# THE RELATIONSHIP OF JOINT KINEMATICS DURING COUNTERMOVEMENT JUMP WITH RELATIVE STRENGTH AND SEGMENT PROPORTIONS IN COLLEGIATE ATHLETES

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## ABSTRACT

THE RELATIONSHIP OF JOINT KINEMATICS DURING COUNTERMOVEMENT JUMP WITH RELATIVE STRENGTH AND SEGMENT PROPORTIONS IN COLLEGIATE ATHLETES

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The purpose of this study was to investigate the association of countermovement jump (CMJ) kinematics with relative strength and segment proportions in collegiate athletes. A total of thirty-six (male=16 and female=20) team sports athletes went through anthropometric measurements, kinematic assessment using inertial measurement units (IMU's), and strength testing consisting of leg extension and hip thrust exercises. The results showed a significant and positive correlation between leg extension-to-bodyweight ratio and the maximum knee flexion angle during the CMJ. It was also found that there is a significant and negative correlation between the femur length to body height ratio and the maximum hip flexion angle in male participants. Another finding was that the leg extension-to-body weight ratio was significantly and negatively associated with the maximum hip flexion angle during CMJ. These results suggested that relative strength and segment proportions may be related to the CMJ strategies athletes utilized. It was concluded that both anthropometric and strength variables should be taken into account by coaches to create individualized programs, highlighting the value of accessible tools like barbells, leg extension machines, and IMU's to conduct meaningful assessments.

**Keywords:** Jumping strategy, biomechanics, segment length, kinematic assessment, joint angles

# ÖZ

ÜNİVERSİTE SPORCULARINDA AKTİF SIÇRAMA SIRASINDA EKLEM KİNEMATİĞİNİN RELATİF KUVVET VE SEGMENT ORANLARI İLE İLİŞKİSİ

Yüksek Lisans Tezi, Beden Eğitimi ve Spor Bölümü
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Bu çalışmanın amacı üniversiteli takım sporcularında, aktif sıçrama (AS) eklem kinematiği ile relatif kuvvet ve segment oranlarının ilişkisi araştırmaktır. Toplam 36 katılımcı (erkek=16 ve kadın=20) antropometrik ölçümler, ataletsel ölçüm üniteleri (IMU'lar) kullanılarak kinematik değerlendirme ve leg extension ile hip thrust egzersizlerinden oluşan kuvvet testlerini tamamlamıştır. Sonuçlar, AS sırasında diz fleksiyon açısıyla bacak ekstansiyon kuvvetinin vücut ağırlığına oranı arasında anlamlı ve pozitif bir korelasyon olduğunu göstermiştir. Ayrıca, erkek katılımcıların femur uzunluğunun boy uzunluğuna oranı ile maksimum kalça fleksiyon açısı arasında anlamlı negatif bir korelasyon olduğu bulunmuştur. Bununla birlikte, bulgular leg extension kuvvetinin vücut ağırlığına oranının, maksimum kalça fleksiyon açısı ile anlamlı negatif bir ilişki olduğunu göstermiştir. Bu sonuçlardan, relatif kuvvet ve segment oranlarının sporcuların kullandığı AS stratejileriyle ilişkili olabileceği ortaya çıkmıştır. Sonuç olarak, bireyselleştirilmiş antrenman programları oluşturulurken hem antropometrik hem de kuvvet değişkenlerinin antrenörler tarafından dikkate alınması gerektiğine ve halter, leg extension makineleri ve IMU

gibi kolay erişilebilir araçların anlamlı değerlendirmeler yapmak için değerli olduğu sonucuna varılmıştır.

**Anahtar Kelimeler:** Sıçrama stratejisi, biyomekanik, segment uzunluğu, kinematik değerlendirme, eklem açıları

*To my family*
*and*
*my beautiful girlfriend*

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# CHAPTER 1

## INTRODUCTION

Since the early times of sports science, the human body has been examined and pushed to its limits to achieve higher levels of performance. One of the disciplines that sports science works closely with is biomechanics. According to McGinnis (2013), biomechanics is the study of forces and their effects on living systems. Sports biomechanists are interested in the forces and how they affect human athletic movement and exercise. In the athletic performance context, biomechanical analysis provides insights into the coordination of body segments and the generation of movement. Biomechanical analysis typically contains two sections: kinetics and kinematics. Kinematics is the description of motion through angles, velocities, and accelerations, while kinetics deals with forces and torques (McGinnis, 2013). For example, the kinematic analysis of a runner would contain knee, hip, and ankle angles during the movement, angular and linear velocities, and accelerations of the segments. Also, trunk inclination, speed, and range of the arm swing, and the flexion and extension of the spine would be a part of the analysis. With all this data, one can visualize the complete motion of the individual.

The kinetic analysis, on the other hand, can give the forces created during movement at different points in time. With the help of inverse dynamic models, which are models that are created to estimate the torques working on different joints and external forces by incorporating both kinetic and kinematic data, scientists can paint the overall picture of the physics behind human movement.

Scientists and practitioners use various devices such as force plates, electromyography (EMG), inertial measurement units (IMUs), and motion capture systems to conduct biomechanical analyses. These technologies help them assess

movement mechanics in greater detail, to enhance performance, and minimize injury risk.

In explosive sports like football, basketball, and volleyball, an athlete's ability to produce power quickly is crucial to their performance (Cabarkapa et al., 2024; Sattler et al., 2015). Sprinting, jumping, and change of direction are examples of movements that call for both strength and the ability to use it rapidly. A key factor in determining success in elite sports is this ability, also referred to as the rate of force development.

Individual differences play a fundamental role in how movement is executed. Even among elite athletes, technical differences in various athletic movements like sprinting, squatting, and throwing are often observed (Rauch et al., 2020; Mastalerz and Sadowski, 2022). These differences may stem from anatomical varieties or compensatory strategies. For example, athletes with longer femurs may adopt more trunk lean while squatting to preserve balance and posture, while longer-legged sprinters often cover more ground with fewer steps (Fuglsang et al., 2017; Miyashiro et al., 2019).

One test that is frequently used to measure lower-body power and neuromuscular preparedness is the countermovement jump (CMJ) (Liebermann and Katz, 2003). The simplicity and repeatability of CMJ make it an invaluable tool for both applied and research settings. Coordinated triple extension of the ankle, knee, and hip joints is used to perform the movement. However, not every athlete depends on these joints in the same way. One may naturally choose a wider stance or a larger knee flexion during the descent, while another may prefer a closer stance or stiffer legs. The CMJ technique with an upright posture, where the athletes rely on their knee extensor muscles more, is referred to as a knee-dominant pattern, and the other strategy is where the athletes utilize a forward-leaning trunk, relying on their hip extensor muscles more, often referred to as a hip-dominant pattern (Seki et al., 2023).

Although CMJ has been widely studied in terms of kinetics and kinematics, the relationship between anatomical and strength profiles and jumping strategies of individuals remains an underexplored topic. Specifically, little is known about how

variables like the relative strength of the muscles responsible for the CMJ performance and the segment proportions of the lower extremities, which may influence whether an athlete shows knee-dominant or hip-dominant patterns.

Different CMJ patterns may be the result of the variety in relative strengths of muscles and anatomical factors. Practitioners may analyze these variables to create training or rehabilitation programs that are better tailored to the needs of the athlete.

### 1.1 Purposes of the study

The purpose of this study was to investigate the relationship between joint kinematics during CMJ with relative strength and segment proportions in collegiate athletes. Specifically, the study aimed to determine how variations in joint angles correlate with differences in athletes' strength-to-bodyweight ratios and limb segment proportions.

### 1.2 Research Questions

(1) What is the relationship between joint angles during the CMJ and relative strength in collegiate athletes?
(2) What is the relationship between joint angles during the CMJ and segment proportions in collegiate athletes?
(3) Are these relationships consistent in the male, female, and combined samples?

### 1.3. Hypothesis

1: It was hypothesized that the leg extension-to-bodyweight ratio would be positively associated with the maximum knee flexion angles during the CMJ.
2: It was hypothesized that the hip thrust-to-bodyweight ratio would be positively associated with the maximum hip flexion angles during the CMJ.
3: It was hypothesized that the femur-to-height ratio would be positively associated with the maximum knee flexion angle during the CMJ.

4: It was hypothesized that the tibia-to-height ratio would be positively associated with the maximum hip flexion angles during the CMJ.

### 1.4. Assumptions

It is assumed that the participants were adequately warmed up, performed the CMJ with maximal effort with the correct technique, and the equipment used to measure joint kinematics, segment proportions, and strength is valid and reliable.

### 1.5. Significance of the Study

Jumping strategy and its association with strength and segment proportions are an understudied area in the literature. Past research has been done with the aim of correlating jump technique to jump height. However, different strategies may be utilized for similar performance outcomes even at the elite level. In this study, the only interest was the strategy and other physical traits of the athletes. By investigating these relationships, it seeks to open a scientific conversation to understand why athletes utilize various jump strategies. With further research on the topic, our understanding of joint dependence and movement technique may be improved. Additionally, the accessibility and practicality of the instruments used in this study, like IMUs and gym equipment, will allow strength and conditioning practitioners to make informed decisions based on data that can be gathered outside of laboratory settings.

### 1.6. Definition of Terms

**Biomechanics:** It is an interdisciplinary field that explains, analyzes, and evaluates human movement (Winter, 2009).

**Kinetics:** Kinetic variables refer to the internal and external forces that cause movement (Winter, 2009).

**Kinematics:** Kinematic variables describe the movement through angles, velocities, and accelerations without the forces and torques that create the movement (Winter, 2009).

**Segment Length:** Distances between joints that specify a specific part of the body.

**Segment Proportions:** Ratios of different segment lengths.

**Inertial Measurement Unit:** Sensors that can be attached to different parts of the body that measure the orientation, magnetic field, and acceleration through the gyroscope, magnetometer, and accelerometer they possess (Osborn et al., 2020).

**Relative Strength:** The ratio of the weight lifted to the body weight of the lifter.

**Collegiate Athlete:** An athlete who is competing in the university league of the country as a member of the university team.

# CHAPTER 2

# LITERATURE REVIEW

An extensive examination of the current literature is needed to gain insight into the topic of interest. For the three main variables of the research, jumping kinematics, relative strength, and segment proportions, one needs to dive into a wide variety of study areas to be able to cover all the necessary aspects of the subject. These include a comprehensive examination of CMJ biomechanics, the contribution of different muscle groups to jumping, the strength levels of these muscles, individual technique differences, and segment proportions, which should help the reader understand the importance of potential factors that contribute to athletic movement variability. In the first section, the contributions of different joints during the CMJ are examined. The second section dives into the relationship between muscular strength and biomechanics of athletic movement. The third section identifies different jumping techniques utilized while mentioning the main kinematic and kinetic variables observed in individuals. Lastly, the fourth section mentions previous studies that looked at segment lengths, segment ratios, and kinematics.

## 2.1. Joint Contributions in the CMJ

The CMJ is a result of three joints working together: the hip, the ankle, and the knee. There are opposing results from various studies on the relative contributions of these joints. Bobbert et al. (1987) investigated the biomechanics of both the CMJ and the drop jump in 13 male handballers. They used a high-speed camera and a motion analyzer to collect the kinematics and a force plate with a four-segment model for kinetics. They reported that the hip is 32%, the knee is 38%, and the ankle is 30% responsible for the total work done. On the other hand, Vanezis and Lees (2005) found different levels of contribution. They used motion capture cameras and

reflective markers placed on 16 points on the 50 male soccer players they recruited. Through the force plate data and 12-segment biomechanical model, they calculated the joint contributions to be 43%, 29%, and 28% respectively, for their higher jumping group and 41%, 31%, and 28% for their lower jumping group. The researchers suggested that this difference may be due to the technical differences of the participants.

