COMPARISON OF LANDING MANEUVERS BETWEEN MALE AND FEMALE VOLLEYBALL PLAYERS

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ABSTRACT

COMPARISON OF LANDING MANEUVERS BETWEEN MALE AND FEMALE VOLLEYBALL PLAYERS

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This study evaluated kinematic (joint angles of hip, knee, ankle and knee flexion angle at impact), kinetic (ground reaction force and stabilization time) and strength (quadriceps and hamstring muscles peak torque to body weight) variables in female volleyball players were compared with matched male counterparts. Sixteen volleyball players (8 females and 8 males) performed forward and sideward landings from 40 cm and 60 cm heights. Landings were filmed with six 50 Hz video cameras, and selected kinematic variables were calculated by the KISS Motion Analysis System. Bertec force plate recorded ground reaction force (GRF) for each landing. A Biodex System isokinetic dynamometer was used to measure quadriceps and hamstring muscles peak torques to body weight at an angular speed of 60 degrees/second. Results demonstrated that females revealed significantly ($p<.05$) lower knee and hip flexion angles for all landing maneuvers, especially knee flexion at 40 cm forward and hip flexion at 40 cm sideward landings differences were significant ($p<.05$). Female players applied significantly ($p<.05$) greater forces onto the force plate when the GRF data was normalized to body weight. Also females showed significantly ($p<.05$) less normalized quadriceps and hamstring peak torque as compared to males. There was a negatively high correlation between knee flexion angles and applied forces for males at 40 cm forward landing. In addition, significantly positive correlations existed between knee flexion angles and both quadriceps and hamstring muscles strength variables for male players. In conclusion both biomechanical and strength variables showed difference between genders during landing activities. Landings that have greater amount of hip and knee flexion resulted in decreased forces upon landings. The lower flexion angles are related with the weaker leg muscles in females. Therefore, females may more susceptible in anterior cruciate ligament injuries. Further researches, which are multidimensional, randomized, prospective and longitudinal, should be performed in investigating the incidence of this injury.

Key Words: Kinetic, Kinematic, Muscle Strength, Male and Female Volleyball players.

ÖZ

ERKEK VE BAYAN VOLEYBOLCULARDA YERE İNİŞ HAREKETLERİNİN KARŞILAŞTIRILMASI

Salcı, Yaşar

Yüksek Lisans, Beden Eğitimi ve Spor Bölümü

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Bu çalışmanın amacı erkek ve bayan voleybolcularda kinematik (kalça, diz ve bilek eklem açıları ve parmak ucu yere değdiği anda ki diz açısı), kinetik (yere uygulanan kuvvet ve dengeye gelme zamanı) ve bacak kuvvet (quadriceps ve hamstring kas kuvvetleri) parametrelerini karşılaştırmaktır. 16 voleybol oyuncusunda (8 erkek ve 8 bayan) 40 cm ve 60 cm yükseklikten öne ve yana doğru yere düşüş hareketleri değerlendirilmiştir. Yere düşüş hareketi 50 Hz hızında altı kamera ile filme alınmış ve kinematik değerler KISS Hareket Analiz Sistemi ile yere uygulanan kuvvet ise Bertec kuvvet platformu ile kaydedilmiştir. Quadriceps ve hamstring kas kuvvetleri Biodex Sistem izokinetik dinamometresi ile 60 derece/sn açısal hızla ölçülmüştür. Bu çalışmada bayanlarda erkeklere göre iki yana her iki yükseklikten düşüşte diz ve kalça eklemlerinde açılanmanın daha az olduğu gözlenmiştir. Özellikle 40 cm'den öne doğru düşüşte diz ekleminde oluşan açı ile 40 cm'den yana doğru düşüşte kalça ekleminde oluşan açılar istatiksel olarak anlamlı daha az bulunmuştur ($p<.05$). Bayan ile erkek voleybolcuların düşüşte yere uyguladıkları kuvvet vücut ağırlıklarına göre normalize edilerek karşılaştırıldığında, bayanların uyguladığı kuvvet istatiksel olarak anlamlı yüksek çıkmıştır ($p<.05$). Aynı zamanda bayan ile erkek voleybolcuların bacak kas kuvvetleri karşılaştırıdığında, bayanların bacak kas kuvvetleri istatiksel olarak anlamlı zayıf bulunmuştur ($p<.05$). Erkeklerde diz ekleminde oluşan açılanma ile yere uygulanan kuvvet arasında negatif, diz ekleminde oluşan açılar ile bacak kas kuvvetleri arasında ise anlamlı ve pozitif bir ilişki bulunmuştur. Bu çalışmanın sonuçlarına göre erkek ve bayan voleybolcular arasında biyomekanik ve kuvvet parametreleri anlamlı farlılıklar göstermektedir. Yere düşüş hareketinde erkekler diz ve kalça eklemlerini bayanlara oranla fazla açılandırarak yer reaksiyon kuvvetini azaltabilmektedir. Bayanlardaki bacak kuvvetindeki zayıflık, yere düşüş hareketinde diz ekleminde oluşan daha az açılanma ile ilgilidir. Bayanların diz eklemlerinde erkeklere oranla yaşadıkları başta ön çapraz bağ kopması olmak üzere sakatlık oranlarının fazlalığı diz ve kalça eklem açılarının yere düşüş hareketindeki azlığının yanısıra bacak kas kuvvetinin zayıflığı olabileceği varsayılabilir. Bu ilişkinin ortaya konabilmesi için prospektif, çok merkezli, randomize kontrollü uzunlamasına bir çalışmanın tasarlanmasında yarar vardır.

Anahtar Kelimeler: Kinetik, Kinematik, Kas Kuvveti, Yere Düşüş, Erkek ve Bayan Voleybolcular.

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thank my parents, whose foremost concern has always been me and my family's happiness.

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LIST OF ABBREVIATIONS

ACL	Anterior Cruciate Ligament
GRF	Ground Reaction Force
PVGRF	Peak Vertical Ground Reaction Force
DJ	Drop Jump
HQR	Hamstring Quadriceps Ratio
ROM	Range of Motion
BMI	Body Mass Index
K(ROM)	Knee Range of Motion
HTL	Heel-Toe Landing
FFL	Forefoot Landing
RT	Rise Time
SREMG	Smoothed Rectified Electromyograms
KF@40for	Knee Flexion at 40 cm Forward Landing
KF@60for	Knee Flexion at 60 cm Forward Landing
KF@40sid	Knee Flexion at 40 cm Sideward Landing
KF@60sid	Knee Flexion at 60 cm Sideward Landing
HF@40for	Hip Flexion at 40 cm Forward Landing
HF@60for	Hip Flexion at 60 cm Forward Landing
HF@40sid	Hip Flexion at 40 cm Sideward Landing
HF@60sid	Hip Flexion at 60 cm Sideward Landing

AF@40for	Ankle Flexion at 40 cm Forward Landing
AF@60for	Ankle Flexion at 60 cm Forward Landing
AF@40sid	Ankle Flexion at 40 cm Sideward Landing
AF@60sid	Ankle Flexion at 60 cm Sideward Landing
FOR40/BW	Applied Body Forces at 40 cm Forward Landing to Body Weight
FOR60/BW	Applied Body Forces at 60 cm Forward Landing to Body Weight
SID40/BW	Applied Body Forces at 40 cm Sideward Landing to Body Weight
SID60/BW	Applied Body Forces at 60 cm Sideward Landing to Body Weight
STA.T40F	Stabilization Time at 40 cm Forward Landing
STA.T60F	Stabilization Time at 60 cm Forward Landing
STA.T40S	Stabilization Time at 40 cm Sideward Landing
STA.T60S	Stabilization Time at 60 cm Sideward Landing
For40imp	Knee Flexion Angles at Impact of 40 cm Forward Landing
For60imp	Knee Flexion Angles at Impact of 60 cm Forward Landing
Sid40imp	Knee Flexion Angles at Impact of 40 cm Sideward Landing
Sid60imp	Knee Flexion Angles at Impact of 60 cm Sideward Landing

CHAPTER I

INTRODUCTION

Volleyball is an increasingly popular and competitive sport. The popularity of this game in both men's and women's increased in 1980s on courts and beaches all around the world. Volleyball was thought as a recreational sport in early years. However, now the level of play of competitive volleyball is very high with bodies flying in the air and collapsing onto the court. Volleyball has therefore become a strong, taking its place in the world as a serious competitive team sports, with a fairly high injury rate (Briner and Benjamin, 1999). It is an intense sport that requires quick physical responses involving the entire body. The stress on the arm from spiking the ball while up in the air and the constant bending of the back and knees can cause injuries.

Injury rates in volleyball are hard to determine precisely because researchers' definitions of injury vary. Nonetheless, some trends are clear. The highest rate of volleyball injury is associated with blocking, followed by spiking (Schafle et al., 1990; Ferretti et al., 1992) and both of the techniques are based on jumping. Jumping and landing movements are integral parts of many sporting activities including volleyball and been investigated by numerous researchers (Devita, 1992). Goodwin reported (1987) rehabilitation records of 106 patients, which were about volleyball injuries found 63% of the injuries, were related to jumping. The knees, along with the ankle, consistently were the most frequently injured joints in sports (Zelisko et al., 1982). Anterior cruciate ligament (ACL) injuries of the knee are common in volleyball. ACL rupture is a potentially career ending injury for the athletes. An estimated 70% of ACL injuries are sports related (Colby et al., 2000).

