and an extendable handle for easy transportation. The suitcase dimensions meet the requirements for most airline hand-luggage. The suitcase contains:<br>• 4 MTx String with three trackers<br>• 6 Motion Trackers (MTx)<br>• 1 Body Pack<br>• 1 Battery Pack<br>• 1 Battery charger<br>• 1 Access Point<br>• 1 Upper Body Cable<br>• 1 Lower Body Cable<br>• 1 Battery Cable<br>• 1 Y Cable<br>• Lycra suit including headband, gloves, shorts, footpads<br>• 1 Segmometer<br>• Quick set-up sheet |

### 2.2 Motion Tracker (MTx)

| Figure | Description |
| --- | --- |
| <br>Figure 2: Motion Tracker (left:MTx, right: MTx-STR) | The MVN Link system contains two types of motion trackers; the single MTx used as end trackers and the string of three MTx-STR. The motion trackers, MTx, and MTx-STR are the miniature inertial measurement units containing 3D linear accelerometers, 3D rate gyroscopes, 3D magnetometers, and a barometer, which measures atmospheric pressure. These trackers are placed at strategic locations on the body (fixed by the suit), to measure the motions of each body segment.<br>The MTx trackers are positioned on the pelvis, sternum, hands, and head. MTx-STR's are used to chain the legs (upper leg, lower leg, and feet), as well as for the upper body (shoulders, upper arms, and for-arms). For more information about Motion Trackers, see Section 5.1.1. |

| Vive Hardware | Location | visuals |
|---|---|---|
|  | Pelvis |   Place the Vive Tracker just above Pelvis Motion Tracker |
| | Fore Arm (R/L) |   Place the Vive Tracker at 1/2 of the forearm (halfway from wrist to elbow) on the outer side of the arm in n-pose. |
| | Lower Leg (R/L) |   Place the Vive Tracker at 1/3 of the lower leg (one-third from the ankle to the knee) on the outer side of the arm in n-pose. |
|  | Head |   Place the headset on the head, as if you are playing a virtual reality game |

# ANNEXURE 7: TURNITIN PLEGIARISM REPORT

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