In a more recent study, Xu et al. (2023) found a higher contribution of the ankle joint, with 36% of the total positive work. Data was collected through 11 motion capture cameras and 42 reflective markers placed on the participants. They recruited 33 physically active sports science students. They found that the hip joint contributed 17% and the knee 47%. This aligns with the findings of Hubley and Wells (1983), who observed a 49% knee joint contribution in six physically active male university students. These mixed outcomes can be viewed as a result of individual technique differences.

### 2.2. Role of Muscular Strength on the Kinetics and Kinematics of Athletic Movement

Lower extremity strength influences movement kinematics across various athletic activities. Studies on this subject typically investigate kinematic variables in either the frontal and transverse planes or the sagittal plane. Although the current study is mainly interested in sagittal plane kinematics, examining the literature on frontal and transverse planes may help understand the importance of strength on movement kinematics in general.

Boling and Padua (2013) investigated the association between hip abduction, external rotators, and extensor strength, and frontal plane kinematics in 15 individuals with patellofemoral pain. Strength tests were conducted with an isokinetic dynamometer, and kinematics were collected with an electromagnetic motion analysis system. They found that decreased eccentric strength of the hip external rotators and abductors is significantly correlated with an increase in the trunk and hip motion in the frontal plane. Another study was done on 24 collegiate

cross-country runners and showed similar results. Ford et al. (2013) showed that hip extensor and abductor strength are negatively correlated with the range of motion of the pelvic obliquity and thorax axial rotation in the frontal plane and the transverse plane, respectively.

In the sagittal plane, one study demonstrated a positive correlation between trunk flexion and hip extensor work, as well as hip angle, in 40 recreational runners (Teng & Powers, 2016). Researchers used a dynamometer to measure hip extensor strength and an 11-camera motion capture system to collect kinematics. Authors have reported that runners with stronger hip extensors performed less knee extensor work. Martinez et al. (2018) reported opposing results. They measured isometric strength by placing a strap on an examination table on which the participants were positioned for the muscle group they wanted to test. The dynamometer was placed between the straps and the participant. The kinematics were collected through motion capture cameras. The findings showed no correlation between isometric hip strength and trunk, knee, and hip kinematics in 23 recreational female athletes.

Stearns et al. (2013) examined the sex differences in knee extensor and hip extensor strength and their relationship with landing mechanics during the drop jump task. Researchers measured the muscular strength with uniaxial force transducers strapped to the lower limbs of the athlete. They found that the knee extensors of males were 28% stronger than those of females, while the hip extensors of males were 44% stronger. Additionally, females exhibited a higher knee-hip extensor moment ratio than males, indicating a greater reliance on knee extensors in females and highlighting the influence of strength on movement execution.

Nagai et al. (2013) investigated the correlation between knee strength, landing kinematics, and knee proprioception. Fifty physically active male participants completed a single-leg stop-jump task, and their kinematics were collected with a six-camera motion capture system. The stop-jump task required participants to jump forward on one leg and then immediately upwards. They found that participants with higher knee extension torques also showed greater knee flexion excursion, meaning

that stronger participants bent their knees more after contact, even though they had already exhibited greater knee bend at initial contact.

While investigating sex differences in strength and lower extremity kinematics, Lephart et al. (2002) identified a significant difference between male and female participants in knee extension angles during landing tasks. They measured quadriceps and hamstring strength with an isokinetic dynamometer and also collected kinematics with electromagnetic tracking sensors. It was found that female participants showed reduced knee flexion angles during landing and lower torque-to-bodyweight ratios during the strength assessment. The authors suggested that this difference might stem from relative muscular weakness in females, especially in the quadriceps muscles. These studies highlight the relationship between lower extremity strength and kinematics.

A systematic review by Mozafaripour et al. (2022) examined five randomized controlled trials. The authors concluded there is moderate evidence showing that strengthening the hip muscles may influence lower body kinematics. Out of the five studies with opposing outcomes, the main study that the systematic review highlighted was Jafarnezhadgero et al. (2019). They recruited 26 older males, created experimental and control groups, and gathered both kinetic and kinematic data from a drop landing task. After two weeks of familiarization and stretching, the experimental group did resistance training with bands for 14 weeks under professional guidance. Results indicated that the experimental group showed reduced knee abduction and increased hip flexion angles. Although this study was done in elderly males, it can shed light on the role of strength in kinematics.

### 2.3. Jumping Strategies and Knee/Hip Dominant Postures

Previous studies (Bobbert et al., 1987; Vanezis and Lees, 2005; Xu et al., 2023; Hubley and Wells, 1983) that investigated the joint contributions during the CMJ showed that there is variability between athletes in joint dependence during the CMJ. These opposing results indicate that there exist some technical differences that enable athletes to use their hip, knee, or ankle extensors more. In their research that

examined joint contributions, Vanezis and Lees (2005) stated that there is significant negative work between the knee and hip joints, meaning that as one joint works more, the other one works less. The authors mentioned that the jump technique of athletes shows important differences.

McErlain-Naylor et al. (2014) highlighted the effect of technique during the CMJ. They examined the variables that best explain the variance in height in CMJ with arm swing. They looked at kinematic variables like isometric knee extension strength and peak torque, and peak power for three joints: ankle, knee, and hip. Also, they captured the joint angles at their minimum and during takeoff. The findings indicated that the three variables that explained the variance the most are peak knee power, peak ankle power, and shoulder angle at takeoff. Since the isometric leg extension strength only explained 18%, the authors stated that the jump technique determines how maximal strength is utilized during the jump.

A recent study by Seki et al. (2023) explored this concept further. They investigated kinetics during CMJ and squat jump using knee-dominant and hip-dominant postures. The authors aimed to understand how posture affects the mechanical work done by the muscles. Twelve healthy male sports science students performed vertical jumps hands akimbo by either staying in a more upright posture, by letting the knees move anteriorly over the toes an amount determined by the researchers, or a hip dominant posture where the athlete bends over a significant amount while keeping the knees behind the toes. The results revealed that in the knee-dominant posture, both the mechanical work on the knee joint and the knee joint torque were higher than in the hip-dominant posture. Similarly, in the hip-dominant posture, hip extension torque and hip mechanical work were higher than in the knee-dominant posture. Also, it is important to note that there is no significant difference in jump heights between postures, showing that even with extreme techniques utilized, performance may be the same between college students. Although participants of this study were students, professional athletes also showed technical differences while jumping.

Rauch et al. (2020) investigated the jumping strategies of NBA players during the CMJ. They categorized 178 NBA players as stiff flexors, hyper flexors, and hip

flexors depending on the posture they adopted during the downward phase of the CMJ trials. The hip flexors went through a larger range of motion at the hip and a smaller range of motion at the knee during the jump. The stiff flexors showed less flexion at the ankle, knee, and hip, while the hyper flexors showed greater flexion angles at these joints. One of the main findings was that the jump height between these clusters showed no significant difference. The authors also found that relative joint contributions have differed between the hip flexor cluster and the other two clusters, with the hip flexor cluster showing greater hip joint contribution.

### 2.4. Segment Proportions and Kinematics

Segment proportions and their associations with movement biomechanics are a very understudied area. Most of the existing literature focuses on the relationship between segment lengths and performance metrics, like jump height and squat performance (Davis et al., 2006; Cooke et al., 2019). Miyashiro et al. (2019) provided regression equations with variables: running speed, leg length, and step characteristics. They aimed to predict the kinematical variables of maximal sprints in 79 male sprinters. They found that leg length changed sprint kinematics. They stated that the sprinter with longer legs will run at the same speed as the shorter-legged sprinter through a lower step frequency, a greater thigh angle during the foot of the contralateral side is on the ground, greater flexion and less extension angles at the knee joint when that leg is on the floor and a slower knee flexion during the leg swing. Although the leg length was taken into consideration in the study design, this cannot be considered a study on segment ratios. They only focused on the absolute leg length measurement.

Another study (McKean and Burkett, 2012) investigated the influence of segment length and ratios on squat coordination and timing in 26 recreational athletes. Kinematics were collected with magnetic motion trackers sampling at 120 Hz. They found that females with longer thighs and torsos completed the squatting motion with lower knee extension angles, meaning that they went through a greater range of motion. Findings also indicated that in males, torso length and height are positively correlated with greater hip extension angles during the squat, meaning that they showed greater forward lean during the squat. The authors did not report a significant

relationship between segment ratios and the timing of the squat. They concluded there is a gender difference in squat technique, which may result from the limb length differences.

# CHAPTER 3

# METHOD

## 3.1. Participants

Thirty-six collegiate team sport athletes (16 males, M = 24.04, SD = 2.06; 20 females, M = 22.56, SD = 1.76) aged between 20 and 28 participated in this study. According to the G*Power (version 3.1), the sample size required for a moderate to high effect (r = 0.45) was calculated as a minimum of 30 (power = 0.8, $\alpha = 0.05$). All participants were recruited from university basketball, flag football, American football, and volleyball teams through direct communication with their coaches. Inclusion criteria required athletes to complete at least one competitive year in the university team and be injury-free from any musculoskeletal conditions in the past 6 months. Exclusion criteria involved recent surgery, pain during daily or physical activities, and any diagnosed cardiovascular or neurological conditions. Prior to the tests, athletes were clearly informed about the test procedures and the risks and were reminded that they are free to withdraw from the study at any time without consequences.Ethical approval for the study was obtained from the Human Subjects Ethics Committee of Middle East Technical University (0283-ODTUİAEK-2024), and written informed consent was collected from all participants before testing.

## 3.2. Data Collection Instruments

### 3.2.1. Stadiometer

A wall-mounted stadiometer (Holtain Ltd, Crosswell, Crymych, UK) was used to measure the body height of the participants. Figure 3.1 shows the stadiometer placement on the wall.



**Figure 3.1.** Wall-mounted stadiometer.

### 3.2.2. Body Composition Analyzer

A bioelectric impedance analysis (BIA) device (TANITA MC-780MA, Japan) (Figure 3.2) was used to measure body mass and body fat percentage. BIA is a widely used method that measures body composition from the electrical resistivity of body tissues.



**Figure 3.2.** TANITA MC-780MA.

Verney et al. (2015) compared the results from TANITA MC-780 and dual-energy X-ray absorptiometry (DXA) when measuring body fat percentage and fat-free mass in young adults. They also compared the data based on the physical activity levels of the participants. Results showed high levels of correlation between DXA and BIA methods for both fat-free mass and body fat percentage. Researchers concluded that BIA is an accurate tool to measure these variables, regardless of the physical activity level of the individual.

### 3.2.3. Sliding Caliper

The sliding caliper (Figure 3.3) provided by Xsens Awinda (Netherlands) was used to measure the required anatomical lengths.



**Figure 3.3.** Xsens Sliding Caliper (Retrieved from the official company website).

### 3.2.4. Wireless Inertial Measurement Units (IMUs)

Xsens Awinda (Movella, Netherlands) was used to collect the kinematics (Figure 3.4). Xsens Awinda consists of 17 sensors, straps for sensor attachment, a sliding caliper, shirts for placing the trunk sensors, a station for wireless connection with the sensors, and the MVN Analyze software, which was used during the data collection process.