The majority of the mechanisms of ACL injuries are non-contact situations where the injured player was not hitting or touching another player. Such injuries frequently occur in certain athletic tasks (Boden et al., 2000; Maffulli et al., 2002). Colby et al. (2000) revealed that these non-contact situations occur near foot strike when the quadriceps is eccentrically contracting to resist flexion and given the non-contact situation of cutting or landing from a jump. While cutting and landing, inertial forces would cause an anterior force on the femur and a posterior force on the tibia, which would stress the posterior and anterior cruciate ligaments. Therefore, it seems reasonable to assume that the mechanism of non-contact injury to the ACL involves internal forces that are generated by the leg muscles of athletes and external forces, such as the ground reaction force, at landing.

The mechanism of injury often described as landing from jumping, stopping, cutting, twisting, and turning (Arendt et al., 1995). However, there are lots of possible risk factors that can cause the occurrence of an ACL injury. Injuries may depend on variations in quadriceps and hamstring muscle strength, knee joint laxity, shoe-surface interaction, intercondylar notch variations, joints biomechanics, and hormonal effects (Egland, 2000).

Strength coordination, and the timely ability to recruit muscles (muscle reaction time) are needed to maintain knee stability. Several researchers have documented that women have significantly less muscle strength when normalized for body weight (Griffin et al., 1993; Huston & Wojtys, 1996). This lack of quadriceps and hamstring muscle strength may place the female athlete at a significant disadvantage because the muscles surrounding the knee protect the joint from deleterious loads. Additionally, some female athletes seem to have different muscle activation patterns compared to their male counterparts (Huston et al., 2000). Female volleyball players tend to activate their quadriceps near full extension at the knee with little hamstring activity and to land with smaller angles of hip flexion and larger angles of valgus compared with males. The combined effects from these findings suggest that women are at an increased risk of ACL injury (Lephart et al., 2002).

Joint laxity is another risk factor that can contribute to injury. Preliminary data (Huston and Wojtys, 1996) presented that women have more joint laxity than their male counterparts. Therefore, in female athletes with above-average hamstring flexibility, the protective ability of this muscle group may be diminished and the forces required to stabilize the knee preferentially transferred to the ligaments. Though these anatomic parameters may not be the primary cause of ACL injury, they may predispose female athletes to ACL disruption. The ability to accurately measure hamstring flexibility and the interplay between the knee flexors and extensors require further study (Boden et al., 2000).

The knee is classified as a hinge joint; in fact, it is the largest and the most complex joint in the body. This tibiofemoral joint allows flexion and extension in the sagittal plane by rolling, spinning, and gliding. The tibial plateau and asymmetrical condyles provide limited bony structural support while the soft tissue structures are largely responsible for providing static and dynamic support to the joint (Lephart et al., 2002).

The soft tissue structures that provide static support to the knee are the capsule, ligaments, and meniscus, which are also referred as primary stabilizers or restraints. These primary restrains are mechanical in nature and are responsible for stabilizing and guiding the skeletal components. In addition, the ACL is responsible for resisting anterior translation of the femur on the tibia, specifically resisting 80-85% of anterior transitory loads (Lephart et al., 2002). The ACL is made of three bundles, the anteromedial, intermediate, and posterolateral. Bundles rise from the posterior medial femoral condyle and insert into the anterior medial (Figure 1.) aspect of the tibial plateau (Lephart et al., 2002).

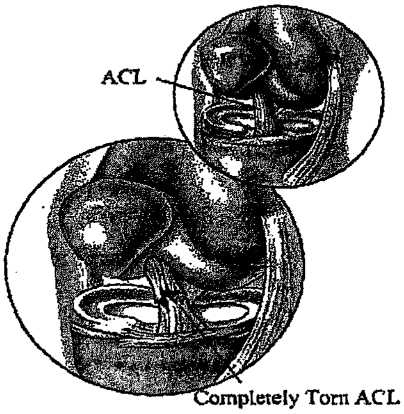


Figure 1. The anterior cruciate ligament is located in the center of the knee and holds the femur and the tibia in place.

The soft tissues that provide dynamic stabilization to the knee are the muscles, which are referred as secondary restraints. The quadriceps, hamstrings, and gastrocnemius are the main dynamic stabilizers of the knee. The orientation of the proximal attachments of the gastrocnemius and the distal attachments of the hamstrings are important for the dynamic stabilization of the knee as they provide a posterior force on the tibia that counteracts anterior translation (Lephart et al., 2002). Specifically, the hamstring muscle group is synergistic to the ACL by unloading the ligament via increasing the load to failure rate, up to 40% (Solomonow et al., 1987). Previous research suggests that several neuromuscular characteristics contribute to this dynamic restraint mechanism (Huston & Wojtys, 1996).

Playing surface and shoes must be considered as risk factors when evaluating ACL injuries. Researchers should also notice the contradiction between the effects of shoe-playing surface interaction on performance. High level of friction between the shoes and playing surface appear to increase the risk of ACL injuries, but enhance performance (Maffulli et al., 2002).

Intercondylar notch geometry is one other intrinsic factor suspected to predispose individuals to ACL injury and may differ between males and females (Tillman et al. 2002). However, this finding is contradictory. Although, males and females incur ACL injuries at different rates (Lephart et al., 2002; Arent et al., 1995 and Messina et al., 1999), no definitive evidence exist that explains this anatomical difference in injury frequency.

Most of landing studies focused on several common biomechanical variables in an effort to characterize the role of different factors in injury. These variables include the joint kinematics and ground reaction force (GRF). The GRF is a concept that is used to describe the reaction force produced by the supporting ground surface. It is derived from Newton's third law (action-reaction) to represent the reaction force of the ground to acceleration of the body. It is of interest to landing biomechanics because it is the main contributor to the internal loads in the lower extremity during landing. These internal loads can cause injury if not sufficiently distributed or attenuated by the musculoskeletal system. A research approach used in the past to investigate the injury potential of landing was to determine how various aspects of landing influence the GRF (McNitt-Gray, 1993; McNitt-Gray et al., 2001; Egland, 2000). By learning how these aspects of landing influence the GRF, there exists the possibility to develop interventions to control the GRF and the internal loads associated with it. Kinematics is the study of the spatial and temporal characteristics of motion without regard to the forces producing the motion. In regards to landing biomechanics, kinematics describes the movement of body segments and joints in terms of position, velocity, and acceleration during the landing movement. The study of kinematics by itself has limited potential for investigating injury aspects of landing. Thus, it has such a large influence on the GRF that it is difficult to discuss one without the other (Madigan, 2001).

When analyzing human movement and noncontact injuries several forces that act on a body, including weight, ground reaction force, joint reaction force, and muscle forces should be considered. Additionally, the biomechanical principle of impulse summarizes potential errors in landing techniques. Impulse is defined as the size of a force multiplied by the time of that forces application. One has ideal impulse if a force is absorbed over a longer period of time. To do so, joints must go through a complete range of motion to ensure the maximum time available to absorb that force was used. Applying this information to potentially dangerous knee injuries is the degree of knee flexion on landing and impact velocity. Lesser degrees of knee flexion may be associated with increased peak vertical or ground reaction forces. The lower the ground reaction forces the greater the impulse and less chance of injury (Lephart et al., 2002).

Hormone levels should be considered as another potential contributory factor. Relaxin, a hormone found only in pregnant women, causes ligamentous relaxation, which allows for pelvic changes that accommodate fetal passage through the birth canal and the role of estrogen and estrogen receptors and shed light on ACL injuries in female athletes, but very few data are currently available (Moeller et al., 1997).

The higher incidence of ACL injuries among females has been well documented, for example, Lephart, et al. (2002) reported that females injure their ACL 2-8 times more frequently than their male counterparts with the risk of injury increasing with participation in basketball, soccer and volleyball. Arent, et al. (1995), Messina, et al. (1999) and Hewett (2000) reported similar findings that non-contact ACL injury rates are 3-4 times greater for female athletes than their male counterparts. Additional investigations needed to identify factors that predispose women athletes to an increase rate of ACL injury.

1.1 Hypotheses

1. Significant difference in kinetics (vertical ground reaction force and stabilization time), kinematics (joint angles of hip, knee, ankle and knee flexion angle at impact) and muscle strength between male and females may cause higher ACL injury rates in female volleyball players.

2. There will be a positive relation between quadriceps and hamstring peak muscle strength and knee kinematics of male and female volleyball players.

3. There will be a negative relation between knee flexion angles and vertical ground reaction force normalized to body weight of male and female volleyball players.

1.2 Purposes of the Study

1- To compare kinetic and kinematic parameters of landing maneuvers of male and female volleyball players.

2- To compare leg strength parameters of male and female volleyball players.

3- To establish relationships between kinetic, kinematic and leg muscle strength patterns that increase the risk of ACL injury in female volleyball players.

1.3 Limitations

1. Landing maneuver, in nature, is a part of jumping activities, like after spike or block activities, however, the ceiling height of the biomechanics

laboratory was limiting such activities, therefore, the landing phase of a jump was simulated by asking the subject to jump from a platform of a constant height.

2. Subjects were the members of the Middle East Technical University and Çankaya University volleyball teams, who voluntarily participated in this study.

1.4 Assumptions

1. The ground reaction force increased with the jumping height.

1.5 Significance of the Study

Although ACL injuries are not gender specific, they do occur at a significantly greater rate in female volleyball players. Biomechanical and muscular deficits have been hypothysed as factors contributing to ACL injuries. It is obvious that sport techniques need to be explained by means of biomechanics (Açıkada, 1991), and the better understanding of biomechanics will help the improvement of the techniques. Thus, this will help preventing ACL injury especially in female volleyball players.

