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Article

Research on optimization of basketball jumping landing techniques and reduction of ankle joint injury risk based on biomechanics analysis

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Abstract: The ankle joint's functional state is crucial during dynamic basketball movements, especially jumping and landing. A higher risk of ankle injuries is linked to limited ankle dorsiflexion, which can result in biomechanical alterations affecting landing safely and effectively. To improve basketball jumping landing skills and decrease the risk of ankle joint injuries, the objective of this research is to examine the way difficulties of dorsiflexion in the ankle influence the biomechanics of the lower extremities. Seventy-five participants completed basketball-specific stop-jumping actions on a flat surface (Control), a 10°, 20°, and 30° incline, using data from their dominant legs. The musculoskeletal framework was developed to simulate and analyze biomechanical data related to landing techniques. Post-hoc Tukey testing is utilized to estimate the category variations and it utilizes the statistical parametric mapping (SPM). As the angle of ankle restrictions increased, significant alterations in lower extremity biomechanics were detected during basketball jumping landings. Hip extension angles, knee external rotation angles, angular velocities, and knee extension angular velocities all showed appreciable increases. These findings indicate that increased ankle limitation has a significant impact on the mechanics of lower limb movements during athletic performance. The peripatellar muscles' co-activation gradually increased, and the landing phase showed a substantial increase in the patellofemoral joint contact force (PTF). The impact of ankle dorsiflexion difficulties in joint strain and kinematics during basketball jumping landings is demonstrated by these findings. An enhanced co-activation of the peripatellar muscles and increased PTF in response to increasing ankle restriction indicate compensatory strategies for maintaining balance during basketball landings. This study emphasizes the significance of improving basketball jumping landing techniques to improve ankle stability and decrease the possibility of ankle joint injuries in players.

Keywords: basketball; ankle joint injury risk; biomechanics; jumping landing techniques; statistical parametric mapping (SPM); ankle stability

1. Background of the research

In many sports like basketball, having the ability to land and jump correctly is essential. Based on the investigation depending on their position basketball players dropped from low jumps regularly and from high jumps during normal activity [1]. Injuries to the anterior ligament are among the most frequent in sports, particularly in youngsters. For teenagers who are returning to eliminating and pivoting activities, anterior ligament reconstruction is the recommended mode of action [2]. Jumping is a frequent move used in both defense and offense in basketball. A basketball player's average jumps during a game can affect individuals during their physical weight as they fall [3]. In basketball, jumping is a crucial skill for both offensive and defensive movements. Jump landing movements are frequently used to examine the stress characteristics and kinematics of the lower limbs during various interventions [4]. In soccer, volleyball, and basketball, termination activities are frequent motions. These motions include side-cutting, landing, and stop-jumping, among others. Particular kinds of termination activities have the potential to severely harm athletes and impair their ability to perform in sports [5]. Injuries to the anterior capsule in particular occur from the high and rapid impact pressures created by landings that translate into significant exterior forces at the knee [6]. Sports involving frequent jumping and landing are capable of ankle sprain injuries, which can be caused by both player and non-player interaction processes. Ankle giving way events and constant lateral ankle sprains are caused by several motor-behavioral variables, including altered lower-body movement mechanics linked to chronic ankle instability (CAI) [7]. Experienced female athletes can suffer a knee ligament injury on landing caused by muscle reaction forces including low muscle force of contraction and excessive quadriceps muscle force [8]. Basketball players perform significant amounts of random activity throughout practice and competition, executing jumps, accelerations, decelerations, and position changes in between collapses of low-to-moderate intensity exercise [9]. The stop-jumping method is essential for demonstrating an athlete's rapidity and body control while playing sports like volleyball and basketball [10].

Aims and contributions of this study

The investigation of the influences of dorsiflexion in ankle limits at lower-extremity biomechanics in the basketball jump and landing techniques is the aim of this research. It intends to find the essential biomechanical modifications linked to various levels of ankle limitation by examining the kinematic and kinetic parameters employing the musculoskeletal model. To enhance the stability of the ankle and reducing the risk of ankle damage in players who play basketball, the research provides the optimization of landing techniques that result in improved sports performance.