El Fezazi et al. (2023) reported a very strong correlation between the Vicon optoelectronic system and Xsens Awinda. They recruited three male and four female

participants. The participants completed standardized tests where they sat, stood up, walked, and turned around. They collected data recording at 60 Hz, and the Vicon system used 8 cameras recording at 100 and 120 Hz. The authors stated that two systems showed excellent agreement and acceptable accuracy when measuring knee angles.

Nijmeijer et al. (2023) also showed high agreement in the sagittal plane joint angles during the jumping tasks between Xsens and Vicon systems. In their study, five male and five female participants completed various tasks, including single-leg hop, running double-leg vertical jump, single-leg deceleration and push-off, and running sidestep cut. Researchers used the Xsens Link system operating at 240 Hz. Results showed an excellent correlation between the Vicon optoelectronic system and Xsens IMU's in the sagittal plane for all joints.




**Figure 3.4.** Xsens Bag carrying straps and IMU's (Retrieved from the official company website).

### 3.2.5. Leg Extension Machine

The leg extension machine in the gymnasium of the university was used. Figure 3.5 shows the machine.

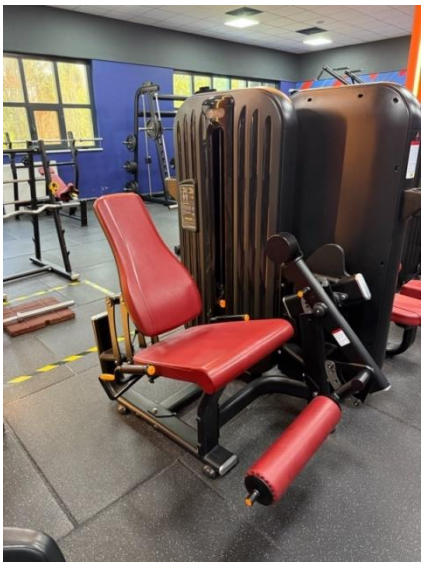


**Figure 3.5.** The leg extension machine used for the strength tests.

### 3.2.6. Barbell and Weight Plates

A 20kg Olympic-grade barbell was used for the hip thrust exercise, as shown in Figure xx. Also, specially made weight plates were used to adjust the weights during the tests. The weight plates were approximately five centimeters smaller in diameter than the Olympic standard of 45cm. For the repeatability of these tests, two platforms that are three centimeters in thickness were placed under the weights. Figure 3.6 shows the bar and the platforms. Figure 3.7 shows the custom-made plates.

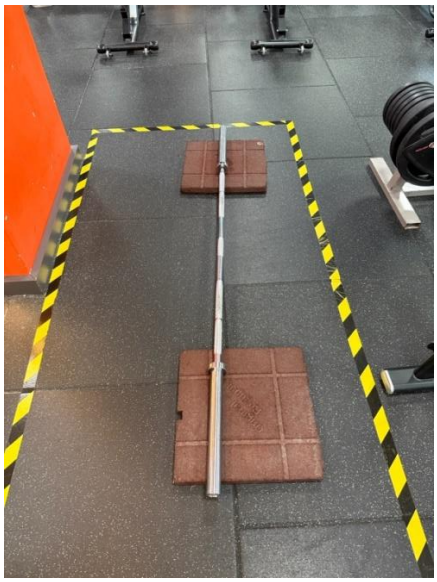


**Figure 3.6.** The Olympic-grade bar and the platforms.




**Figure 3.7.** One of the weight plates used.

### 3.3. Data Collection Procedures

All tests were conducted by experienced graduate sport science students who had previously used these instruments in earlier projects. Participants were tested in two sessions. The first session included anthropometric measurements and kinematic data collection. Anthropometric data were collected before the warm-up. After the dynamic warm-up, the IMU's were attached and calibrated. Following a couple of familiarization attempts, kinematics were collected. Between sessions, there were only 15-20 minutes where the participants were taken to the gymnasium of the university. After warming up with submaximal weights, leg extension and hip thrust strength tests were conducted. Strength test orders were randomized to remove the order effect. The data collection process took around four weeks to complete.

#### 3.3.1. Anthropometric Measurements

Anthropometric measurements were conducted in the Performance Laboratory of the Department of Physical Education and Sports. The temperature in the laboratory was 20-22 °C. Body weight, body fat percentage, body height, shoulder height, hip

height, hip width, knee height, ankle height, shoe length, shoe sole thickness, femur and tibia lengths, and foot length were collected. Both femur and tibia lengths were measured according to the Davis et al. (2006). Femur length was from the greater trochanter to the lateral condyle. Tibia length was measured from the lateral joint line of the knee to the medial malleolus. Foot length was measured while the participant was standing, from the calcaneus to the tip of the longest toe. Shoulder height, hip height, hip width, knee height, ankle height, shoe length, and shoe sole thickness were measured according to the Xsens body measurements guide, used only for the MVN Analyze software and not included in the analysis.

### 3.3.2. Countermovement Jump (CMJ)

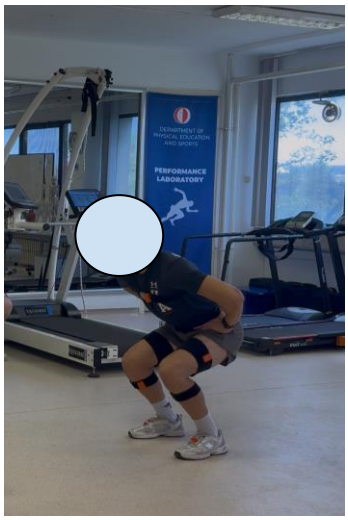
All participants completed a standardized warm-up before testing, including 5 minutes of jogging on a treadmill and 5–7 minutes of dynamic stretching exercises, in line with the Pagaduan et al. (2012) and Ryan et al. (2014) protocols. Dynamic stretching exercises were performed rhythmically with a full range of motion for 2 sets of 20 seconds each in the following order; Straight Leg March, Butt Kicks, Carioca, High Knees, Reverse Lunge with Twist, Power Shuffle, and Jogging with Squats. This protocol was used to elevate body temperature and prepare the lower limbs for explosive activity.

After completing the warm-up, wireless inertial measurement units (IMUs) from the Xsens Awinda system were attached to the participants, sampling at 100 Hz. Sensors were placed on the feet, thighs, lower legs, coccyx, and sternum following the standard lower-body configuration of Xsens to capture trunk and lower limb kinematics. After placing the sensors in the required places, the calibration process was done with the directions of the MVN Analyze software (Movella, Netherlands). At first, the participants stayed still in the N-position for a couple of seconds until the application gave the signal to continue. N-position is shown as standing straight up, looking forward, with hands resting naturally on the sides. For the next 10 seconds, participants moved around, avoiding sudden movements. After 10 seconds, the application gave another signal to stop and wait until the calibration process is complete.

Each participant then performed the CMJs under the supervision of the researcher. Participants began in an upright stance with feet shoulder-width apart and hands on their hips to eliminate arm swing. Figure 3.8.a. shows the starting position of the CMJ. They were instructed to descend to a self-selected depth and immediately perform a maximal vertical jump without pausing, as shown in Figure 3.8.b. and 3.8.c. Participants completed three jumps to familiarize themselves with the task. After every jump, a 15-30 second rest was provided to minimize fatigue. The fourth jump was recorded using the MVN Analyze software. The researchers extracted the maximum flexion angles of knees and hips reached during the eccentric phase of the CMJ from the Excel sheet provided by the software. All testing was conducted in a controlled environment within the Performance Laboratory.



a




b



c.

**Figure 3.8.** An athlete performing a CMJ with the IMU's attached (a. Standing b. Eccentric Phase c. Flight Phase).

### 3.3.3. Strength Testing

To assess isolated joint strength relevant to jumping biomechanics, participants performed 5-repetition maximum (5RM) tests for the leg extension (Figure 3.9) and barbell hip thrust (Figure 3.10) exercises. A 5RM test was chosen instead of 1RM due to safety concerns. It has been previously discussed that the 5RM strength test is a valid and safe option for testing maximal strength (Dohoney et al., 2002). Exercises were chosen to represent the strength of the knee extensors and hip extensors, respectively. Strength testing took place after the CMJ session. The order of the strength tests was randomized to eliminate the effect of fatigue and order bias. The leg extension was machine-based, and the barbell hip thrust was performed using a regulation barbell and a flat bench. Leg extension was done one-legged due to the equipment not having enough resistance to test 5RM two-legged. After completing the test for both legs separately the result from the stronger leg was used for the analysis. Each test began with a standardized warm-up. Participants completed submaximal sets at progressively increasing loads, following the protocol of Ross et al. (2022). They performed 10 repetitions at 40–50% of their known one-repetition maximum, followed by 5 repetitions at 60–70%, and finally 3 repetitions at 80%.

Participants were supervised throughout the tests and informed that they should use a full range of motion from the start of the exercise. A successful repetition for the leg extension would mean extending the knees to a complete lockout and completing the eccentric phase of the movement in a controlled manner without the weights touching the bottom of the weight stack. For the hip thrust, a successful repetition was the hip completely extended with heels on the floor and in the eccentric, lowering the bar as low as they can without touching the floor with the weights.

The heaviest load with which participants could perform five full repetitions in 3–4 trials with correct form was recorded as their 5RM for each movement. Participants were given 3-4 minutes to rest between trials to ensure they could perform with maximum effort. The leg extension-to-bodyweight ratio was calculated for each athlete by dividing their 5RM single leg extension value by their bodyweight, and the hip thrust-to-bodyweight ratio was calculated for each athlete by dividing their 5RM hip thrust value by their bodyweight. Since the maximum load capacity of the leg extension machine was exceeded by five of the participants, they did a maximum repetition set with the maximum load available, which was 85 kilograms. Then, Bryzcki's formula (1993) was used to estimate the 5RM of those participants.



**Figure 3.9.** An athlete performing the single-leg leg extension.



**Figure 3.10.** An athlete performing the hip thrust.

### 3.4. Statistical Analysis

Descriptive statistics (mean ± SD) were calculated for all variables, including anthropometric measurements, results of the strength tests, and variables of the CMJ. Q-Q plots and histograms were checked. Additionally, the Shapiro–Wilk test, skewness, and kurtosis were used to assess the normality of the data distributions before conducting the correlation analysis. Pearson product-moment correlation coefficients (r) were computed to investigate the relationships between anthropometric variables, strength test results, and CMJ kinematic parameters. The significance level was set at $p < 0.05$ for all analyses. The magnitudes of the correlations were determined based on Hopkins et al. (2009) as small ($r < 0.1$), moderate ($r = 0.1 - 0.3$), large ($r = 0.3 - 0.5$), very large ($r = 0.5 - 0.7$), and extremely large ($r = 0.7 - 0.9$). All statistical analyses were performed using IBM SPSS (v.26.0) for Windows (SPSS Inc., Chicago, IL).