In this present study, male and female volleyball players' landing differences were investigated. Leg strength variables of the subjects' were also measured and used to establish relations with landing height and stance. Finally, investigation on landing differences and relations of the strength variables were used to identify increased ACL injury risk in female volleyball players. Based on the findings of this study, preventative training programs and skill-specific training can be designed (Schnirring, 1999).

CHAPTER II

REVIEW OF LITERATURE

The ACL is one of the most commonly disrupted ligaments in the knee. Despite the explosion of information on the ACL over the past 25 years, little attention has been focused on the causes and prevention of injury (Boden et al., 2000).

Chappell and his colleagues (2002) compared the knee kinetics of 10 male and 10 female recreational athletes (aged 19 to 25 years) performing forward, vertical, and backward stop-jump tasks. Three-dimentional videography and force plate data were used to record the subjects' performance of the three stop-jump tasks, and an inverse dynamic procedure was used to estimate the knee joint resultant forces and moments. Women exhibited greater proximal anterior shear force than men during the landing phase. All subjects exhibited greater proximal tibia anterior shear force during the landing phase of the backward stop-jump task than during the other two stop-jump tasks. Women also exhibited greater knee extension and valgus moments than men during the landing phase of each stop-jump task. Men exhibited greater proximal tibia anterior shear force than women during the takeoff phase of vertical and backward stop-jump tasks. These results indicate that female recreational athletes may have altered motor control strategies that result in knee positions in which anterior cruciate ligament injuries may occur. The landing phase was more stressful for the anterior cruciate ligament of both women and men than the takeoff phase in all stop-jump tasks. Technical training for female athletes may need to be focused on reducing the peak proximal tibia anterior shear force in stop-jump tasks. Further studies are needed to determine the factors associated with the increased peak proximal tibia anterior shear force in female recreational athletes.

In this study Huston and his colleagues (2001) analyzed the neuromuscular performance characteristics of elite female athletes. Twenty healthy, height-matched patients (mean age: 28+/-5 years) participated in a study testing the hypothesis that no significant gender differences would be found in the knee flexion angle upon impact from a drop landing. Patients performed three unconstrained jumps from three vertical heights (20, 40, and 60 cm). Ankle, knee, and hip angles in the sagittal plane were measured at 120 Hz using a two-dimensional motion analysis system. Significant gender differences in knee flexion angles were found at ground impact during the drop landing ($p<.05$). The largest gender differences in the knee angle occurred when landing from a height of 60 cm: men landed with 16 degrees of knee flexion, whereas women landed with a significantly straighter knee flexion angle of 7 degrees ($p<.05$). A similar gender difference was found when landing from the medium jump height (40 cm).

In another study (Lephart, 2002) evaluated kinematic and strength variables in healthy collegiate female basketball, volleyball, and soccer players compared with matched male subjects. Thirty athletes did single-leg landing and forward hop tasks. An electromagnetic tracking device synchronized with a force plate provided kinematic data and vertical ground reaction force data, respectively. An isokinetic device measured quadriceps and hamstring peak torque to body mass at 60 degrees /second. With both tasks, females had significantly less knee flexion and lower leg internal rotation maximum angular displacement, and less knee flexion time to maximum angular displacement than males. For the single-leg land, females had significantly more hip internal rotation maximum angular displacement, and less lower leg internal rotation time to maximum angular displacement than males. Females also had significantly less peak torque to body mass for the quadriceps and hamstrings than males. Weaker thigh musculature may be related to the abrupt stiffening of the knee and lower leg on landing in females.

Self and Paine (2001) examined the ankle biomechanics during four landing techniques. An understanding of landing techniques is important for the prevention of injuries in a number of athletic events. In the current study, four-drop conditions from a 30.48-cm (12-inch) height were tested. The conditions were a) BN: Bent knee (self-selected), Natural (self-selected) plantar flexor contraction; b) SN: Stiff-knee, Natural plantar flexors; c) SP: Stiff-knee, Plantar flexors absorbing the impact; and d) SH: Stiff-knee, absorbing most of the impact in the heels. Peak vertical forces and accelerations were measured, and Achilles tendon forces and stiffness were calculated. Peak vertical forces and peak tibial accelerations were highest for the SH condition (2418 N and 20.7 G), whereas peak Achilles tendon force was highest for SP drops. The overall average AT stiffness was 166,345 $N.m^{-1}$. The results from the study were used in an extensive cadaver study to investigate ankle injuries. The data from the current study indicate that athletes may not use their full energy absorbing potential in landings during sporting activities.

Cowling and Steele (2001) examined whether lower limb muscle synchrony during abrupt landings was affected by gender, thereby predisposing females to a higher incidence of non-contact ACL injuries than males. Seven males and 11 females landed in single-limb stance on a force platform after receiving a chest-height netball pass and decelerating abruptly. Ground reaction force and electromyographic data for rectus femoris, vastus lateralis, vastus medialis, semimembranosus (SM), biceps femoris, and gastrocnemius were sampled (1000 Hz) during landing. Subjects' sagittal plane motion was also filmed (200 Hz). Knee joint reaction forces and sagittal planar net moments of force were estimated using Newtonian equations of motion and inverse dynamics. Tibiofemoral shear forces (F_s) were obtained and muscle bursts temporally analyzed with respect to initial foot-ground contact (IC) and peak F_s times. Males displayed significantly delayed SM onset relative to IC (113 ± 46 ms) compared to females (173 ± 54 ms; p = 0.03) and significantly delayed SM peak activity relative to peak F_s (54 ± 27 ms) compared to females (77 ± 15 ms; p = 0.03). Delayed SM activity during landing was suggested to allow peak muscle activity to better coincide with high anterior F_s, thereby acting as an ACL synergist via increased joint compression and posterior tibial drawer. It was concluded that females displayed muscle synchrony less protective of the ACL than males, possibly increasing their susceptibility to non-contact ACL injuries.

Saphiro and his friends (2001) examined the landing maneuvers of ten male and ten female athletes, from the lower height (27 cm) and the greater height (53 cm). They found that there was no significant observed difference in knee flexion at impact. Results of these investigations do not provide support for the hypothesis that is significant differences in knee deceleration mechanics between males and females. While some differences do exist they are not currently sufficient to explain the rate of injury. In the two-leg landing females tended toward greater dorsiflexion and eversion. This may suggest that at landing males and females were executing different strategies for stability on landing.

Sterner (2001) investigated the lower extremity kinetic and kinematics following a functional fatigue protocol. Nine subjects, serving as their own control. Subjects completed a series of three 30 cm drop jumps for the pretests and each of four posttests. The fatigue conditions began two days after the control session. Participants completed 10 repetitions of the functional fatigue protocol with a 30-second rest period between each repetition. A descriptive analysis was completed on lower extremity kinetic and kinematics for the deceleration and acceleration phases of the drop jump. The lower extremity experienced little range of motion (ROM) changes, altered angular velocities, rightward shifts in the force-time curve, and greater fluctuations in joint moments for the drop jump's deceleration phase. The acceleration phase showed changes in ROM, angular velocities, vertical GRF and mean joint moments that are consistent with implementing different movement strategies to complete the drop jump under fatigue conditions. It appears that high intensity; intermittent functional activities performed over a prolonged time may affect lower extremity joint kinetics and kinematics.

In another study (Colby et al., 2000) examining the muscle activation of the quadriceps and hamstrings, as well as knee flexion angle during the eccentric motion of athletic maneuvers most involved with ACL injury: sidestep cutting, cross-cutting, stopping, and landing. Healthy and recreational athletes (N= 15) were tested. EMG (600 Hz) and two-dimentional kinematic data (60 Hz) were collected while the subjects performed four athletic maneuvers: sidestep cutting, crosscutting, stopping, and landing. Landing was performed with the subjects jumping down from a height of 0.5 meters, landing on both legs. Qualitatively, all maneuvers demonstrated increasing activity in the quadriceps heel strike. Meanwhile, all maneuvers except landing were characterized by increasing hamstring activity at and following heel strike. Heel strike occurred at an average of 22 of knee flexion for all maneuvers. The result of this study indicated that quadriceps activation begins just before heel strike and peaks in mid eccentric motion for these movements. This may be related to non-contact injuries.

Egland (2000) in his study compared the landing strategies utilized by healthy female volleyball players with differing quadriceps strength. The subjects were 15 collegiate volleyball players who performed landings following a jump smash of a volleyball. Three landing strategies were utilized: a self-selected landing style, a tall landing strategy, and a soft landing strategy. A CYBEX II isokinetic dynamometer was used to measure isometric quadriceps strength and the hamstrings-to-quadriceps strength ratio. The subjects were divided into weaker and stronger groups based on quadriceps strength. Sagittal plane motion was filmed with high-speed videography and frontal plane motion was filmed with a conventional speed video camera. A Kistler force plate recorded peak vertical ground reaction force (PVGRF:) upon impact with each style of landing. The data were analyzed using a 2 x 3 analysis of variance with repeated measures. The results showed no significant difference (p .05) between the strength groups in the kinetic and kinematic measures across all the landing strategies. Differences (p .05) existed between landing strategies and between strength groups within the landing strategies for PVGRF, the amount of hip flexion at toe touch and knee acceleration. Pearson's Correlation Coefficient was computed to test the relationship between the quadriceps strength measures and each of the landing strategy parameters. There was a significant (p .05) correlation between quadriceps strength and increased PVGRF in both the soft and tall landings. A significant (p .05) correlation also existed between the hamstrings-to-quadriceps strength ratio and an increase in right knee valgus with soft landing strategies. It was concluded that female, collegiate volleyball player with stronger quadriceps strength do not land from jumping different than weaker players for all landing strategies. Landing strategies that have greater amounts of hip and knee flexion result in decreased forces upon landing. Athletes with stronger quadriceps generate a greater amount of knee flexion deceleration regardless if landings are soft or stiff and that the increased PVGRFs upon landing in those jumps are related to increased quadriceps strength.