- In this research, there are 75 participants were obtained for the performance. Basketball-specific stop-jumping exercises were performed on a level surface (Control), at 10°, 20°, and 30° inclines, utilizing information from their dominant legs.
- The experimental design based on the landing surface incline was carried out for this research.
- Dataset description consists of motion capturing method and force plates to measure the force that the basketball players provide during jumping.
- Musculoskeletal modeling was demonstrated and the devices to estimate the jumping and landing at the time of playing basketball.

Writing Framework: The relevant researches are provided in phase 2. The research methodology is determined in phase 3. In phase 4, results are presented. Conclusions are explored in phase 5.

2. Related works

The stabilization of healthy females to limit ankle dorsiflexion could reduce the impact of mental demands on landing biomechanics were intended by Haines et al. [11]. The findings showed that effectively reducing the flexion of the ankle couldn't reduce the impact of external focus (EF) training on jump-landing performance in normal females by enhancing joint biomechanics. Romanchuk et al. [12] investigated both the male and female sex-specific absorption of energy techniques and the relationship between observed processes and strength. The Pearson and Spearman coefficients of correlation were employed to determine the relationship between the obtained kinematic and energy absorption and isometric joint strength. Tang et al. [13] investigated how the biomechanics of ankle and stability in dynamic were affected by football footwear with different collar levels. A high-collar shoe considerably reduced the ankle flexion range of motion (ROM) at the frontal single-leg jump landings compared to both flexible and low-collar categories. The high-collar shoe displayed a lower overall ankle axial ROM than the low-collar type. An anterior cruciate ligament (ACL) damage biomechanical characteristics and ankle plantar-flexion posture at the initial phase of the interaction were examined by Lee and Shin [14] to determine the significant correlations. Based on the outcomes, the elevated ankle plantar-flexion angle on initial contact could be the cause of less knee anterior plane stress, and altering the self-selective ankle position could cause biomechanical modifications related to the enhanced difficulties in ACL injury. The impact of particular knee muscle injuries on the axial plane landing with a drop vertical jump (DVJ) was determined by Tsatalas et al. [15]. During eccentric exercise, the results showed significant improvements in every indicator ($p< 0.05$). Hovey et al. [16] assessed the lower-extremity biomechanical single-leg landings, drop jump (DJ), and countermovement jump (CMJ) landing using gender variations in consideration. These results demonstrated that landing mechanics and total risk were directly impacted by activities preceding the landing moment. The feedforward neuromuscular regulation in a set of chronic ankle instability (CAI), copper, and undamaged controls was characterized by Han et al. [17] in a maximal jump landing test. Before initial interaction, both copers and CAI players showed alterations in feedback neural power in complex jumping and land evaluation. The impact of landing with height in biomechanical lower-extremity in players having and not having the CAI was compared by Watanabe et al. [18]. It could be essential to examine the mechanical demands that affect the altered landing action of CAI individuals in biomechanics research and treatments. The ankle inversion discrimination apparatus for landing or AIDAL was employed to assess ankle position during landing explored by Kang et al. [19]. In conclusion, individuals with CAI performed significantly lower in terms of ankle inversion orientation during landing than people without CAI. Landing height increased with increased loads resulting in a reduction of ankle proprioceptive sensitivity. Nishino et al. [20] explained the mechanisms of landing by trunk inclination that could result in a knee ligament breakage by evaluating the physical dynamics of ineffective and accurate trials. These results indicated that the trunk lean landing mechanics included the numerous biomechanical elements associated with anterior cruciate ligament damage and illustrated the improper trunk position during the descending phase. In comparison to impartial and plantar flexion shoes, Garcia et al. [21] determined that when dorsiflexion (DF) negatively impacts landing mechanics associated with patellofemoral discomfort along with the probability of injury of cruciate ligament. When testing shoes for DF and unbiased generated landing sequences, landing mechanics need to be considered as potential issues produce more stress on the passive aspects of the knee. There could be a trade-off between improved performance and a higher chance of injury. Cadens et al. [22] employed the Tuck Jump Assessment (TJA) that explored and compared the leaping and landing limitations for young female handball players with chronological age. It established the relationship between the numerical asymmetry values and the qualitative asymmetrical values obtained through the TJA, beginning at the single-leg CMJ (SL-CMJ). The quantitative asymmetry levels in younger groups were correlated with the qualitative asymmetry values evaluated by TJA. Liu et al. [23] investigated drop landing to clarify how the tiredness impacts the stability and ankle sense of balance in players with CAI. The balance and foot proprioception of CAI patients were significantly impacted by fatigue. Fatigue could be a major contributor to recurrent ankle sprains in CAI patients. Xu et al. [24] investigated that various ankle plantar flexion angles in SL affect the probability of knee-related injuries. Based on the research, using greater ankle plantarflexion angles on landing could assist with lower knee impact load and the chance of an ACL injury in the medial femoral linking position. By comparing the effect of the ankle joint in the leg at landing across players who experienced instability and an uninjured control group (coper group), Kikumoto et al. [25] established the impacts of kinetic energy from other joints. Based on the research, the group with CAI changed the joint's moment and angle on landing which could have raised the possibility of ligament damage. The pattern of landing was distinct from that of the copper category.