# CHAPTER 4

# RESULTS

**Table 4.1.** The descriptive statistics for anthropometric characteristics

| Variables | Female athletes (n=20) | | Male athletes (n=16) | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Body height (cm) | 168.76 | 5.66 | 181.39 | 7.00 |
| Body mass (kg) | 61.77 | 8.28 | 87.98 | 9.27 |
| Body mass index (kg/m$^2$) | 21.73 | 3.07 | 26.77 | 2.67 |
| Body fat percentage (%) | 20.18 | 6.02 | 14.38 | 4.95 |
| Femur length (cm) | 41.23 | 1.9 | 45.94 | 2.67 |
| Tibia length (cm) | 39.88 | 2.96 | 42.56 | 2.38 |
| Femur-to-height ratio | 0.24 | 0.02 | 0.25 | 0.01 |
| Tibia-to-height ratio | 0.24 | 0.01 | 0.24 | 0.01 |

Means and standard deviations for the anthropometric characteristics of the athletes are presented in Table 4.1. Among male participants, body mass index (BMI) ranged from 22.44 to 32.15 kg/m², while the chronological age ranged from 21.10 to 28.71 years. The minimum height of male participants was 164.5cm, and the maximum was 191.5cm, with body fat percentages varying from 5.9% to 24.6%. Segment lengths of the male participants ranged from 42cm to 52cm for the femur and 39cm to 47cm for the tibia. The descriptive data of the female participants also showed variance with BMI values spanning from 17.2 to 29.16, and the chronological age ranging from 19.72 to 28.22 years. The minimum height of females was 153cm, the maximum was 175.5cm, and the body fat percentages were between 8.7% and

30.8%. Segment lengths spanned from 38cm to 44cm for the femur and 35cm to 44.5cm for the tibia. The femur-to-height ratio of male participants varied between 0.24 and 0.27, while the ratio range for females was from 0.23 to 0.26. The tibia-to-height ratio ranged between 0.22 and 0.25 for males and 0.21 and 0.26 for females.

**Table 4.2.** Means and standard deviations for strength measurements and relative strength ratios

| Variables | Female athletes (n=20) | | Male athletes (n=16) | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Single-leg leg extension 5RM (kg) | 46.00 | 9.95 | 86.94 | 15.12 |
| Hip thrust (kg) | 114.25 | 31.05 | 206.88 | 37.94 |
| Leg extension-to-body weight ratio | 0.79 | 0.16 | 0.78 | 0.15 |
| Hip thrust-to-body weight ratio | 1.93 | 0.45 | 1.83 | 0.43 |

The descriptive statistics for maximum strength measurements and relative strength ratios of male and female athletes are represented in Table 4.2. Single-leg leg extension 5RM test of male participants varied between 70kg and 123kg, with leg extension-to-bodyweight ratio ranging from 0.7 to 1.25. Hip thrust 5RM results were between 150kg and 300kg for males, with the hip thrust-to-bodyweight ratio spanning from 1.93 and 3.04. For female participants, the single-leg leg extension 5RM test results varied between 35kg and 65kg. Leg extension-to-bodyweight ratio spanned from 0.55 to 1.12. The hip thrust 5RM test ranged between 75kg and 185kg, with the hip thrust-to-bodyweight ratio varying from 1.27 to 2.5.

**Table 4.3.** The descriptive statistics for joint angles during the CMJ

| Variables | Female athletes (n=20) | | Male athletes (n=16) | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Maximum knee flexion angle (º) | 97.91 | 11.34 | 104.62 | 13.21 |
| Maximum hip flexion angles (º) | 99.99 | 12.60 | 100.32 | 11.34 |

The means and standard deviations for the joint angles during the CMJ of male and female collegiate athletes are given in Table 4.3. The maximum knee flexion angles ranged from 85.30º to 133.25º for males and 82.56º to 124.80º for females. The maximum hip flexion angles were between 85.58º and 126.40º for male participants, and for females, they spanned from 69.50º to 128.02º.

**Table 4.4.** The associations of maximum knee flexion joint angles during CMJ with relative strength and segment proportions

| Variables | Knee Flexion Angle | | | | | |
|---|---|---|---|---|---|---|
| | Female athletes (n=20) | | Male athletes (n=16) | | All athletes (n=36) | |
| | *r* | *P* | *r* | *P* | *r* | *P* |
| Leg extension-to-body weight ratio | 0.256 | 0.138 | 0.319 | 0.114 | 0.396 | **0.008** |
| Hip thrust-to-body weight ratio | 0.131 | 0.291 | -0.032 | 0.454 | 0.367 | **0.014** |
| Femur-to-height ratio | 0.203 | 0.196 | -0.103 | 0.352 | 0.184 | 0.142 |
| Tibia-to-height ratio | -0.048 | 0.421 | -0.202 | 0.226 | -0.122 | 0.240 |

The relationship between maximum knee flexion joint angles during CMJ with relative strength and segment proportions in collegiate athletes is presented in Table 4.4. The results revealed a significant and moderate to large positive correlation ($r$ = 0.396, $p$ = 0.008) between the maximum knee flexion angle during the CMJ and the leg extension-to-bodyweight ratio in the combined sample. The maximum knee flexion angle is also significantly and positively correlated ($r$ = 0.367, $p$ = 0.014) to the hip thrust to body weight ratio in the combined sample. The magnitude of this correlation is moderate to large. These associations are smaller and not significant when the analysis is conducted for each sex separately. There is no statistically significant correlation between segment ratios and the maximum knee flexion angle.

The relationship between maximum hip flexion joint angles during CMJ with relative strength and segment proportions in collegiate athletes is presented in Table 4.5. The results indicated that there is a significant and large negative correlation ($r$ = -0.529, $p$ = 0.018) between femur-to-height ratio and hip flexion angles in male

participants. Also, a significant and moderate to large negative correlation ($r$ = -0.413, $p$ = 0.035) was found between leg extension-to-bodyweight ratio and hip flexion angles in female participants.

**Table 4.5.** The associations of maximum hip flexion joint angles during CMJ with relative strength and segment proportions

| Variables | Hip Flexion Angle | | | | | |
|---|---|---|---|---|---|---|
| | Female athletes (n=20) | | Male athletes (n=16) | | All athletes (n=36) | |
| | *r* | *P* | *r* | *P* | *r* | *P* |
| Leg extension-to-body weight ratio | -0.413 | **0.035** | -0.182 | 0.249 | 0.095 | 0.291 |
| Hip thrust-to-body weight ratio | -0.335 | 0.074 | -0.251 | 0.174 | -0.052 | 0.381 |
| Femur-to-height ratio | -0.174 | 0.232 | -0.529 | **0.018** | -0.254 | 0.067 |
| Tibia-to-height ratio | 0.170 | 0.237 | -0.406 | 0.059 | -0.033 | 0.424 |

# CHAPTER 5

# DISCUSSION

Identifying and examining physical variables that relate to movement biomechanics provides valuable insights into why and how athletes move the way they do. The current study aimed to discover the relationship between joint kinematics during the countermovement jump (CMJ) and relative strength and segment proportions in collegiate athletes. The current literature provides limited evidence on the relationship between CMJ kinematics and relative strength. According to the authors' knowledge, this study was the first to investigate the association between CMJ kinematics and segment proportions. The findings showed that there is a significant and positive correlation of moderate to large magnitude between the knee flexion angle during the CMJ and both relative strength measures. Also, the femur-to-height ratio was significantly and negatively correlated with the maximum hip flexion angle utilized during the CMJ.

Findings indicated a positive relationship between the maximum knee flexion angle during the eccentric phase of the CMJ and the leg extension-to-bodyweight ratio of the participants. This result supports our hypothesis. A stronger leg extension relative to body weight is a strong indicator of knee extensor strength, which plays an important role in CMJ. Seki et al. (2023) showed that utilizing an upright posture with knees traveling anteriorly during the CMJ will increase the total work and the torque created by the knee extensors. Also, Rauch et al. (2020) showed an increase in hip joint contribution with increased hip flexion angles and decreased knee joint contribution with reduced knee joint flexion angles. It is possible that athletes with stronger knee extensor muscles would rely more on those muscles for the best CMJ performance. To achieve that, athletes could have preferred to stay more upright during the jump and to bend their knees to a greater degree. This explanation is

supported by Nagai et al. (2013), as they showed that participants who could create higher knee extension torques bent their knees more during the initial contact of a stop-jump task just before the vertical jump.

The data revealed a significant and negative relationship between the maximum hip flexion angle and leg extension-to-bodyweight ratio in females, with a correlation magnitude of moderate to large. This finding can also be explained by joint dependency. As knee extensors got stronger, athletes may have relied on their hip joints less. While this correlation was statistically significant only for the female participants, a similar trend was shown in the male participants.

Moreover, results indicated a significant positive correlation between the hip thrust-to-bodyweight ratio and maximum knee flexion angle. One reason for this relationship could be that the increased knee extension angle enables participants anatomically to go into greater hip flexion angles. Without flexing the knee to the required amount, it is harder to go into deeper ranges of motion due to hamstring flexibility constraints and coordination. Another reason could be the positive and significant correlation between hip extension strength and knee extension strength, meaning that individuals who have relatively stronger hip extensors are more likely to have relatively stronger knee extensors.

The results showed a significant and large negative association between the femur-to-height ratio and maximum hip flexion angle in male athletes. It was hypothesized that a relatively longer femur would be significantly correlated with a greater maximum hip flexion angle, as in the squat (McKean and Burkett, 2012). The discrepancy between results could have stemmed from the squat exercise requiring athletes to balance the weight placed on their backs. To be able to squat with additional weight, athletes need to properly adjust their postures and stance widths according to the bar placement and the new center of mass. Another reason could be that squat exercise requires athletes to keep their heels on the ground, but the CMJ does not. Since athletes were free to lift their heels, they could have utilized a technique that allows forward translation of the knee without the constraint of ankle mobility.

It was hypothesized that there would be a positive correlation between the hip thrust-to-bodyweight ratio and maximum hip flexion angle. The findings, on the other hand, showed no significant relationship between these variables. Although the joint dependency and relative strength for the knee joint were discussed by stating that a greater flexion angle in the knees could mean higher dependence, this may not be the case for hip extensors. It is possible that participants with stronger hip extensors could have utilized a stiffer jumping strategy, with smaller hip joint angles.

Data also showed a significant and positive association between leg extension-to-bodyweight ratio and femur-to-height ratio. Although this study did not aim to investigate the relationship between relative strength and segment proportions, we believe this is an important outcome. Although causality in the current study cannot be established, the significant association between an anatomical variable, determined solely by genetics, and a variable that can be trained is an important finding worth mentioning.

Results showed close to zero correlation between the tibia-to-height ratio and the maximum hip flexion angle. This was contrary to the hypothesis, expecting participants with relatively longer tibias to show greater hip flexion angles. Longer tibias would lead to a higher knee position, requiring these participants to show greater hip flexion to reach the same knee flexion angles as others. This hypothesis misses the ankle dorsiflexion amounts of participants during the deepest range of flexion and the fact that there were no constraints to keep the heels on the ground. Another reason can be that the athletes with longer tibia-to-height ratios preferred stiffer jumping strategies, with smaller joint angles on both the hip and the knee, with less depth in the eccentric phase. This stiffer jumping technique is widely utilized, even by elite athletes (Rauch et al., 2020).

There are several limitations to this study that should be mentioned. Our sample only consists of collegiate team sport athletes and is limited in size, which restricts the generalizability of the findings. Another limitation is the measurement techniques used for the kinematics and muscular strength. Although IMU's show high validity, the use of a gold standard motion capture technology would give results with higher

validity. Also, the use of isokinetic dynamometers instead of gym equipment for strength tests would present more reliable data. An important limitation would be the formula used for the 5RM estimation in the leg extension. Although the significance of findings does not change when we extracted those who did more than 5 repetitions in the leg extension with maximum resistance, the estimation formula used presents some error rate. Another limitation is that the menstrual cycles of the female athletes were not taken into consideration, which may have altered the outcomes of the tests.