Ball et al. (1999) claimed that inappropriate coordination of several common anatomical mechanisms might in part be responsible for the dramatic rise in ACL injuries amongst athletes. Firstly, two biarticular muscle groups, the hamstrings and quadriceps, cross both the hip and the knee. Secondly, coactivation is common amongst these antagonists. Certain sporting activities may permit injurous (unstable) conditions to exist at one joint (the knee) as a result of inappropriate muscular control at a second joint (the hip). Specifically, if reduced hip flexion postures are used to conduct sudden landing or deceleration movements (common to volleyball spikes, basketball lay-ups), then the quadriceps' high compensatory knee extensor torques, acting in combination with large transferred ground reaction forces, may excessively accelerate the tibia anteriorly from beneath the femur, hence, ACL injury may be incurred. Twenty female subjects were tested to determine the simultaneous effects of 5 hip and 5 knee postures (10°, 30°, 50 , 70 , and 90 each) upon the knee's isometric Hamstrings/Quadriceps Ratio (HQR). HQR increases of 38% to 99% (p<. 05) were produced when the hip angle was increased from 10° to 90° for the 10° to 90° knee conditions, respectively. These findings imply that to facilitate ACL-protective hamstrings' tension, athletes should concentrate upon using both hip- and knee-flexed postures whenever large knee extensor torques is demanded.

McLean et al. (1999) have reported that females landed in a more abducted position and reached peak knee flexion earlier in a cutting maneuver, the result of this investigation while showing no significant differences between males (n=16) and females (n=14) suggested that females reached peak knee flexion later than males when landing from greater height. Gender differences possessed limited clinical significance with all maximum values well within safe ranges of knee motion. Gender differences in knee motions during cutting did not contribute to the increased risk of noncontact ACL injury in women compared with men. The reason for this increased incidence, therefore, remains unclear.

McNair and Prapavessis (1999) provided normative data of vertical ground reaction forces associated with landing from a jump. Subjects were 234 adolescents (mean age: 16 years) who were categorized by gender, activity level and type of sport played. Subjects jumped from a box 0.3 meters high to land on a force plate. Results showed that there were no significant differences ($p>0.05$) across gender, activity levels, and type of sport played. Across all subjects, the mean peak vertical GRF was 4.5 body weight (SD: 1.7). In regard to gender, mean peak vertical GRFs were 4.6 (SD: 1.7) and 4.2 (SD: 1.4) for males and females respectively. The mean peak vertical GRF for subjects involved in recreational sport 1-3 times per week was 4.4 bodyweights (SD: 1.7). The mean peak vertical GRF for subjects participating in sports involving jumping and landing activities was 4.6 bodyweights (SD: 1.8) as compared to 4.4 bodyweights (SD: 1.5) for subjects in sports that did not involve jumping activities.

Kovács and his friends (1999) investigated the modification of foot placement kinematics and kinetics during drop jumping. The purpose of this work was to compare lower extremity kinematics and kinetics and muscle activation patterns between drop vertical jumps performed with heel-toe (HTL) and forefoot (FFL) landings. Ten healthy male university students performed two types of drop jump from 0.4 meters high box placed 1.0 meter from the center of the force plate. They were instructed to either perform forefoot-landing jump (FFL), or to perform heel-toe landing jump (HTL). The first peak and second peak determined from the vertical force-time curves were 3.4 times greater and 1.4 times lower for HTL compared with those with FFL (P<0.05). In the flexion phase of HTL, the hip and knee joints contributed 40% and 45% to the total torque, whereas during FFL the greatest torque contributions were 37% for both the knee and ankle joints. During the extension phase, the greatest torque contributions to the total torque were 41% and 45% by the knee and ankle joints during HTL and 34% and 55% during FFL. During the flexion phase, power production was 20% greater (P<0.05) in HTL than in FFL, whereas during the extension phase power production was 40% greater in FFL than in HTL. In the flexion phase of HTL the hip and knee joints produced the greatest power, and during the extension phase the knee and ankle joints produced the greatest power. In contrast, during both the flexion and extension phases of FFL, the knee and ankle joints produced the greatest power. Foot placement strategy modifies the individual joint contributions to the total power during drop jumping.

The purpose of Bobbert and Zandwijk (1999) was to gain insight into the importance of stimulation dynamics for force development in human vertical jumping. Maximum height squat jumps were performed by 21 male subjects. As a measure of signal dynamics rise time (RT) was used, i.e., the time taken by the signal to increase from 10% to 90% of its peak value. RT was calculated for time histories of smoothed rectified electromyograms (SREMG) of seven lower extremity muscles, net moments about hip, knee, and ankle joints, and components of the ground reaction force vector. Average RT values were 105-143 ms for SREMG signals, 90-112 ms for joint moments, and 120 ms for the vertical component of the ground reaction force. A coefficient of linear correlation of 0.88

was found between RT of SREMG of m. gluteus maximus and RT of ground reaction force. To explain this correlation, it was speculated that for an effective transfer from joint extensions to vertical motion of the center of mass (CM), the motion of CM needs a forward component during the push-off. Given the starting position, only the hip extensor muscles are able to generate such a forward acceleration of CM. To preserve the forward motion of CM, RT of knee and ankle joint moments need to be adjusted to RT of the hip joint moment. Thus, the greater RT of the hip joints moment and RT of gluteus maximus-SREMG, the greater RT of ground reaction force. Overall, it was concluded that the time it takes to develop muscle stimulation has a substantial effect on the dynamics of force development in vertical jumping and that this effect should not be neglected in studies of the control of explosive movements.

The objectives of the Neptune et al. (1999) in this study were to: 1) establish a database of kinematic and EMG data during cutting movements 2) describe normal muscle function and coordination of 12 lower extremity muscles during cutting movements susceptible to ankle sprains, and 3) identify potential muscle coordination deficiencies that may lead to ankle sprain injuries. Kinematic, EMG, and GRF data were collected from 10 recreationally active male subjects during both a side-shuffle and v-cut movement. The data showed that muscles functioned similarly during both movements. The primary function of the hip and knee extensors was to decelerate the center-of-mass during landing and to provide propulsion during toe-off. The hip add/abductors functioned primarily to stabilize the hip rather than provide mechanical power. The ankle plantar flexors functioned to provide propulsion during toe-off, and the gastrocnemius had an additional burst of activity to plantarflex the foot before touchdown during the side-shuffle to help absorb the impact. The tibialis anterior functioned differently during each movement: to dorsiflex and supinate the foot after toe-off in preparation for the next step cycle during the side-shuffle and to dorsiflex the foot before impact to provide the heel-down landing and ankle stability in the stance phase during the v-cut. The muscles crossing the ankle joint, especially the tibialis anterior and peroneus longus, may play an important role to prevent ankle sprain injuries. Both muscles provided stability about the subtalar joint by preventing excessive joint rotations. Future theoretical studies with forward dynamic simulations incorporating individual muscle actuators are needed to quantify the segment accelerations induced by active muscles, which may prevent or lead to ankle sprain injuries.

Santello and McDonagh (1998) studied on the control of self-initiated falls from different heights. The objective of the study was to investigate in a quantitative manner the modulation of EMG timing (i.e. onset from take-off and duration from onset to touch-down) and amplitude (before and after foot contact) as a function of fall height. The muscles studied were m. soleus and m. tibialis anterior. Kinematic (ankle joint angle) and kinetic (ground reaction force) variables were also measured. Six subjects took part in the experiments that consisted of ten landing from each of five heights (0.2, 0.4, 0.6, 0.8 and 1 m) onto a force platform. They found a consistent pattern of co-contraction before and after touchdown across the fall heights studied. In both muscles, the onset of pre-landing EMG activity occurred at a longer latency following take-off when landing from greater heights. The absolute EMG duration was affected to a lesser extent by increasing fall height. These findings suggest that the onset of muscle activity of the muscles studied prior to foot contact is timed relative to the expected time of foot contact. Pre- and post-landing EMG amplitude tended to increase with height. Despite a doubling in the magnitude of ground reaction force, the amplitude of ankle joint rotation caused by the impact remained constant across heights. These findings suggest that the observed pattern of co-contraction is responsible for increasing ankle joint stiffness as fall height is increased. The attainment of an appropriate level of EMG amplitude seems to be controlled by (a) timing muscle activation at a latency timed from the expected instant of foot contact and (b) varying the rate at which EMG builds up.

In this study the purpose of the Dufek and Zhang (1996) was to longitudinally evaluate lower extremity landing performance of elite volleyball players. Seven female members of a Division 1 NCAA volleyball team completed three data collection sessions (pre-, post-, off-season) during which they performed block-jumps on a dual force platform system (1000 Hz) while being simultaneously videotaped from the right sagittal view (200 Hz). Selected kinetic and lower extremity kinematic variables were calculated. Three dependent variables representing landing impact were identified: first (F 1) and second (F 2) maximum vertical force and knee joint range of motion (K(ROM)). A non-landing performance measure, jump height was also evaluated. Results of repeated measures univariate ANOVAs identified a significant ($p < 0.05$) difference for test session for K(ROM) suggesting a kinematic change in landing performance across the season. Multiple regression models to predict landing impact identified 88.1 and 98.3% explained variance for F1 and F2 with no significant K(ROM) model identified. F1 was predicted by ankle joint angular velocity during the jump while F2 was best predicted by jump phase braking impulse. Application of the group prediction equations to individual athletes produced differential results across subjects, suggesting the need to tailor the model to the athlete. The results further suggest training/practice-related kinematic differences and have implications for training and assessment of individuals who perform dynamic landing activities.