Research gaps

The existing research provided above emphasized the numerous jump-landing biomechanics, such as footwear, weariness, sex-specific mechanics, and CAI. There persist unresolved issues on how to effectively optimize jump-landing techniques unique to basketball and implement the focused process for reducing the injuries generated during jumping and landing basketball playing. Basketball's particular biomechanical demands, like quick vertical jumps and lateral movements, require sport-specific analysis as the majority of research concentrates on general athletic individuals or sports other than basketball. The kinetic chain and neuromuscular training's roles in enhancing basketball-specific landings have received less attention. The previous research has focused on specific components such as tiredness and ankle range of motion and has not sufficiently addressed multilevel efficient techniques that find a balance between performance improvement and reducing injuries. This research addresses these difficulties by concentrating on jumping and landing techniques for basketball and simulating the constraints using inclined surfaces. It utilizes the posthoc Tukey test with the SPM with the musculoskeletal model to examine the biomechanics that include the peripatellar muscle co-activation.

This technique presents the focused comprehensive to improve ankle stability, enhance landing mechanics, and lower the basketball player's risk of injury.

3. Research methodology

In this phase, the participant's details, experimental design, dataset description, and musculoskeletal model are presented.

3.1. Participants details

There are 75 participants were obtained in the research and were assessed with certain demographic characteristics like age, gender, experience in basketball, injury history, and physical conditions. **Table 1** depicts the participant's demographic characteristics. **Figure 1a–c** represents certain demographic details.

Table 1. Demographic information about the basketball players.

Characteristics		***N* = 75**
Age	18 to 26	75 (100%)
Gender	Men	40 (53.33%)
	Women	35 (46.66%)
Years of Experience in Basketball	< 4	20 (26.67%)
	5 to 10	30 (40%)
	> 10	25 (33.33%)
Injury History	Low	10 (13.33%)
	Moderate	32 (42.67%)
	High	33 (44%)
Physical Conditions	Good	37 (49.33%)
	Bad	38 (50.67%k)

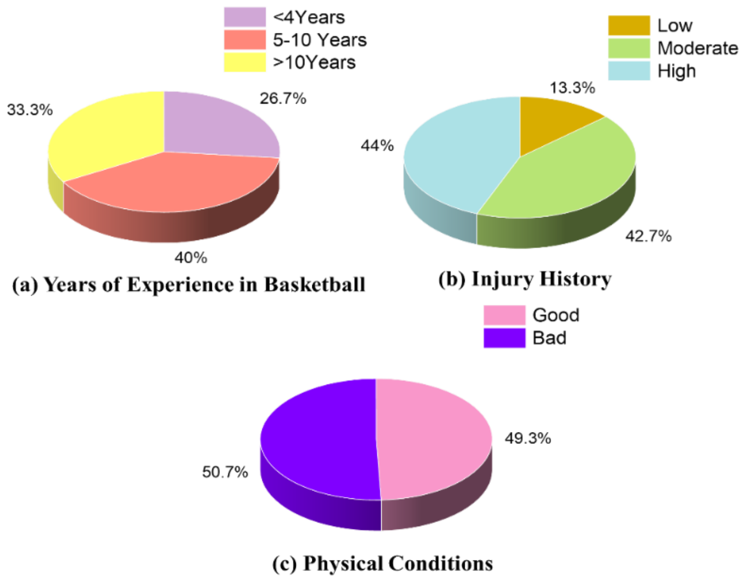

Figure 1. (a) Years of experience in basketball; **(b)** injury history; **(c)** physical conditions.