Future studies should use the gold standard measurement equipment with a larger sample size, with athletes from different sports and performance levels. Also, various types of athletic activities like drop and stop jumps, change of direction, and sprinting should be investigated to discover whether anatomical factors and relative muscular strength parameters have a relationship.

Findings suggest that both strength tests and anatomical variables can provide information on the athlete's movement strategies. Since the instruments used in this study are cheaper and thus more accessible, strength and conditioning coaches and other practitioners could conduct biomechanical analysis on their athletes to gain insight into what they need and create individualized training depending on the needs of their athletes.

### 5.1. Conclusion

In conclusion, this study investigated how CMJ joint kinematics are related to relative strength measures and segment proportions in collegiate athletes. The findings indicated that both leg extensor strength and hip extensor strength are significantly and positively correlated with the maximum knee flexion angle reached during the eccentric phase of the CMJ. Also, a longer femur relative to height is negatively associated with the maximum hip flexion angle reached during the eccentric phase of the CMJ. The results contributed to the limited research on jumping strategy and its relationship with strength and anatomical variables. The different techniques observed in athletes can provide insight into the needs and strengths, which should help practitioners during their assessments. While the results

are informative, several limitations should be noted, including sample size, instrumentation, and the strength assessment method. Future studies should focus on a bigger sample size recruited from various sports and collect data with more advanced instruments. Since the equipment used in the study is easy to access and affordable, coaches can conduct similar analyses without advanced and expensive tools.

## REFERENCES


Bobbert, M. F., Huijing, P. A., & van Ingen Schenau, G. J. 1987. Drop jumping. I. The influence of jumping technique on the biomechanics of jumping. *Journal of Biomechanics*. 19 (11), 883-898.

Boling, M., & Padua, D. A. (2013). Relationship between hip strength and trunk, hip, and knee kinematics during a jump-landing task in individuals with patellofemoral pain. *International Journal of Sports Physical Therapy*, *8*(5), 661–669.

Brzycki, M. (1993). Strength testing—Predicting a one-rep max from reps-to-fatigue. *Journal of Physical Education, Recreation & Dance, 64*(1), 88–90.

Cabarkapa, D., Cabarkapa, D. V., Aleksic, J., Scott, A. A., & Fry, A. C. (2024). Relationship between vertical jump performance and playing time and efficiency in professional male basketball players. *Frontiers in Sports and Active Living, 6*, Article 1399399.

Cooke, D. M., Haischer, M. H., Carzoli, J. P., Bazyler, C. D., Johnson, T. K., Varieur, R., Zoeller, R. F., Whitehurst, M., & Zourdos, M. C. (2019). Body mass and femur length are inversely related to repetitions performed in the back squat in well-trained lifters. *Journal of Strength and Conditioning Research, 33*(3), 890–895.

Davis, D. S., Bosley, E. E., Gronell, L. C., Keeney, S. A., Rossetti, A. M., Mancinelli, C. A., & Petronis, J. J. (2006). The relationship of body segment length and vertical jump displacement in recreational athletes. *Journal of Strength and Conditioning Research*, 20(1), 136–140

Dohoney, P., Chromiak, J., Lemire, D., Abadie, B., & Kovacs, C. 2002. Prediction of one repetition maximum (1RM) strength from a 4-6RM and a 7-10RM submaximal strength test in healthy young adult males. *Journal of Exercise Physiology.* 5 (3), 54-59.

El Fezazi, M., Achmamad, A., Jbari, A., & Jilbab, A. (2023). A convenient approach for knee kinematics assessment using wearable inertial sensors during home-based rehabilitation: Validation with an optoelectronic system. *Scientific African, 20,* Article e01676

Ford, K. R., Taylor-Haas, J. A., Genthe, K., & Hugentobler, J. (2013). Relationship between hip strength and trunk motion in college cross-country runners. *Medicine & Science in Sports & Exercise, 45*(6), 1125–1130

Fuglsang, E. I., Telling, A. S., & Sørensen, H. (2017). Effect of ankle mobility and segment ratios on trunk lean in the barbell back squat. Journal of Strength and Conditioning Research, 31(11), 3024–3033.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise, 41*(1), 3–13.

Jafarnezhadgero, A., Madadi-Shad, M., McCrum, C., & Karamanidis, K. (2019). Effects of corrective training on drop landing ground reaction force characteristics and lower limb kinematics in older adults with genu valgus: A randomized controlled trial. *Journal of Aging and Physical Activity, 27*(1), 9–17.

Lephart, S. M., Ferris, C. M., Riemann, B. L., Myers, J. B., & Fu, F. H. 2002. Gender differences in strength and lower extremity kinematics during landing. *Clinical Orthopaedics and Related Research*. 401, 162-169.

Liebermann, D. G., & Katz, L. (2003). On the assessment of lower-limb muscular power capability. *Isokinetics and Exercise Science, 11*(2), 87–94.

Martinez, A. F., Lessi, G. C., Carvalho, C., & Serrao, F. V. (2018). Association of hip and trunk strength with three-dimensional trunk, hip, and knee kinematics during a single-leg drop vertical jump. *Journal of Strength and Conditioning Research, 32*(7), 1902–1908.

Mastalerz, A., & Sadowski, J. (2022). Variability of performance and kinematics of different shot put techniques in elite and sub-elite athletes–a preliminary study. *International Journal of Environmental Research and Public Health, 19*(3), 1751.

McErlain-Naylor, S. A., King, M. A., & Pain, M. T. G. 2014. Determinants of countermovement jump performance: A kinetic and kinematic analysis. *Journal of Sports Sciences*. 32 (19), 1805-1812.

McGinnis, P. M. 2013. Biomechanics of Sport and Exercise. 3rd edition. *Human Kinetics*, Champaign, IL.

McKean, M. R., & Burkett, B. J. (2012). Knee behaviour in squatting. *Journal of Australian Strength & Conditioning, 20*(2), 23–36.

Miyashiro, K., Nagahara, R., Yamamoto, K., & Nishijima, T. (2019). Kinematics of maximal speed sprinting with different running speed, leg length, and step characteristics. *Frontiers in Sports and Active Living, 1*, 37.

Mozafaripour, E., Bayattork, M., & Shahrbanian, S. (2023). Can hip muscle strengthening interventions improve lower extremity kinematics among healthy subjects? A systematic review of randomized controlled trials. *Sport Sciences for Health, 19*(2), 453–460.

Nagai, T., Sell, T. C., House, A. J., Abt, J. P., & Lephart, S. M. (2013). Knee proprioception and strength and landing kinematics during a single-leg stop-jump task. *Journal of Athletic Training,* 48(1), 31–38.

Nijmeijer, E. M., Heuvelmans, P., Bolt, R., Gokeler, A., Otten, E., & Benjaminse, A. (2023). Concurrent validation of the Xsens IMU system of lower-body kinematics in jump-landing and change-of-direction tasks. *Journal of Biomechanics, 154*, 111637.

Osborn, L. E., Iskarous, M. M., & Thakor, N. V. (2020). Sensing and control for prosthetic hands in clinical and research applications. In J. Rosen & P. W. Ferguson (Eds.), Wearable Robotics (pp. 445–468). Academic Press.

Pagaduan, J. C., Pojskić, H., Užičanin, E., & Babajić, F. 2012. Effect of various warm-up protocols on jump performance in college football players. Journal of Human Kinetics. 35, 127-132.

Rauch, J., Leidersdorf, E., Reeves, T., Borkan, L., Elliott, M., & Ugrinowitsch, C. (2020). Different movement strategies in the countermovement jump amongst a large cohort of NBA players. *International Journal of Environmental Research and Public Health, 17*(17), 6394.

Ross, J. A., Keogh, J. W. L., & Lorenzen, C. (2022). Reliability of kettlebell swing one and five repetition maximum. PeerJ, 10, e14370. https://doi.org/10.7717/peerj.14370

Ryan, E. D., Everett, K. L., Smith, D. B., Pollner, C., Thompson, B. J., Sobolewski, E. J., & Fiddler, R. E. (2014). Acute effects of different volumes of dynamic stretching on vertical jump performance, flexibility, and muscular endurance. Clinical Physiology and Functional Imaging, 34(6), 485–492.

Sattler, T., Sekulic, D., Hadzic, V., Uljevic, O., & Dervisevic, E. (2012). Vertical jumping tests in volleyball: Reliability, validity, and playing-position specifics. *Journal of Strength and Conditioning Research*. 29 (6), 1480-1489.

Seki, K., Nagano, T., Aoyama, K., & Morioka, Y. (2023). Squat and countermovement vertical jump dynamics using knee-dominant or hip-dominant strategies. *Journal of Human Kinetics, 86*(1), 63–71.

Stearns, K. M., Keim, R. G., & Powers, C. M. (2013). Influence of relative hip and knee extensor muscle strength on landing biomechanics. *Medicine & Science in Sports & Exercise, 45*(5), 935–941.

Teng, H.-L., & Powers, C. M. (2016). Hip-extensor strength, trunk posture, and use of the knee-extensor muscles during running. *Journal of Athletic Training, 51*(7), 519–524.

Vanezis, A., & Lees, A. (2005). A biomechanical analysis of good and poor performers of the vertical jump. *Ergonomics*. 48 (11-14), 1594-1603.

Verney, J., Schwartz, C., Amiche, S., Pereira, B., & Thivel, D. (2015). Comparisons of a multi-frequency bioelectrical impedance analysis to the dual-energy X-ray absorptiometry scan in healthy young adults depending on their physical activity level. *Journal of Human Kinetics, 47*(1), 73–80.

Winter, D. A. (2009). Biomechanics and Motor Control of Human Movement. 4th edition. John Wiley & Sons.

Xu, J., Turner, A., Comyns, T. M., Harry, J. R., Chavda, S., & Bishop, C. (2023). Countermovement rebound jump: A comparison of joint work and joint contribution to the countermovement and drop jump tests. *Applied Sciences, 13*(19), 10680.

# APPENDICES

## A. APPROVAL OF THE METU HUMAN SUBJECTS ETHICS COMMITTEE

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

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12 MAYIS 2025

Konu : Değerlendirme Sonucu
Gönderen : ODTÜ İnsan Araştırmaları Etik Kurulu
İlgi : İnsan Araştırmaları Etik Başvurunuz

Sayın Doç. Dr. Mustafa Söğüt,
Sayın Bora Boşat,

"Exploring the Relationship Between Segment Lengths, Strength Ratios, and Countermovement Jump Kinematics in Collegiate Athletes" başlıklı araştırmanız ODTÜ İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek 0239-ODTÜİAEK-2025 protokol numarası ile onaylanmıştır.

Bilgilerinize sunarım.

# B. TURKISH SUMMARY / TÜRKÇE ÖZET

## 1. GİRİŞ

Spor biliminin ilk dönemlerinden itibaren insan bedeni daha yüksek performans seviyelerine ulaşmak için incelenmiş ve sınırları zorlanmıştır. Bu alanın yakın ilişkili olduğu disiplinlerden biri biyomekaniktir. McGinnis'e (2013) göre biyomekanik, kuvvetlerin kendilerinin ve bu kuvvetlerin canlı sistemler üzerindeki etkilerinin incelenmesidir. Spor biyomekanikçileri, kuvvetlerin atletik hareketler ve egzersizlerdeki etkilerini araştırır. Bu bağlamda biyomekanik analiz, vücut segmentlerinin koordinasyonu ve hareketin nasıl üretildiği hakkında önemli bilgiler sunar.