McNitt-Gray (1993) studied on landing preferences of gymnasts (n = 6) and recreational athletes (n = 6) determining by comparing the changes in lower extremity kinetics of drop landings performed from three heights (0.32, 0.72, and 1.28 m). Net joint moments and work done on the extensor muscles of the ankle, knee, and hip were selected as variables representative of the demand placed on the muscles responsible for controlling flexion and dissipating the load. Kinematic and kinetic two-dimentional data were acquired simultaneously using high-speed film (202.4 fps) and a force plate (1000 Hz). Significantly larger ankle and hip peak moments were observed for the gymnasts across velocities as compared to the recreational athletes. No significant differences in work done on the extensor muscles were noted between groups. The greater demands placed on the ankle and hip extensors by the gymnasts, as compared to the recreational athletes, may be explained by the need to maintain balance during competitive gymnastics landing or, perhaps, by the inability of recreational athletes to produce larger extensors moments at the ankle or hip during landings from great heights.

Devita and Skelly (1992) studied on effect of landing stiffness on joint kinetics and energetics in the lower extremity. In this study ground reaction forces, joint positions, joint moments, and muscle powers in the lower extremity were compared between soft and stiff landings from a vertical fall of 59 cm. Soft and stiff landings had less than and greater than 90 degrees of knee flexion after floor contact. Soft and stiff landings averaged 117 and 77 degrees of knee flexion. The stiff landing had larger GRFs. The action of landing from a vertical fall applied forces and moments to the lower extremities that accelerated hip and knee flexion and ankle dorsiflexion. Thus causing the extremities to collapse. The goal of a successful landing was to resist this collapse by applying counter extensor moments at these joints in such a way that the body's negative velocity was reduced to zero without injury. These extensor moments primarily worked eccentrically to absorb kinetic energy from the skeletal system and stop the person's fall.

Bobbert et al. (1987) examined the influence of dropping height on the biomechanics of drop jumping. This study was designed to investigate for the performance of bounce drop jumps in the influence of dropping height on the biomechanics of the jumps. Six subjects executed bounce drop jumps (DJ) from heights of 20 cm, 40 cm and 60 cm. During jumping, they were filmed, and ground reaction forces were recorded. The results of a biomechanical analysis showed no difference between DJ20 and DJ 40 in mechanical output about the joints during the push-of phase. Peak values of moment and power output of the ankles during the push-of phase were found to be smaller in DJ60 than in DJ40 (DJ20 = DJ60). The amplitude of joint reaction forces increased with dropping height.

CHAPTER III

MATERIALS AND METHODS

Measurement of the selected kinematic (joint angles of hip, knee, ankle and knee flexion angle at impact) and kinetic (ground reaction force and stabilization time) parameters was performed at the Middle East Technical University Biomechanical Laboratory of Mechanical Engineering Department. Isokinetic (quadriceps and hamstring muscle peak torque to body weight) parameters were measured at the Medical Center Physiotherapy Laboratories of the same university.

3.1. Selection of the Subjects

Sixteen healthy university volleyball teams players (8 male and 8 female) were recruited voluntarily as subjects from Middle East Technical University (METU) and Çankaya University, with no known significant knee injury in this study. The mean and standard deviation of the males and female players' age, weight, height, BMI and years of experience were measured.

Body height was measured without shoes in meters. Subjects' body weight was measured in kilograms using a calibrated platform. Body mass index (BMI) (kg/ht^2) was calculated to examine the relationship of height to weight.

3.2. Landing Tasks

Landing in volleyball was simulated by asking the subjects to jump down from a platform as vertically as possible on the force plate evenly balanced on both feet. The platform was placed 10 cm away from the edge of the force plate (Figure. 2) and heights were adjusted as 40 cm and 60 cm according to Huston et al. (2001). Each subject was introduced to carefully step off the platform without jumping up or lowering his/her body prior to leaving the platform. After landing, subjects were informed to stand on their normal positions. They were also instructed to keep their hands on their hips. Subjects were allowed practicing forward landings for each height until they felt comfortable with the tests. After that for both 40 cm and 60 cm heights, they performed three forward landings. Three successfully performed trials were included in the analysis.

In the second landing task, the platform was placed 15 cm near the edge of the force plate where the subjects' non-dominant leg was close to the force plate and subjects performed sideward landing for both 40 cm and 60 cm heights, simulating the block performed in the game. Meanwhile, they did also practice for familiarization and after that three successful trials were recorded to analyze. To avoid the coaching effect on the subjects' natural performance of the landings, instruction was not given about landing techniques.

For each condition (40 & 60 cm forward and 40 & 60 cm sideward landings) while choosing the correct landing, the proper foot position at contact were judged from video records and the shape of force-time curve were analyzed for three landings.

3.3. Kinetic and Kinematic Measurements

Landing maneuvers were recorded with six 50 Hz video cameras. KISS Motion Analysis System was used to obtain the kinematic data, which was developed at the Middle East Technical University - Mechanical Engineering Department. BERTEC force plates were used to record ground reaction force at a sampling rate of 500 samples per second.

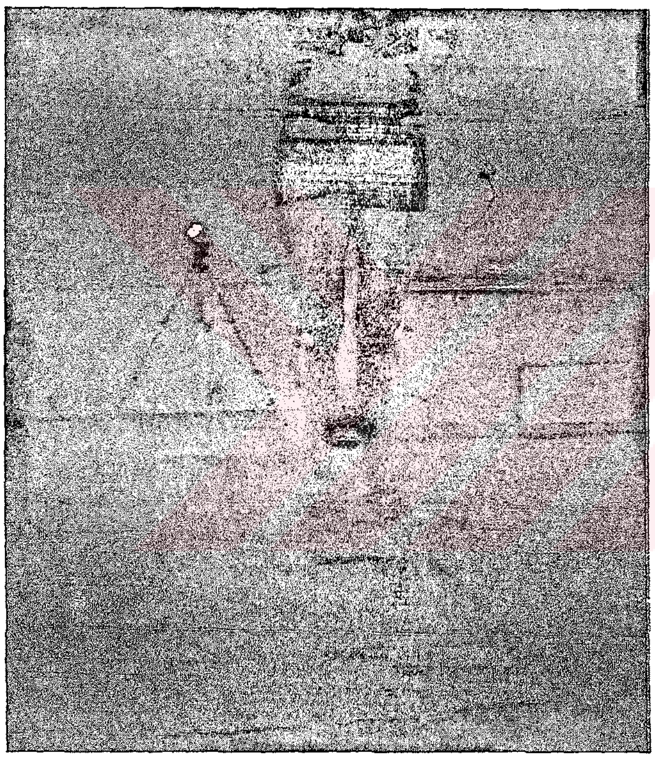


Figure 2. Placement of the retroreflective markers and landing platform.

Thirteen retroreflective markers were placed on the right and left anterior superior iliac spines, thighs, lateral condyles, shanks, lateral malleolies, second metatarsals and sacrum (Figure 2), with the aid of these markers angles of maximum hip, knee, and ankle flexions were collected as kinematic parameters. Both legs' measurements were taken but just the measurement of the dominant leg was included in this work. Peak vertical ground reaction force (Fz) and stabilization time were recorded as kinetic parameters. To compare the forces PVGRF was normalized to body weight for each subject. In this manner, the players' applied forces of how many times of body weights' to force plate were observed. Stabilization time was recorded manually as the time between the subject's toes touched the force plate and turned into his/her own weight value.

3.4. Isokinetic Measurements

Isokinetic strength data were recorded with the Biodex System Dynamometer (Biodex Medical Inc, Shirley, NY) to assess peak torque to body weight of the quadriceps and hamstrings. Subjects were placed in a comfortable upright-seated position on the Biodex dynamometer chair and was secured using thigh, pelvis and torso straps in order to minimize extraneous body movements. The lateral femoral epicondyle was used as the bony landmark for matching the axis of rotation of the knee joint with the axis rotation of the dynamometer resistance adapter. Once the subject was placed in apposition that allowed for a comfortable and unrestricted motion of knee extension and flexion from a position of 90 degrees of flexion to terminal extension. Gravity correction was obtained by measuring the torque exerted on the on the dynamometer resistance adapter with the knee in a relaxed state at terminal extension. Values for the isokinetic variables measured were automatically adjusted for gravity for the Biodex Advantage Software Rev. 3.27.

In testing procedure subjects performed 20 repetitions at high speed (180 degrees/sec) for warm-up and then stretched their body parts. Before the test trials, subjects were instructed to perform their maximum efforts and subjects did five isokinetic concentric knee flexion and extension repetitions at 60 °/second of their dominant limb.

3.5. Statistical Analysis

Statistical Program for Social Sciences 10.0 (SPSS 10.0) for Windows package program was used for statistical analysis. The mean and standard deviation were calculated for all variables. Mann-Whitney U test was used to evaluate whether the medians on a test variable differ significantly between two groups. Pearson Product Moment Correlation was also used to analyze correlations.