3.2. Experimental design

Important physical parameters that represent joint movement and velocity are knee external rotation angles, hip extension angles, knee extension angular velocities, and overall angular velocities. Patellofemoral Joint Force (PTF), which measures pressure on the thigh cap, and muscular co-activation, which evaluates simultaneously agonist-antagonist muscular interaction, are both included in force evaluations. Determining the stability of joints and distribution of strain throughout inclined rotations requires an awareness of these elements. Major variations among slope situations can be found using Tukey analysis, which offers information on how to improve effectiveness, avoid injuries, and guide recovery procedures. Basketball-specific stop-jumping drills were performed with data from the participant's dominant legs on flat ground (Control) at 10°, 20°, and 30° inclines. **Figure 2** shows the degrees of basketball player's foot positions at 10° to 30°.

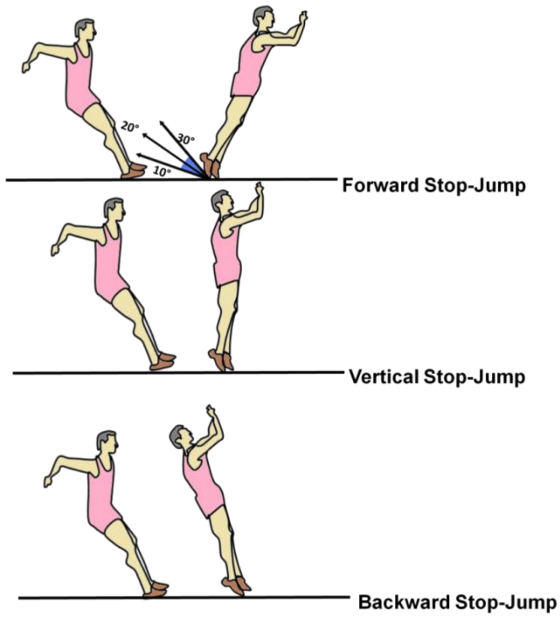

Figure 2. Inclination of landing surface (10°, 20°, 30°).

3.3. Dataset description

Biomechanical data is gathered through the effective method of motion capturing for the identification of movement that detects injuries and tracks joint angles. Basketball players can enhance their performance and safety by using motion capture technology, which evaluates the movements of the basketball player instantaneously. Systems that record motion gather information on acceleration and speed. The sensors are used to detect the movement and are placed in the ankle and knee. By using these details, potential injuries can be detected and quick indications can be provided. The ground reaction forces are evaluated at the time of landing by using the force plates, which are placed on the landing surface. The force that the player applied to the surface while jumping, standing and landing was measured using force plates. The player's movement, strength, and positions can be examined with it. College basketball athletes between the ages of 18 and 25 players who had been playing for a minimum of two years and had not experienced any serious lower limb difficulties. were included in the study. The study was carried a controlled environment on a residential basketball court using sensors attached to clothing, pressure plates, and rapid connectivity motion-sensitive cameras to gather mechanical and energetic data. To evaluate landing strategies and the danger of injury, respondents engaged in repeating jump-landing exercises, such as perpendicular and horizontal jumps, whereas important factors such as ankle flexion angles, ground response power, and recruitment of muscles were examined. **Figure 3** illustrates the force plates on the landing surface.

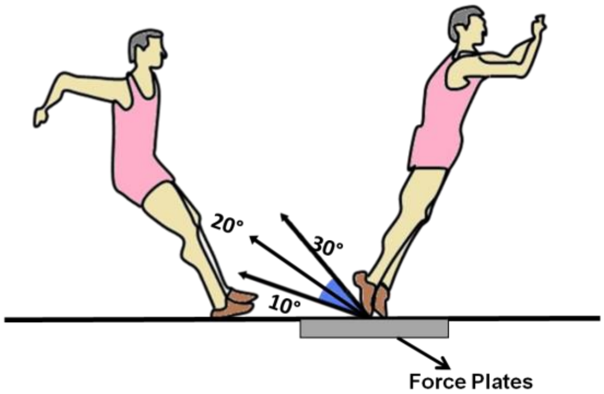

Figure 3. Force plates in the landing surface.