Biyomekanik analiz iki ana bölüme ayrılır. Kinematik ve kinetik. Kinematik, hareketin açı, hız ve ivme gibi özelliklerini tanımlar. Örneğin bir koşucunun kinematik analizi diz, kalça ve ayak bileği açılarını, segmentlerin hızlarını ve ivmelerini, gövde eğimini, kol salınımını ve omurga hareketlerini içerir. Kinetik analiz ise hareket sırasında ortaya çıkan kuvvetleri ve momentleri içerir. Ters dinamik modeller yardımıyla hem kinematik hem de kinetik veriler kullanılarak eklemlerdeki torklar ve dış kuvvetler de tahmin edilebilir.

Bu analizler genellikle kuvvet plakaları, elektromiyografi (EMG), ataletsel ölçüm üniteleri (IMU) ve hareket yakalama sistemleri gibi cihazlarla yapılır. Bu teknolojiler sayesinde sporcuların hareket mekanikleri ayrıntılı biçimde değerlendirilebilir, performans artırılabilir ve sakatlık riski azaltılabilir.

Futbol, basketbol ve voleybol gibi patlayıcı güç gerektiren sporlarda sporcunun kısa sürede yüksek kuvvet üretebilmesi performansın temel belirleyicisidir (Cabarkapa ve ark., 2024; Sattler ve ark., 2015). Sprint, sıçrama ve yön değiştirme gibi hareketler hem kuvveti hem de bu kuvvetin hızla kullanılmasını gerektirir. Bu özellik genellikle

kuvvet üretim hızı olarak adlandırılır. Ancak elit sporcular arasında bile sprint, squat veya atış gibi hareketlerde teknik farklılıklar gözlemlenir (Rauch ve ark., 2020; Mastalerz ve Sadowski, 2022). Bu farklılıklar çoğunlukla anatomik çeşitliliklerden veya telafi stratejilerinden kaynaklanır. Örneğin uzun femura sahip sporcular squat sırasında dengeyi korumak için daha fazla gövde eğimine başvurabilir veya uzun bacaklı sprinterler ise daha az adımla daha fazla mesafe katedebilir (Fuglsang ve ark., 2017; Miyashiro ve ark., 2019).

Alt ekstremite gücünü ve nöromüsküler hazırlığı ölçmek için en sık kullanılan testlerden biri aktif sıçrama (AS)'dır (Liebermann ve Katz, 2003). Basitliği ve güvenilirliği nedeniyle hem saha uygulamalarında hem de araştırmalarda önemli bir yöntemdir. AS sırasında ayak bileği, diz ve kalça koordineli şekilde ekstansiyon gerçekleştirir. Ancak her sporcu aynı stratejiyi kullanmaz. Bazıları daha dik bir duruş ve daha fazla diz fleksiyonu ile diz dominant, bazıları ise gövde eğimini artırarak kalça ekstansörlerine daha çok yüklenen kalça dominant bir teknik kullanır (Seki ve ark., 2023).

AS üzerine çok sayıda kinematik ve kinetik çalışma yapılmış olsa da, bireylerin anatomik oranları ve relatif kuvvet profilleri ile tercih ettikleri sıçrama stratejileri arasındaki ilişki henüz yeterince araştırılmamıştır. Bu tür ilişkilerin ortaya konulması, antrenman ve rehabilitasyon programlarının sporcuların ihtiyaçlarına daha uygun biçimde uyarlanmasına katkı sağlayacaktır.

## 2. LİTERATÜR TARAMASI

### 2.1. AS'de Eklemlerin Katkıları

Aktif sıçrama (AS), kalça, diz ve ayak bileği eklemlerinin koordineli biçimde kuvvet ve iş üretmesine dayanan çok eklemli bir harekettir. Literatürde farklı katılımcı gruplarında eklem katkılarının değişkenlik gösterdiği ve bunun da teknik farklılıklardan kaynaklanabileceği vurgulanmaktadır. Bobbert ve ark. (1987), Erkek hentbolcularda, yüksek hızlı kamera ve hareket analizi ile kinematik değişkenleri, kuvvet platformu ve dört segmentli model ile de kinetik değişkenleri hesaplanmıştır.

Pozitif mekanik işin eklem katkıları kalça %32, diz %38, ayak bileği %30 bulunmuştur. Vanezis ve Lees (2005) ise 50 erkek futbolcu, 12 segmentli model kullanarak, kuvvet platformu ve 16 yansıtıcı işaretleyici ile incelenmiştir. Daha yükseğe sıçrayan grupta eklem katkıları kalça %43, diz %29, ayak bileği %28 olarak bildirilerken daha alçak sıçrayan grupta kalça %41, diz %31, ayak bileği %28 rapor edilmiştir. Çalışma ayrıca kalça ve diz eklemleri arasında negatif bir iş ilişkisi göstererek "biri daha çok iş yaparken diğerinin daha az iş yaptığını" belirtmiş ve sıçrama tekniğindeki bireysel farklılıklara dikkat çekmiştir. Xu ve ark. (2023) araştırmalarında 11 kamera, 42 işaretleyici kullanarak 33 fiziksel olarak aktif beden eğitimi öğrencisinde, pozitif işin dağılımı ayak bileği %36, kalça %17, diz %47 olarak rapor etmiştir. Hubley ve Wells (1983) ise altı aktif erkek üniversite öğrencisinde diz ekleminin pozitif işe katkısını %49 olarak göstermiştir.

Bu bulgular birlikte değerlendirildiğinde, AS performansında diz ve kalça eklemlerinin baskın rolü doğrulanmakla birlikte, eklem katkı oranlarının örnekleme, teknik ve ölçüm yaklaşımına göre değişebildiği görülmektedir. Söz konusu değişkenlik gösteren sonuçlar, sporcuların bireysel teknik farklılıkları ile açıklanabilir.

### 2.2. Atletik Hareketin Kinetik ve Kinematiğinde Kas Kuvvetinin Rolü

Kas kuvveti, çeşitli sportif hareketlerde kinematikleri önemli ölçüde etkiler. Literatürde bu ilişki hem sagittal düzlemde hem de frontal ve transvers düzlemlerde incelenmiştir. Boling ve Padua (2013), patellofemoral ağrı sendromu olan 15 bireyde kalça abdüktör, dış rotatör ve ekstansör kuvvetini frontal düzlem kinematikleriyle ilişkilendirmiş, eksantrik kuvvet azalmasının da gövde ve kalça hareketlerinde artışla ilişkili olduğunu göstermiştir. Benzer şekilde Ford ve ark. (2013) de kalça ekstansör ve abdüktör kuvvetinin, pelvis eğikliği ve gövde rotasyonu hareket açıklığıyla negatif ilişkili olduğunu göstermiştir. Sagittal düzlemde ise Teng ve Powers (2016), 40 koşucuda kalça ekstansör kuvvetinin gövde fleksiyonu ve kalça açısıyla pozitif ilişkili olduğunu, daha güçlü bireylerin de diz ekstansörlerine daha az yük bindiğini raporlamıştır. Buna karşın Martinez ve ark. (2018), 23 kadın sporcuda izometrik

kalça kuvvetini incelemişlerdir ve gövde, diz ve kalça kinematikleri arasında ilişki bulmamıştır.

Kuvvetin sıçrama ve iniş mekaniğine etkisi farklı çalışmalarla ortaya konmuştur. Örneğin Stearns ve ark. (2013), erkeklerin diz ve kalça ekstansörlerinin kadınlara kıyasla sırasıyla %28 ve %44 daha güçlü olduğunu, kadınların ise inişlerde diz ekstansörlerine daha fazla yük bindirdiğini göstermiştir. Nagai ve ark. (2013), daha yüksek diz ekstansiyon torku gösteren erkeklerin tek bacak dur-sıçra görevinde iniş sonrası daha fazla diz fleksiyonu yaptığını bulmuştur. Lephart ve ark. (2002), kadınların inişlerde daha düşük diz fleksiyonu gösterdiğini ve kuvvet/beden ağırlığı oranlarının daha az olduğunu raporlamıştır. Son olarak Mozafaripour ve ark. (2022) tarafından yapılan sistematik derleme, kalça kaslarının kuvvetlendirilmesinin alt ekstremite kinematiklerini değiştirebileceğine dair orta düzeyde kanıt olduğunu vurgulamış. Derlemedeki en önemli araştırma olan Jafarnezhadgero ve ark. (2019), direnç bandı ile yapılan 14 haftalık antrenman sonrası yaşlı erkeklerde diz abdüksiyonunun azaldığı, kalça fleksiyonunun da arttığı gösterilmiştir. Bu bulgular, kuvvetin hareket kinematiği üzerindeki çeşitli etkisini ortaya koymaktadır.

### 2.3. Sıçrama Stratejileri ve Diz/Kalça Dominant Postürler

Seki ve ark. (2023), üniversite öğrencilerinde hem diz dominant, yani gövdenin daha dikken dizlerin parmakların sagittal düzlemde önüne geçmesine izin verilen, hem de kalça dominant, gövdenin belirgin öne eğildiği ve dizlerin parmakların gerisinde tutulduğu, postürleri manipüle ederek AS ve squat sıçrama kinetiğini karşılaştırmıştır. Diz dominant postürde diz eklemi üzerindeki torku ve mekanik işi daha yüksek, kalça dominant postürde ise kalça ekstansiyon torkun ve mekanik işin daha yüksek olduğu bulunmuştur. Bu esnada sıçrama yüksekliği postürler arasında anlamlı farklılık göstermemiştir, bu da farklı teknikler kullanılsa bile performansın benzer kalabildiğini işaret etmektedir.

Rauch ve ark. (2020), 178 aktif NBA oyuncusunu AS sırasında kullandıkları stratejiye göre "stiff flexors", "hyper flexors", "hip flexors" şeklinde kümelere ayırmıştır. Hip flexors kümesi, kalçada daha geniş ama dizde daha sınırlı hareket

aralığı göstermişlerdir. Stiff flexors daha az ve hyper flexors daha fazla diz ve kalça fleksiyon göstermiştir. Kümeler arasında sıçrama yüksekliği farklı çıkmamıştır ancak kalça katkısı, hip flexor kümesinde diğerlerine göre daha yüksektir.

Bu iki çalışma birlikte değerlendirildiğinde, strateji seçiminin ve postürün eklem torku ve mekanik iş dağılımını değiştirdiği, ancak performans ölçütü olan sıçrama yüksekliğinin her zaman farklılaşmayabileceği anlaşılmaktadır.

### 2.4. Segment Oranları ve Kinematik

Bu alan, literatürde az çalışılmış bir konudur ve segment oranları ile hareket biyomekaniği arasındaki ilişkileri doğrudan inceleyen çalışmalar sınırlıdır. Mevcut kanıtlar, segment uzunluklarının kullanılan sıçrama tekniğinin eklem açı kalıpları üzerinde etkili olabileceğini düşündürmektedir.

Örneğin, squat kinematiğini inceleyen bir çalışmada 120 Hz manyetik hareket izleme sistemi kullanılmış, femur ve gövdesi daha uzun olan kadınlar hareketi daha geniş hareket aralığı ile tamamladığı, erkeklerde ise hem gövde uzunluğu hem de boy uzunluğunun, gövdenin öne daha fazla eğilmesi ile pozitif ilişkili bulunduğu rapor edilmiştir. Segment oranları ile zamanlama arasında anlamlı bir ilişki bildirilmemiş ve cinsiyete bağlı teknik farkların, ekstremite uzunluklarından kaynaklanabileceği tartışılmıştır.