CHAPTER IV

RESULTS

Subject Characteristics

In this study, 8 of the subjects were male and 8 were female university volleyball team players. The mean age of male volleyball players was 22.3 ± 2.5 years (ranging from 19 to 27 years) and 20.5 ± 1.9 years (ranging from 19 to 24 years) for female volleyball players. The mean body weight for male volleyball players and female volleyball players were 79.0 ± 8.0 kg (ranging from 70 to 91 kg) and 58.9 ± 6.8 kg (ranging from 51 to 71 kg), respectively. The mean height of the male volleyball players was 1.84 ± 0.1 m (ranging from 1.75 to 1.90 m) and 1.69 ± 0.1 m (ranging from1.55 to 1.83 m) for the female volleyball players. The mean BMI of the male players was 23.4 ± 2.0 (ranging from 20.0 to 25.9) and 20.6 ± 1.5 (ranging from19.3 to 23.3) for the female players. The mean year of experience for male volleyball players and female volleyball players were 9.0 ± 3.1 years (ranging from 14 to 4 years) and 7.7 ± 2.4 years (ranging from 3 to 10 years), respectively. The data are presented in Table I.

Table I. Selected Physiological Parameters of the Subjects

	N	Age	Weight	Height	BMI	Experien
Male	8	22.3 ±	79.0 ± 8.0	1.84 ±	23.4 ± 2.0	9.0 ± 3.1
Femal	8	20.5 ±	58.9 ± 6.8	1.69 ±	20.6 ± 1.5	7.7 ± 2.4

Table II. Comparison of Knee Flexion Angles between Male and Female Volleyball Players

		N	Mean ± SD	Mean Rank	Z value	P
KF@40for	Male	8	79.6 ± 17.9	11.4	-2.42	0.02*
	Female	8	59.3 ± 9.5	5.6		
KF@60for	Male	8	87.9 ± 16.7	10.2	-1.47	0.14
	Female	8	76.2 ± 7.6	6.7		
KF@40sid	Male	8	72.7 ± 14.3	9.9	-1.21	0.23
	Female	8	63.8 ± 7.1	7.1		
KF@60sid	Male	8	84.9 ± 13.2	10.2	-1.47	0.14
	Female	8	75.7 ± 8.1	6.7		

*Significantly different ($p<0.05$)

Mann-Whitney U test was conducted to evaluate the hypothesis that female volleyball players would have lower knee flexion, on average, than male volleyball players on a 40 cm forward landing task. The result of the test was significant, $z = -2.42$, $p = .02$. Female volleyball players had an average rank of 5.6, while the male players had an average rank of 11.4. Male volleyball players' 60 cm forward landing, 40 cm sideward landing, and 60 cm sideward landing mean knee flexion angles were also higher than female players, however, the results were not significant. Figure 3 shows the distributions of the scores on landing tasks for the two groups.

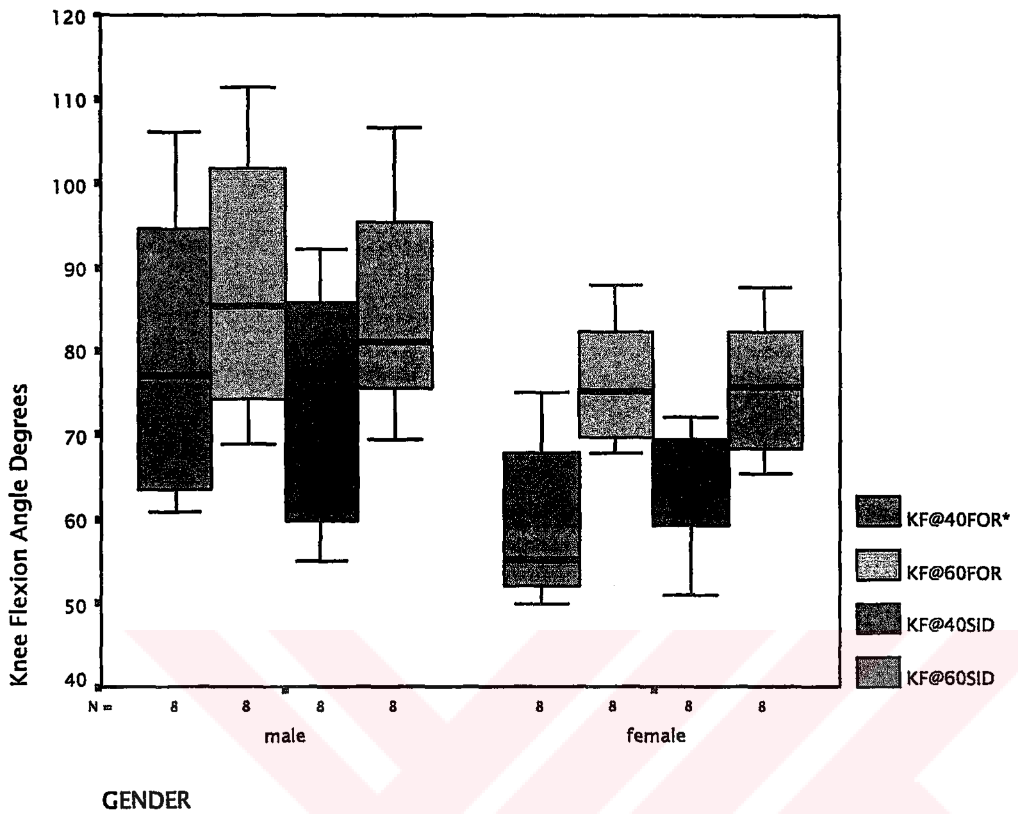


Figure 3. The distributions of knee flexion angle scores for male and female volleyball players (*. Significantly different ($p<0.05$)).

Table III. Comparison of Hip Flexion Angles between Male and Female Volleyball Players

		N	Mean ± SD	Mean Rank	Z value	P
HF@40for	Male	8	60.3 ± 22.6	10.2	-1.47	.14
	Female	8	44.9 ± 11.3	6.7		
HF@60for	Male	8	72.0 ± 19.3	9.9	-1.21	.23
	Female	8	61.4 ± 10.0	7.1		
HF@40sid	Male	8	67.3 ± 17.0	10.9	-2.00	.05*
	Female	8	52.8 ± 9.8	6.1		
HF@60sid	Male	8	74.2 ± 14.4	9.2	-0.63	.53
	Female	8	68.9 ± 13.2	7.7		

*Significantly different ($p<0.05$)

Mann-Whitney U test was conducted to evaluate the hypothesis that female volleyball players would have lower hip flexion, on average, than male volleyball players on a 40 cm sideward landing task. The result of the test was significant, $z = -2.00$, $p = .05$. Female volleyball players had an average rank of 6.1, while the male players had an average rank of 10.9 on a 40 cm sideward landing. Male volleyball players' 40 cm forward landing, 60 cm forward landing, and 60 cm sideward landing mean hip flexion angles were also higher than the female volleyball players, however, results were not significant. Figure 4 shows the distributions of the hip flexion angle scores on landing tasks for the two groups.

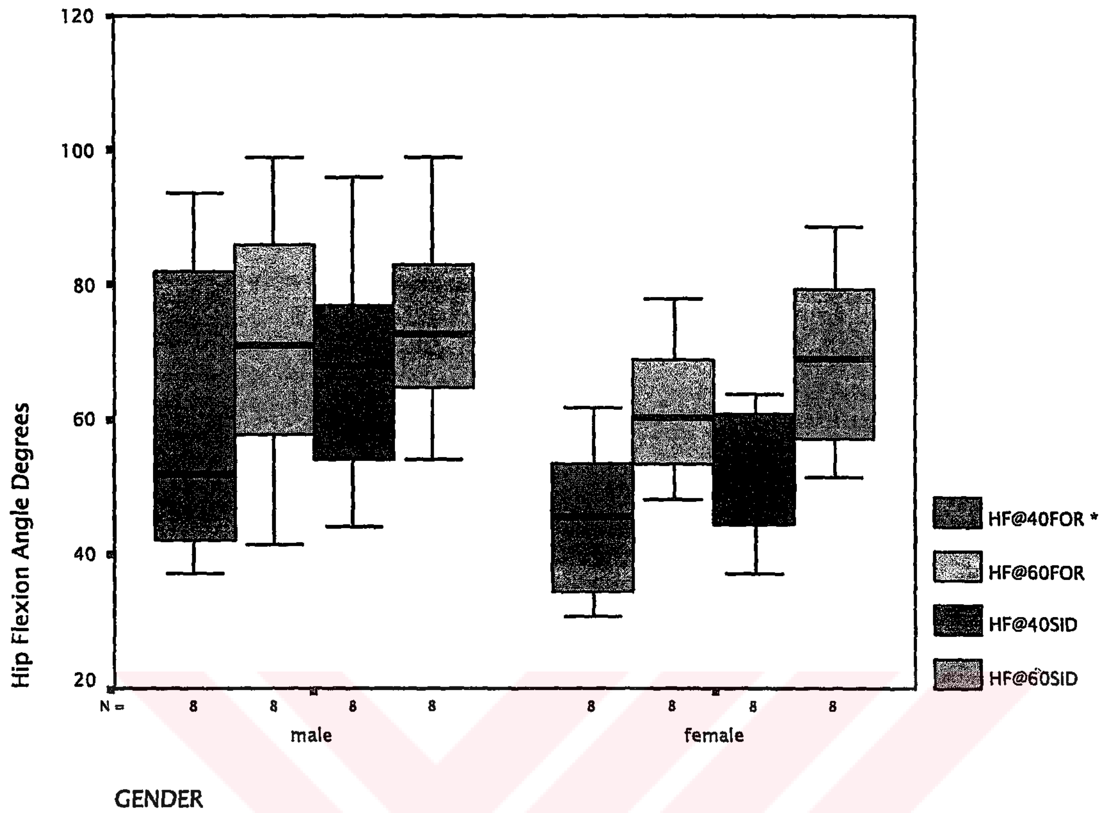


Figure 4. The distributions of hip flexion angle scores on landing tasks for male and female volleyball players (*. Significantly different (p<0.05)).