3.4. Musculoskeletal model

Basketball players employ the quadriceps, hamstring muscles, hamstring enlargement, stomach muscles, and soleus muscles in their jumping and landing movements. In combination, these muscles stabilize the legs and extend the knees, hips, and ankles. Fractures, injuries, injury to the ankle, and tendinitis are the common musculoskeletal injuries that players experience. Acute ankle sprains are the most frequent injury that follows quick knee injuries and hip or hip muscle strains. The musculoskeletal modeling was created to assess the landing techniques of biomechanics. **Figure 4** depicts the musculoskeletal model.

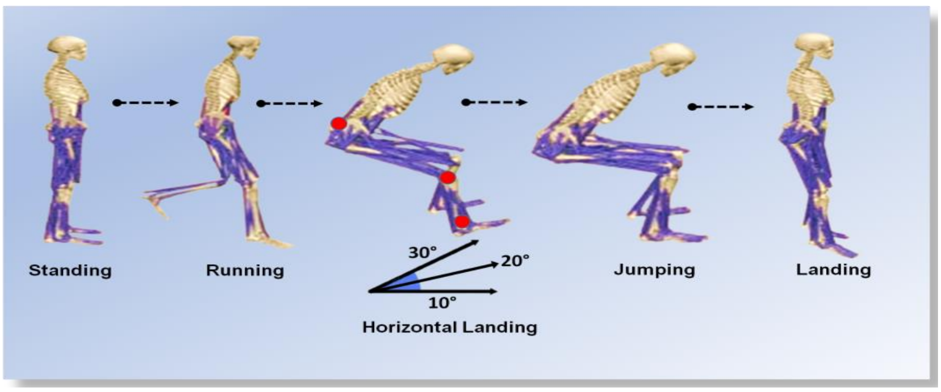

Figure 4. Musculoskeletal model.

3.5. Statistical assessment

To evaluate between-group differences in outcome variables, post-hoc Tukey tests were employed together with statistical parametric mapping (SPM). During basketball jumping landings, significant changes in lower-extremity biomechanics were observed in the inclination of ankle difficulties increased. Tukey's method is the most widely used post hoc test for analyzing all potential group combinations. Post hoc test results can be presented with simultaneous confidence intervals or adjusted *p*-values. This analysis method is used to evaluate the angle analysis such as angular velocities, knee extension angular velocities, external rotation angles of the knee, and angles of hip extension with various slopes (10°, 20°, and 30°). The force analysis with co-activation muscles and PTF are assessed with slopes of 10°, 20°, and 30°.

4. Experimental results

Joint mechanical and force propagation on slopes of 10°, 20°, and 30° are assessed in this work. Important physical parameters that represent joint movement and velocity are knee external rotation angles, hip extension angles, knee extension angular velocities, and overall angular velocities. Patellofemoral Joint Force (PTF), which measures pressure on the thigh cap, and muscular co-activation, which evaluates simultaneously agonist-antagonist muscular interaction, are both included in force evaluations. Determining the stability of joints and distribution of strain throughout inclined rotations requires an awareness of these elements. Major variations among slope situations can be found using Tukey analysis, which offers information on how to improve effectiveness, avoid injuries, and guide recovery procedures.

4.1. The post-hoc Tukey tests for the analysis of angles

The post-hoc Tukey test determines the variances among the combinations of the mean significance. If there is no zero in the reliability range, the variation is considered significant. **Table 2** examines the angle analyses with a 10° incline in knee external rotation angles, hip extension angles, knee extension angular velocities, and angular velocities. The biomechanical factors affecting movement characteristics during jump-landing tasks are analyzed in the following table. Changes in knee biomechanics during arrival were indicated by the significant average variations across elements, with knee extension velocity variations displaying a mean difference of 12.5°/s ($p = 0.041$). The mean variation in knee-rotated external angles was 3.1° ($p = 0.018$), indicating a shift in rotational coordination. While angular velocities (mean difference: 8.3°/s, $p = 0.026$) emphasize overall speed disparities in joint motions, hip extension angles (mean difference: 2.4°, $p = 0.032$) show variability in hip rotation. Every variable has substantial *p*-values (< 0.05), highlighting how crucial they are for assessing risks of injury.