## 3. YÖNTEM

### 3.1. Katılımcılar

Çalışmaya, yaşları 18 ile 28 arasında değişen toplam 36 üniversiteli takım sporu sporcusu (16 erkek, 20 kadın) gönüllü olarak katılmıştır. Katılımcıların tamamı aktif olarak antrenman yapan, son altı ay içerisinde alt ekstremiteyi etkileyen herhangi bir sakatlık geçirmemiş bireylerden seçilmiştir. Çalışma öncesinde tüm katılımcılara araştırmanın amacı, prosedürleri ve olası riskleri hakkında ayrıntılı bilgi verilmiş ve yazılı onam formu imzalatılmıştır. Çalışma için, ilgili üniversiteden etik kurul onayı alınmıştır.

### 3.2. Genel Prosedür

Veri toplama süreci tek bir günde, iki ayrı oturumda gerçekleştirilmiştir. Birinci oturumda antropometrik ölçümler ve AS kinematik verileri toplanmıştır, ikinci oturumda da kuvvet testleri yapılmıştır. Oturumlar arasında yaklaşık 20 dakika süre vardır. Tüm ölçümler standartlaştırılmış çevresel koşullarda (~23°C sıcaklıkta) yapılmıştır.

### 3.3. Antropometrik Ölçümler

Boy uzunluğu stadiometre (Seca 213, Hamburg, Almanya) kullanılarak çıplak ayakla ölçülmüştür. Vücut kompozisyonu ölçümleri TANITA MC-780MA biyolojik empedans analiz cihazı ile gerçekleştirilmiş ve vücut ağırlığı (kg), yağ yüzdesi (%) değerleri toplanmıştır. Segment uzunlukları, Xsens ayarlanabilir metre kullanılarak ölçülmüş ve femur, tibia, gövde ve ayak uzunlukları belirlenmiştir. Segment uzunluklarının boy uzunluğuyla oranları, ölçüm değerlerinin boy uzunluğuna bölünmesiyle hesaplanmıştır.

### 3.4. Kinematik Ölçümler

AS kinematik verileri, Xsens Awinda ataletsel ölçüm üniteleri (IMU) kullanılarak elde edilmiştir. IMU'lar, üretici firmanın önerilerine uygun olarak şu bölgelere yerleştirilmiştir: her iki ayak üstüne, her iki uyluğun orta kısmına, her iki alt bacağın orta kısmına, sakrumun üstüne ve sternuma. Ölçümler öncesinde, sensörler Xsens MVN yazılımı aracılığıyla kalibre edilmiştir.

### 3.5. Isınma ve Test Protokolü

Her iki oturumda da katılımcılar standartlaştırılmış bir ısınma tamamlamıştır. Isınma 5 dakika hafif tempo koşu, ardından alt ekstremite için dinamik esneme hareketleri şeklinde gerçekleştirilmiştir. AS testinde katılımcılar eller belde pozisyonunda sıçrama yapmıştır. Her bir katılımcıya üç adet deneme tekrarı yaptırılmış, dördüncü deneme kayıt altına alınmıştır. Analizde, eksantrik fazdaki maksimum diz fleksiyon

açısı ve maksimum kalça fleksiyon açısı temel kinematik parametreler olarak kullanılmıştır.

### 3.6. Kuvvet Testleri

Alt ekstremite kuvvet ölçümleri leg extension ve hip thrust egzersizleri ile yapılmıştır. Leg extension testi katılımcının iki bacağı da ayrı ayrı test edildikten sonra daha kuvvetli bacağının sonucu kullanılarak gerçekleştirilmiştir. Hip thrust testi, 20 kg Olimpik bar ve sehpa kullanılarak yapılmıştır.

Her iki testte de 5 Tekrar Maksimum (5TM) protokolü uygulanmıştır. Katılımcılar, yaklaşık 3-5 tekrar yapabilecekleri ağırlıklarla başlamış ve yükler, denemeler arasında 3-5 dakikalık dinlenme verilerek giderek artırılmıştır. Maksimum 5 tekrarın tamamlandığı en yüksek ağırlık 5TM olarak kaydedilmiştir. Alınan değerler katılımcının vücut ağırlığına bölünerek relatif kuvvet değerleri hesaplanmıştır.

### 3.7. Veri Analizi

Toplanan veriler, SPSS yazılımı (IBM SPSS Statistics 29.0) ile analiz edilmiştir. Tanımlayıcı istatistikler hesaplanmış, değişkenler arasındaki ilişkiler Pearson korelasyon analizi ile değerlendirilmiştir. Korelasyon büyüklükleri düşük ($r < 0.1$), orta ($r = 0.1 - 0.3$), büyük ($r = 0.3 - 0.5$), çok büyük ($r= 0.5 - 0.7$) ve son derece büyük ($r = 0.7 - 0.9$) olarak sınıflandırılmışlardır. Analizlerde anlamlılık düzeyi $p < 0.05$ olarak kabul edilmiştir.

## 4. BULGULAR

### 4.1. Tanımlayıcı İstatistikler

Toplam 36 (16 erkek, 20 kadın) katılımcının tanımlayıcı verileri Tablo 4.1'de sunulmuştur. Erkekler, kadınlara kıyasla daha uzun boy ve daha yüksek vücut ağırlığına sahiptir. Vücut yağ yüzdesi kadınlarda daha yüksek bulunmuştur.

**Tablo 4.1.** Katılımcıların tanımlayıcı istatistikleri

| Değişkenler | Kadın Sporcular (n=20) | | Erkek Sporcular (n=16) | |
|---|---|---|---|---|
| | Ortalama | SS | Ortalama | SS |
| Boy Uzunluğu (cm) | 168.76 | 5.66 | 181.39 | 7.00 |
| Vücut Ağırlığı (kg) | 61.77 | 8.28 | 87.98 | 9.27 |
| Vücut Kütle Endeksi ($kg/m^2$) | 21.73 | 3.07 | 26.77 | 2.67 |
| Vücut Yağ Oranı (%) | 20.18 | 6.02 | 14.38 | 4.95 |
| Femur uzunluğu (cm) | 41.23 | 1.9 | 45.94 | 2.67 |
| Tibia uzunluğu (cm) | 39.88 | 2.96 | 42.56 | 2.38 |
| Femur/Boy Uzunluğu oranı | 0.24 | 0.02 | 0.25 | 0.01 |
| Tibia/Boy Uzunluğu oranı | 0.24 | 0.01 | 0.24 | 0.01 |

### 4.2 Kuvvet ve Kinematik Değerler

Leg extension ve hip thrust 5TM testlerinden elde edilen mutlak ve relatif kuvvet değerleri ile AS sırasında ölçülen maksimum diz ve kalça fleksiyon açıları Tablo 4.2'de verilmiştir. Erkekler her iki egzersizde de daha yüksek kuvvet değerlerine ulaşmıştır. Relatif kuvvet ise leg extension testinde erkekler biraz daha kuvvetli çıkmalarına rağmen hip thrust testinde ise cinsiyetler arasında fark görülmemiştir.

**Tablo 4.2.** Kuvvet ve kinematik değişkenlerin ortalama ve standart sapmaları

| Değişkenler | Kadın Sporcular (n=20) | | Erkek Sporcular (n=16) | |
|---|---|---|---|---|
| | Ortalama | SS | Ortalama | SS |
| Tek bacak leg extension 5TM (kg) | 46.00 | 9.95 | 86.94 | 15.12 |
| Hip thrust 5TM (kg) | 114.25 | 31.05 | 206.88 | 37.94 |
| Leg extension/ vücut ağırlığı oranı | 0.79 | 0.16 | 0.78 | 0.15 |
| Hip thrust/ vücut ağırlığı oranı | 1.93 | 0.45 | 1.83 | 0.43 |

### 4.3. Korelasyon Analizleri

Pearson korelasyon analizi sonuçları Tablo 4.3 ve Tablo 4.4'te gösterilmiştir. Leg extension relatif kuvvet ile maksimum diz fleksiyon açısı arasında pozitif ve anlamlı bir ilişki bulunmuştur. Femur boyu/boy uzunluğu oranı ile maksimum kalça fleksiyon açısı arasında erkeklerde negatif ve anlamlı bir ilişki tespit edilmiştir. Leg extension relatif kuvveti ile maksimum kalça fleksiyon açısı arasında tüm katılımcılarda negatif ve anlamlı ilişki bulunmuştur.

**Tablo 4.3.** Diz fleksiyon açısı ile Kuvvet ve antropometrik değişkenler arasındaki korelasyonlar

| Değişkenler | Diz Fleksiyon Açısı | | | | | |
|---|---|---|---|---|---|---|
| | Kadın Sporcular (n=20) | | Erkek Sporcular (n=16) | | Bütün Sporcular (n=36) | |
| | *r* | *P* | *r* | *P* | *r* | *P* |
| Leg extension/vücut ağırlığı oranı | 0.256 | 0.138 | 0.319 | 0.114 | 0.396 | **0.008** |
| Hip thrust/vücut ağırlığı oranı | 0.131 | 0.291 | 0.032 | 0.454 | 0.367 | **0.014** |
| Femur/Boy uzunluğu oranı | 0.203 | 0.196 | 0.103 | 0.352 | 0.184 | 0.142 |
| Tibia/Boy uzunluğu oranı | 0.048 | 0.421 | 0.202 | 0.226 | 0.122 | 0.240 |

Tablo 4.4. Kalça fleksiyon açısı ile Kuvvet ve antropometrik değişkenler arasındaki korelasyonlar

| Değişkenler | Kalça Fleksiyon Açısı | | | | | |
|---|---|---|---|---|---|---|
| | Kadın Sporcular (n=20) | | Erkek Sporcular (n=16) | | Bütün Sporcular (n=36) | |
| | *r* | *P* | *r* | *P* | *r* | *P* |
| Leg extension/ Vücut ağırlığı oranı | 0.413 | **0.035** | 0.182 | 0.249 | 0.095 | 0.291 |
| Hip thrust/Vücut ağırlığı oranı | 0.335 | 0.074 | 0.251 | 0.174 | 0.052 | 0.381 |
| Femur/Boy uzunluğu oranı | 0.174 | 0.232 | 0.529 | **0.018** | 0.254 | 0.067 |
| Tibia/Boy uzunluğu oranı | 0.170 | 0.237 | 0.406 | 0.059 | 0.033 | 0.424 |

## 5. TARTIŞMA

Hareket biyomekaniği ile ilişkili fiziksel değişkenlerin belirlenmesi ve incelenmesi, sporcuların neden ve nasıl hareket ettiklerine dair değerli bilgiler sunar. Bu çalışma üniversite düzeyinde spor yapan atletlerde AS sırasında eklem kinematiği ile relatif kuvvet ve segment oranları arasındaki ilişkiyi araştırmayı amaçladı. Literatürde AS kinematiği ile relatif kuvvet arasındaki ilişkiye dair çok sınırlı çalışma bulunmaktadır. Yazarların bilgisine göre bu çalışma AS kinematiği ile segment oranlarının ilişkisini inceleyen ilk çalışmadır. Bulgular AS sırasında diz fleksiyon açısı ile her iki relatif kuvvet ölçümü arasında orta ile büyük düzeyde pozitif ve anlamlı bir korelasyon olduğunu göstermiştir. Ayrıca femur/boy uzunluğu oranı ile AS sırasında kullanılan maksimum kalça fleksiyon açısı arasında anlamlı ve negatif bir ilişki gösterilmiştir.