Table IV. Comparison of Ankle Flexion Angles between Male and Female Volleyball Players

		N	Mean ± SD	Mean Rank	Z value	P
AF@40for	Male	8	27.5 ± 8.6	9.5	-0.84	0.40
	Female	8	23.4 ± 6.7	7.5		
AF@60for	Male	8	27.2 ± 9.3	8.1	-0.32	0.75
	Female	8	27.4 ± 9.7	8.9		
AF@40sid	Male	8	29.1 ± 9.2	7.6	-0.74	0.46
	Female	8	30.2 ± 7.4	9.4		
AF@60sid	Male	8	30.1 ± 9.7	8.1	-0.37	0.71
	Female	8	30.5 ± 6.7	8.9		

*Significantly different ($p<0.05$)

Ankle flexion angles of the subjects are present in Table IV. The mean ankle flexion at 40 cm forward, 60 cm forward, 40 cm sideward, and 60 cm sideward landings of male and female volleyball players were 27.5 ± 8.6, 27.2 ± 9.3, 29.1 ± 9.2, 30.1 ± 9.7 and 23.4 ± 6.7, 27.4 ± 9.7, 30.2 ± 7.4, 30.5 ± 6.7, respectively. There was no significant difference in ankle flexion angles of male and female volleyball players.

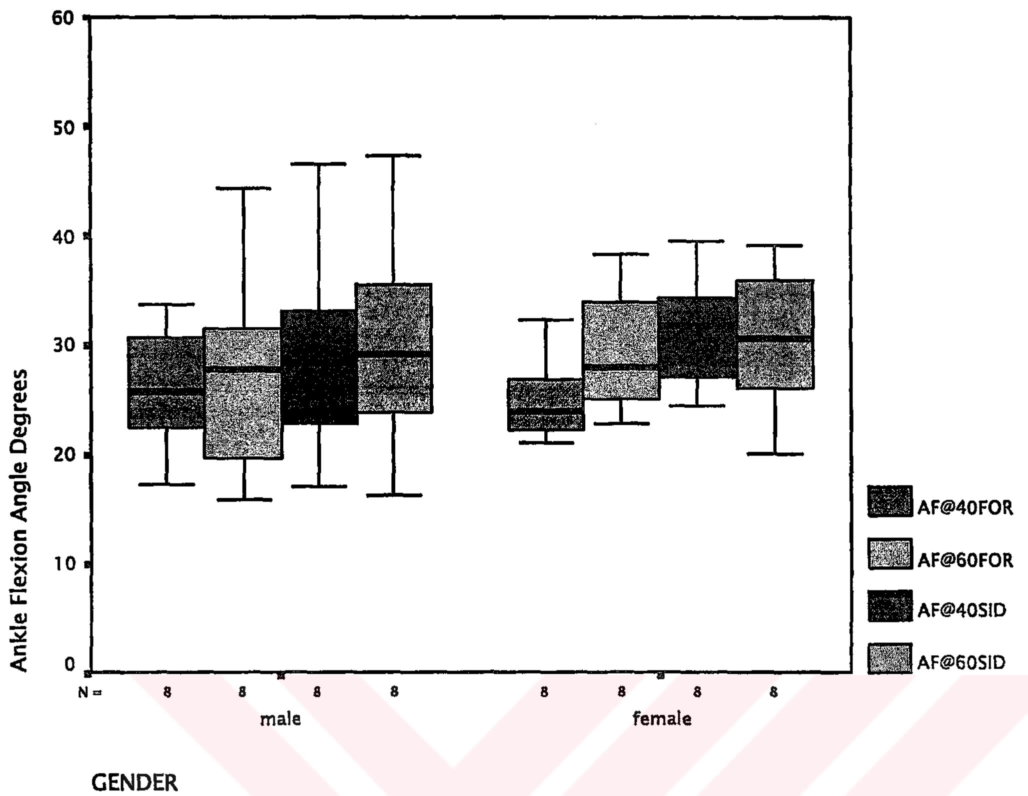


Figure 5. The distributions of ankle flexion angle scores on landing tasks for male and female volleyball players (*. Significantly different (p<0.05)).

Table V. Comparison of Applied Body Forces on Force Plate between Male and Female Volleyball Players

		N	Mean ± SD	Mean Rank	Z value	P
FOR40/BW	Male	8	3.3 ± 0.5	4.8	-3.11	0.00*
	Female	8	4.6 ± 0.6	12.2		
FOR60/BW	Male	8	3.9 ± 0.7	4.9	-3.01	0.00*
	Female	8	5.7± 1.0	12.1		
SID40/BW	Male	8	3.6 ± 0.5	4.9	-3.05	0.00*
	Female	8	5.1 ± 0.7	12.1		
SID60/BW	Male	8	4.4 ± 1.1	5.7	-2.31	0.02*
	Female	8	6.2 ± 1.3	11.2		

*Significantly different ($p<0.05$)

Mann-Whitney U test was conducted to evaluate the hypothesis that female volleyball players would have higher applied body forces on force plate, on the average, than male volleyball players on all of the four landing tasks. The results of the test were significant, $z = -3.11$, $p = .00$, $z = -3.01$, $p = .00$, $z = -3.05$, $p = .00$, and $z = -2.31$, $p = .02$, respectively. Female volleyball players had an average rank of 12.2, 12.1, 12.1, and 11.2 while the male players had an average rank of 4.8, 4.9, 4.9, and 5.7 on all four landing tasks. Figure 6 shows the distributions of applied body force scores on landing tasks for the two groups.

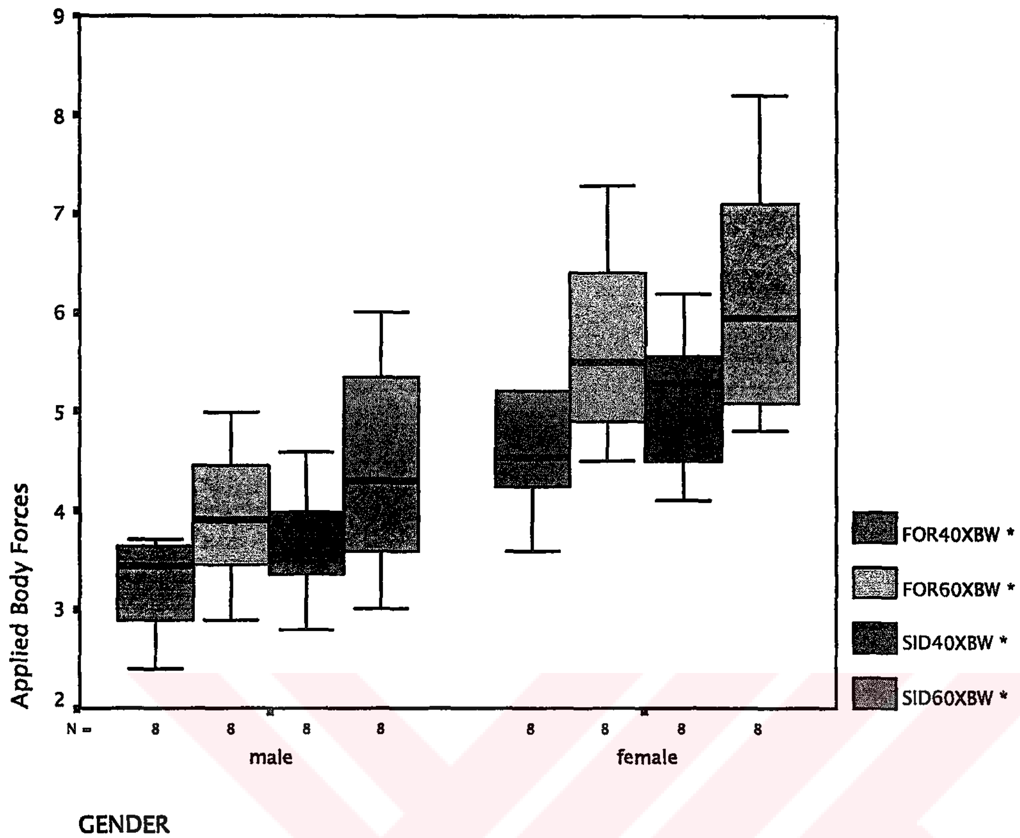


Figure 6. Distributions of applied body forces on the force plate for 40 & 60 cm forward and 40 & 60 cm sideward landings for male and female volleyball players (*. Significantly different (p<0.05)).

Table VI. Comparison of Stabilization Time after Landing on Force Plate between Male and Female Volleyball Players

		N	Mean ± SD	Mean Rank	Z value	P
STA.T40F	Male	8	0.8 ± 0.2	9.6	-0.95	0.34
	Female	8	0.7 ± 0.1	7.4		
STA.T60F	Male	8	0.8 ± 0.2	9.2	-0.58	0.56
	Female	8	0.8 ± 0.1	7.8		
STA.T40S	Male	8	0.8 ± 0.2	10.4	-1.58	0.11
	Female	8	0.6 ± 0.1	6.6		
STA.T60S	Male	8	0.8 ± 0.1	9.8	-1.11	0.27
	Female	8	0.7 ± 0.1	7.2		

$P<0.05$

Stabilization times on force plate of the subjects after landing are present in Table VI. The mean stabilization time on 40 cm forward, 60 cm forward, 40 cm sideward, and 60 cm sideward landings of male and female volleyball players were 0.8 ± 0.2, 0.8 ± 0.2, 0.8 ± 0.2, 0.8 ± 0.1, and 0.7 ± 0.1, 0.8 ± 0.1, 0.6 ± 0.1, 0.7 ± 0.1, respectively. There was no significant difference in stabilization times on force plate between male and female volleyball players.