Table 2. Estimation of angles in 10° incline.

Variables	**Mean Difference**	**Standard Error**	***P*-value**
Knee Extension Angular Velocities	12.5°/s	3.2	0.041
Knee External Rotation Angles	3.1°	0.6	0.018
Hip Extension Angles	2.4°	0.5	0.032
Angular Velocities	8.3°/s	2.4	0.026

Key biomechanical factors during jump-landing activities are statistically analyzed in the table, and each one reveals notable variations. Significant variations in knee velocity of motion during landing were shown by the mean difference of 18.9°/s (p = 0.005) in knee extension accelerations. Significant differences in knee rotation were reflected in the mean difference of 4.6° (p = 0.002) between the knee-rotated outward angles. While angle velocities (mean difference: 14.7°/s, p = 0.003) show general variations in joint movement velocity, hip extension inclinations (mean difference: 4.1°, p = 0.007) show notable changes in hip motion. In evaluating jump-landing mechanical and possible risk of injury, every factor exhibits p-values significantly below 0.05, indicating their statistical importance. **Table 3** represents the evaluation of the angle in 20° incline.

Table 3. Estimation of angles in 20° incline.

Variables	**Mean Difference**	**Standard Error**	***P*-value**
Knee Extension Angular Velocities	18.9°/s	3.5	0.005
Knee External Rotation Angles	4.6°s	0.8	0.002
Hip Extension Angles	4.1°	0.6	0.007
Angular Velocities	14.7°/s	3.0	0.003

The investigation of important biomechanical factors during jump-landing tasks is shown in the table, and each one demonstrates extremely substantial variations. A significant increase in knee movement speed was indicated by the mean difference of 24.3°/s (p = 0.001) in knee extension velocity measurements. There was a substantial change in knee rotation, as evidenced by the mean difference of 6.8° (p = 0.001) in knee-rotated outside angles. While angular velocities (mean difference: 19.5°/s, p = 0.001) show considerable variations in joint movement rates, hip extension angles (mean difference: 5.9°, p = 0.001) show substantial changes in hip mobility during the landing process. The statistical relevance of each variable in assessing biomechanical and danger of injury throughout jumping recoveries is confirmed by p-values less than 0.05. The evaluation of angles in 30° incline is shown in **Table 4**.

Table 4. Estimation of angles in 30° incline.

Variables	**Mean Difference**	**Standard Error**	***P*-value**
Knee Extension Angular Velocities	24.3°/s	4.1	0.001
Knee External Rotation Angles	6.8°	1.0	0.001
Hip Extension Angles	5.9°	0.9	0.001
Angular Velocities	19.5°/s	3.5	0.001

Significant changes in lower extremity biomechanics were observed during basketball jumping landings as the angle of ankle constraints increased. Angular velocities, hip extension angles, angle of external rotation, and angular velocities of knee extension all demonstrated essential improvements. These results suggest that the mechanics of lower limb movement during sports activities are significantly impacted by higher ankle limitations.

4.2. The post-hoc Tukey tests for the analysis of forces

The force assessment with the muscle's co-activation and PTF are performed in 10°, 20°, and 30° inclines. The following **Table 5** demonstrates the co-activation of muscles and PTF in various inclines. The evaluation of patellofemoral joint force (PTF) and muscle co-activation at three different slopes (10°, 20°, and 30°) is shown in the table. With average variations of 10° (10°: 5.2%, p = 0.019), 20° (9.8%, p = 0.002), and 30° (14.5%, p = 0.001), muscle interaction rose with higher pitches, suggesting a greater degree of muscle involvement as the angle increased. Likewise, PTF rose dramatically with slope as well: 45.3 N at 10° (p = 0.015), 85.7 N at 20° (p = 0.003), and 120.5 N at 30° (p = 0.001), indicating that steeper inclines result in higher knee joint stress. Every p-value is less than 0.05, which denotes significance in statistics.

Table 5. Results of muscle's co-activation and PTF.

Variables		Mean Difference	Standard Error	*P*-value
Muscle's Co-Activation	10°	5.2%	1.1	0.019
	20°	9.8%	1.3	0.002
	30°	14.5%	1.5	0.001
PTF	10°	45.3 N	8.2	0.015
	20°	85.7 N	9.1	0.003
	30°	120.5 N	10.4	0.001

Note: N refers to Newton.