Sonuçlar AS'nin eksantrik fazında ulaşılan maksimum diz fleksiyon açısı ile bacak ekstansiyonu/vücut ağırlığı oranı arasında pozitif bir ilişki olduğunu ortaya koymuştur. Bu bulgu hipotezi desteklemektedir. Vücut ağırlığına göre daha güçlü bacak ekstansiyonu, diz ekstansör kuvvetinin bir göstergesidir ve AS'de önemli bir rol oynar. Seki ve ark. (2023), AS sırasında dizlerin sagital düzlemde ileri gittiği dik bir postürün toplam işi ve diz ekstansörlerinin ürettiği torku artırdığını göstermiştir. Ayrıca Rauch ve ark. (2020), artan kalça fleksiyon açılarında kalça ekleminin katkısının arttığını ve diz fleksiyon açısı azaldığında ise diz ekleminin katkısının azaldığını göstermiştir. Bu nedenle diz ekstansörleri güçlü olan sporcuların, en yüksek performanslarını sergilemek için bu kaslara daha çok güvenmeleri olasıdır. Bunun için daha dik bir postür tercih ederek dizlerini daha fazla bükmüş olabilirler. Bu açıklama Nagai ve ark. (2013) tarafından da desteklenmektedir çünkü daha yüksek diz ekstansiyon torku üretebilen katılımcıların, stop jump görevinde dizlerini daha fazla büktükleri görülmüştür.

Veriler kadın sporcularda maksimum kalça fleksiyon açısı ile bacak ekstansiyonu-vücut ağırlığı oranı arasında orta ile büyük düzeyde negatif bir ilişki olduğunu ortaya koymuştur. Bu bulgu eklem bağımlılığı ile açıklanabilir. Diz ekstansörleri güçlendikçe sporcular kalça eklemlerine daha az yüklenmiş olabilir. Bu ilişki

yalnızca kadın sporcularda istatistiksel olarak anlamlı olsa da erkeklerde de benzer bir eğilim gözlenmiştir.

Ayrıca, sonuçlar kalça ekstansör kuvveti (hip thrust/vücut ağırlığı oranı) ile maksimum diz fleksiyon açısı arasında anlamlı bir pozitif korelasyon göstermiştir. Bunun bir nedeni diz fleksiyon açısındaki artışın katılımcılara daha büyük kalça fleksiyon açılarına anatomik olarak olanak sağlaması olabilir. Diz yeterince bükülmediğinde hamstring esnekliği ve koordinasyon sınırlamaları nedeniyle daha derin kalça fleksiyon açılarına ulaşmak zordur. Bir diğer neden kalça ekstansiyon kuvveti ile diz ekstansiyon kuvveti arasındaki anlamlı ve pozitif korelasyon olabilir. Yani kalça ekstansörleri güçlü olan bireyler büyük olasılıkla diz ekstansörlerinde de güçlüdür.

Sonuçlar erkek sporcularda femur/boy uzunluğu oranı ile maksimum kalça fleksiyon açısı arasında anlamlı ve güçlü negatif bir ilişki olduğunu göstermiştir. Hipotez daha uzun femurun daha büyük kalça fleksiyon açısı ile ilişkili olacağı yönündeydi (McKean ve Burkett, 2012). Ancak bu çalışmada farklı sonuçlar bulunmuştur. Bunun nedeni squat egzersizinde sporcuların sırtlarında ağırlık taşımak zorunda olmaları olabilir. Ekstra ağırlıkla squat yaparken sporcuların postürlerini ve duruş genişliklerini barın yerleşimine ve ağırlık merkezine göre ayarlamaları gerekir. Ayrıca squat sırasında topukların yerde kalması zorunludur fakat AS'de böyle bir kısıtlama uygulanmamıştır. Sporcular topuklarını kaldırabildikleri için dizin öne doğru hareketine izin veren farklı bir teknik tercih etmiş olabilirler.

Hipotez, kalça ekstansör kuvveti ile maksimum kalça fleksiyon açısı arasında pozitif bir ilişki olacağı yönündeydi. Ancak bulgular, bu iki değişken arasında anlamlı bir ilişki göstermemiştir. Diz ekleminde görülen relatif kuvvet ve eklem bağımlılığı tartışmaları kalça eklemi için geçerli olmayabilir. Güçlü kalça ekstansörlerine sahip sporcular, daha küçük kalça açılarında daha gergin bir sıçrama stratejisi tercih etmiş olabilirler.

Veriler ayrıca leg extension/vücut ağırlığı oranı ile femur/boy uzunluğu oranı arasında anlamlı ve pozitif bir ilişki olduğunu göstermiştir. Çalışma ne kadar relatif

kuvvet ve segment oranları arasındaki ilişkiyi araştırmayı amaçlamasa da, bu önemli bir bulgu olarak değerlendirilebilir. Bu çalışmada nedensellik kurulamayacak olsa da, tamamen genetik olan anatomik bir değişken ile antrenmanla geliştirilebilen başka bir değişken arasında anlamlı bir ilişki bulunması dikkat çekicidir.

Tibia/boy uzunluğu oranı ile maksimum kalça fleksiyon açısı arasında neredeyse sıfır korelasyon bulunmuştur. Bu, hipoteze zıt bir sonuçtur. Daha uzun tibiaların, aynı diz fleksiyon açılarına ulaşabilmek için daha büyük kalça fleksiyon açıları gerektireceği düşünülmüştü. Ancak bu hipotez, katılımcıların ayak bileği dorsifleksiyon miktarlarını ve topuklarını yerde tutmak zorunda olmadıklarını göz önüne almamaktadır. Ayrıca tibia/boy uzunluğu oranı yüksek olan sporcular, hem kalça hem de dizde daha küçük açılar kullanarak daha sert bir sıçrama stratejisi tercih etmiş olabilir. Bu teknik elit sporcular tarafından da sıklıkla kullanılmaktadır (Rauch ve ark., 2020).

Bu çalışmanın bazı sınırlılıkları vardır. Örneklem yalnızca üniversite sporcularından oluşmaktadır ve sınırlı sayıda katılımcı içermektedir. Bu durum sonuçların genellenebilirliğini sınırlandırmaktadır. Ayrıca kinematik ve kuvvet ölçümlerinde kullanılan yöntemler de bir diğer sınırlılıktır. IMU'lar yüksek geçerlilik gösterse de, altın standart olan optik hareket yakalama teknolojisi daha güvenilir sonuçlar sağlayabilirdi. Benzer şekilde, kuvvet testlerinde kullanılan spor salonu ekipmanları yerine izokinetik dinamometreler daha güvenilir sonuçlar verebilirdi. Ayrıca leg extension egzersizinde kullanılan 5TM tahmin formülü belirli bir hata payı içermektedir. Bunun dışında kadın sporcuların menstrüel döngüleri göz önünde bulundurulmamıştır. Bu durum test sonuçlarını etkilemiş olabilir.

Gelecekteki çalışmalar, daha geniş bir örneklemle ve farklı spor branşlarından atletlerle yapılmalı. Ayrıca drop jump, stop jump, yön değiştirme ve sprint gibi farklı hareket tipleri incelenmelidir.

Bulgular, hem kuvvet testlerinin hem de anatomik değişkenlerin sporcuların hareket stratejileri hakkında bilgi sağlayabileceğini göstermektedir. Bu çalışmada kullanılan ekipmanların ucuz ve ulaşılabilir olması, antrenörlerin ve araştırmacıların benzer

biyomekanik analizleri gelişmiş ve pahalı cihazlara gerek duymadan yapmalarını mümkün kılar.

## 5.1 Sonuç

Sonuç olarak, bu çalışma AS eklem kinematiği ile relatif kuvvet ölçümleri ve segment oranları arasındaki ilişkiyi araştırmıştır. Bulgular, hem bacak ekstansiyon kuvvetinin hem de kalça ekstansiyon kuvvetinin AS'nin eksantrik fazında ulaşılan maksimum diz fleksiyon açısı ile anlamlı ve pozitif ilişki içinde olduğunu göstermiştir. Ayrıca, femur/boy uzunluğu oranı daha yüksek olan sporcularda maksimum kalça fleksiyon açısı daha düşük bulunmuştur. Bu sonuçlar literatürde sınırlı olan sıçrama stratejisi, kuvvet ve anatomik değişkenler ilişkisine katkı sağlamaktadır. Sporcular arasında gözlenen farklı teknikler, antrenörlerin değerlendirmelerinde yol gösterici olabilir. Bununla birlikte, örneklem büyüklüğü, kullanılan ölçüm cihazları ve kuvvet değerlendirme yöntemleri çalışmanın sınırlılıkları arasında sayılmalıdır. Gelecekteki araştırmalar, daha büyük örneklemlerle ve gelişmiş ölçüm cihazlarıyla yapılmalıdır. Bu çalışmada kullanılan uygun maliyetli ekipmanlar antrenörlerin gelişmiş araçlara gerek kalmadan da benzer analizler yapabileceğini göstermektedir.

## C. INFORMED CONSENT FORM / ARAŞTIRMAYA GÖNÜLLÜ KATILIM FORMU

Bu araştırma, Orta Doğu Teknik Üniversitesi Beden Eğitimi ve Spor Bölümü yüksek lisans öğrencisi Bora Başat tarafından yürütülmektedir. Bu form, sizi araştırma koşulları hakkında bilgilendirmek için hazırlanmıştır.

Bu çalışma, alt ekstremite segment uzunlukları (femur ve tibia) ve gövde uzunlukları ile bu segment oranlarının; leg extension ve hip thrust egzersizleriyle belirlenen kuvvet oranı ve aktif sıçrama (AS) sırasındaki kinematik verilerle olan ilişkilerini incelemeyi amaçlamaktadır.

Araştırma iki aşamada gerçekleştirilecektir. İlk aşamada, performans laboratuvarında katılımcıların boy uzunluğu, vücut ağırlığı, tibia, femur ve gövde uzunlukları gibi antropometrik ölçümleri alınacak ve katılımcıya sensörler bağlanarak sıçrama testi yapılacaktır. İkinci aşamada ise, Orta Doğu Teknik Üniversitesi spor salonlarında leg extension cihazı ile leg extension ve olimpik halter ekipmanları ile hip thrust kuvvet testleri uygulanacaktır.

Araştırmaya katılımınız tamamen gönüllülük temelinde olmalıdır. Katılım zorunlu değildir ve çalışmaya katılmayı reddedebilir veya herhangi bir aşamada gerekçe göstermeden ayrılabilirsiniz. Verileriniz tamamıyla gizli tutulacak ve yalnızca araştırmacı tarafından değerlendirilecektir. Katılımcılardan elde edilen bilgiler anonimleştirilerek analiz edilecek ve bilimsel yayımlarda toplu halde raporlanacaktır.

Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz. Çalışma hakkında daha fazla bilgi almak için Bora Başat ile iletişim kurabilirsiniz.

***Yukarıdaki bilgileri okudum ve bu çalışmaya tamamen gönüllü olarak katılıyorum.***

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Ad Soyad Tarih İmza

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**Bölümü** / Department : Beden Eğitimi ve Spor / Physical Education and Sports

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