The co-activation of the peripatellar muscles increased gradually, and the PTF improved significantly in the landing phase. These findings demonstrated that ankle joint limitations influence joint loads and kinematics during basketball jumping landings. Whereas ankle limitation increases, the peripatellar muscles' raised co-activation, and PTF suggests adaptive processes for preserving balance during basketball landing.

4.3. Discussion

The angle and forces in the jumping and landing at basketball are evaluated in this research to provide improved results. Significant mean difference was observed in the knee extension angular velocity that shows 12.5°/s and it has 0.5 of standard error in 10° incline. The significant p-value is provided by the knee external rotation angle (0.018) than other variables at 10° incline. During the 20° incline, the improved mean difference is found in the knee extension angular velocity (18.9°/s) variable, the standard error in this variable is 0.6 and it is more improved than other variables. There is significance with a 0.002 p-value in the knee external rotation angle presented. In the 30° incline, there is the essential p-value obtained in all the variables with 0.001. Mean difference increased at 24.3°/s in knee extension angular velocity and standard error with 1.0 presented in knee external rotation angle determines the enhancement in the evaluation of angle assessment. Co-activation musclesat a 10° incline provide the p-value with 0.019 of significance, a mean difference of 5.2%, and a 1.1 standard error. The 9.8% mean difference, 1.3 standard error, and 0.002 *p*-values are explored at a 20° incline. At 30° incline, the standard error is 1.5, the significance of *p*-value provides the 0.001, and the mean difference of 14.5% is obtained in the muscle's co-activation in the forced assessment. Thus, the PTF provides the improved outcomes in terms of various inclines 10° (mean-variance (45.3 N), *p*-value (0.015) and standard error (8.2)), 20° (*p*-value (0.003), standard error (9.1) and mean-variance (85.7 N)) and 30° (a standard error has 10.4, mean-variance has 120.5 N and significance (*p*-value has 0.001). Ankle joint tension and the chance of injury are greatly influenced by physiological parameters, including knee and hip articulation angles, angular velocity, and muscle co-activation, according to an examination concerning basketball landing and getting strategies. The patellofemoral joint force and muscle contractions increased while descending on steeper slopes, underscoring the significance of the technique in reducing the risk of injuries. These results highlight the necessity of training regimens that are optimized and center on appropriate biomechanics to lower the incidence of ankle cartilage damage among basketball athletes.

5. Conclusion

The biomechanical examination of basketball springing and resting approaches provides important information on lowering the risk of ankle joint injuries. The study emphasizes how important joint perspectives, angular velocity values, and muscle interaction are in reducing ankle stress. Basketball players' chance of suffering ankle injuries can be considerably reduced by improving landing methods through focused training. The ankle joint is crucial for dynamic basketball movements, including jumping and landing. Reduced ankle dorsiflexion can lead to biomechanical changes that affect landing performance and safety, and are associated with ankle injuries. A study involving 75 participants found that ankle dorsiflexion difficulties significantly impacted lower extremity biomechanics during basketball jumping landings. Increased ankle limitations led to significant changes in angular velocities, hip extension angles, knee rotation angles, and knee extension angular velocities. The study concluded that steeper slopes resulted in substantial biomechanics alterations, including a 14.5% increase in muscle co-activation at 30° and a 24.3°/s increase in knee extension angular velocities, which are correlated with higher patellofemoral joint stresses (120.5 N). These results highlight the necessity of using optimal landing procedures to lower the incidence of ankle joint injuries. The study also revealed that increased ankle constraints affected joint pressures and kinematics in basketball jumping landings. The study underscored the importance of honing landing methods to increase ankle stability and reduce ankle fractures in players.

Limitations and future scope

The research examines the controlled surface conditions and weaknesses that could affect landing mechanics in practical instances are not taken into concern. By its sufficient size, the sample could not accurately represent the variation of players. Further research needs to investigate the extended training plans to enhance ankle stability and how the strain impacts the biomechanical reactions during basketball landings.

Ethical approval: Not applicable.

Conflict of interest: The author declares no conflict of interest.

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