Table VII. Correlations Among the Male Volleyball Players' Knee Flexion Angles and Applied Body Forces on Force Plate for each Landing Conditions

Variables (N=8)	R	P
KF@40for - FOR40/BW	-.90	.002*
KF@60for - FOR60/BW	-.29	.484
KF@40sid - SID40/BW	-.47	.237
KF@60sid - SID60/BW	-.44	.271

*. Correlation is significant at the 0.05 level

The results obtained through Pearson Product Moment Correlations between the male volleyball players' knee flexions and applied body forces on force plate showed that there was a significant negative relationships (r = -.90) between the knee flexion angles at 40 cm forward landing and applied body forces.

Table VIII. Correlations Among the Female Volleyball Players' Knee Flexion Angles and Applied Body Forces on Force Plate for each Landing Conditions

Variables (N=8)	R	P
KF@40for - FOR40/BW	-.62	.098
KF@60for - FOR60/BW	.54	.163
KF@40sid - SID40/BW	-.20	.629
KF@60sid - SID60/BW	.67	.069

$P < 0.05$

The results obtained through Pearson Product Moment Correlations between the female volleyball players' knee flexions and applied body forces on force plate showed that there was no relationship between the knee flexion angles and applied body forces in all four landings.

Table IX. Comparison of Quadriceps and Hamstring Muscle Peak Torque to Body Weight at 60°/Second between Male and Female Volleyball Players

		N	Mean ± SD	Mean Rank	Z value	P
Quadriceps	Male	8	302.5 ± 90.7	11.7	-2.73	.01*
	Female	8	195.2 ± 32.1	5.2		
Hamstring	Male	8	127.8 ± 27.5	11.1	-2.20	.03*
	Female	8	95.4 ± 21.3	5.9		

*Significantly different (p<0.05)

Quadriceps and hamstring peak torque to body weight of subjects are present in Table IX. The results of the test were significant, z = -2.73, p = .01, and z = -2.20, p = .03, respectively. As expected the female volleyball players had an average rank of 5.2 and 5.9 while the male players had an average rank of 11.7 and 11.1 in muscle strength test. Figure 7 shows the distributions of the scores on quadriceps and hamstring peak torque to body weight for the two gender groups.

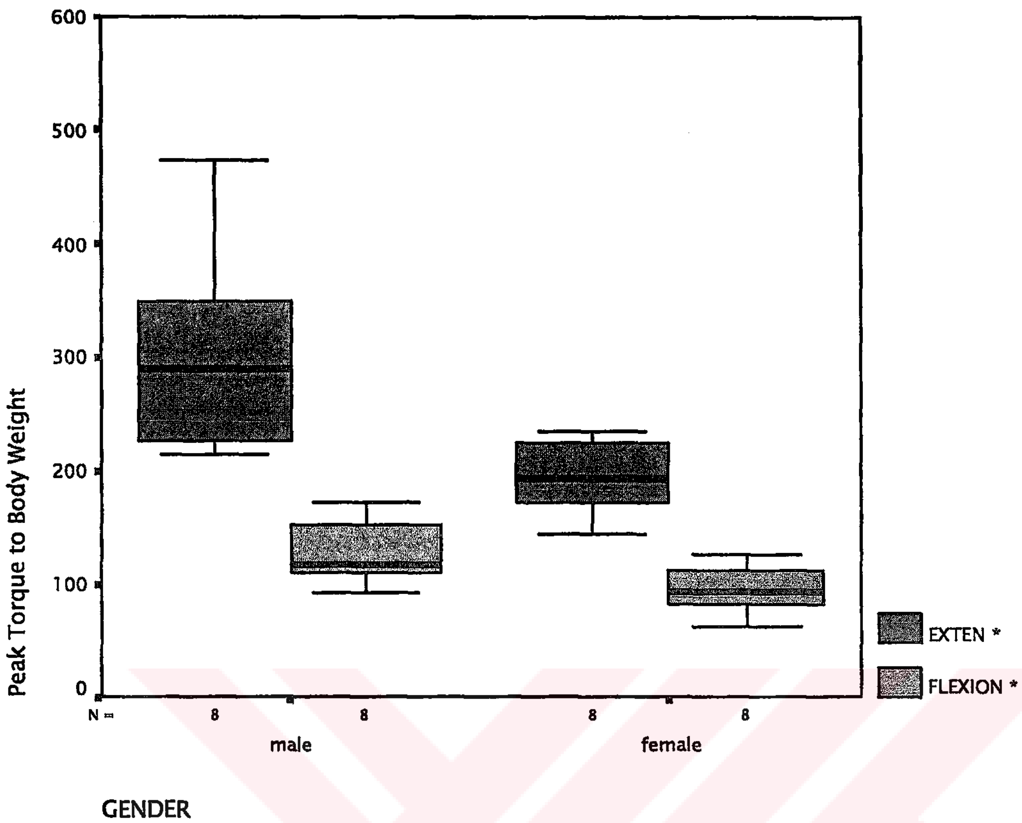


Figure 7. The distributions of quadriceps and hamstring peak torque to body weight scores for male and female volleyball players (*. Significantly different ($p<0.05$)).

Table X. Correlations Between the Male Volleyball Players' Leg Strength Parameters and Knee Flexion Angles

Variables (N=8)	R	P
KF@40for - Quadriceps	.88	.004**
KF@60for - Quadriceps	.90	.002**
KF@40sid - Quadriceps	.69	.054
KF@60sid - Quadriceps	.76	.028*
For40imp - Quadriceps	.26	.541
For60imp - Quadriceps	.76	.027*
Sid40imp - Quadriceps	.58	.129
Sid60imp - Quadriceps	.60	.114
KF@40for - Hamstring	.86	.006**
KF@60for - Hamstring	.90	.003**
KF@40sid - Hamstring	.89	.003**
KF@60sid - Hamstring	.93	.001**
For40imp – Hamstring	.63	.092
For60imp – Hamstring	.65	.084
Sid40imp – Hamstring	.53	.169
Sid60imp - Hamstring	.63	.093

*. Correlation is significant at the 0.05 levels
**. Correlation is significant at the 0.01 levels

The results obtained through Pearson Product Moment Correlations between the male volleyball players' leg strength parameters and knee flexion angles. The significant positive relationships between the variables as follows; KF@40for - Quadriceps, KF@60for - Quadriceps, KF@60sid - Quadriceps, For60imp - Quadriceps, KF@40for - Hamstring, KF@60for - Hamstring, KF@40sid - Hamstring, and KF@60sid - Hamstring.

Table XI. Correlations Between the Female Volleyball Players' Leg Strength Parameters and Knee Flexion Angles

Variables (N=8)	R	P
KF@40for - Quadriceps	-.12	.768
KF@60for - Quadriceps	-.28	.493
KF@40sid - Quadriceps	.40	.331
KF@60sid - Quadriceps	.05	.904
For40imp - Quadriceps	-.29	.478
For60imp - Quadriceps	.07	.867
Sid40imp - Quadriceps	-.17	.694
Sid60imp - Quadriceps	.13	.758
KF@40for - Hamstring	-.64	.087
KF@60for - Hamstring	.03	.951
KF@40sid - Hamstring	.16	.696
KF@60sid - Hamstring	.11	.788
For40imp – Hamstring	-.44	.276
For60imp – Hamstring	-.19	.646
Sid40imp – Hamstring	-.42	.294
Sid60imp - Hamstring	.07	.877

*. Correlation is significant at the 0.05 levels
**. Correlation is significant at the 0.01 levels

The results obtained through Pearson Product Moment Correlations between the female volleyball players' leg strength parameters and knee flexion angles. There were no significant relationships between the variables.

Table XII. Comparison of Knee Flexion Angles at Impact between Male and Female Volleyball Players

		N	Mean ± SD	Mean Rank	Z value	P
KF@40for	Male	8	25.4 ± 8.7	11.2	-2.26	.02*
	Female	8	15.7 ± 7.5	5.8		
KF@60for	Male	8	28.9 ± 13.7	9.2	-.63	.53
	Female	8	23.2 ± 11.9	7.7		
KF@40sid	Male	8	25.8 ± 9.8	10.5	-1.68	.09
	Female	8	17.6 ± 10.0	6.5		
KF@60sid	Male	8	28.6 ± 9.9	10.1	-1.37	.17
	Female	8	21.7 ± 9.0	6.9		

*Significantly different ($p<0.05$)

A Mann-Whitney U test was conducted to evaluate the hypothesis that female volleyball players would have lower knee flexion angle at impact, on the average, than male volleyball players on 40 cm forward landing task. The result of the test was significant, $z = -2.26$, $p = .02$. As expected the female volleyball players had an average rank of 5.8 while the male players had an average rank of 11.2 on 40 cm forward landing task. Male players' 60 cm forward landing, 40 cm sideward landing, and 60 cm sideward landing mean knee flexion angles at impact were also higher than the female volleyball players, however, results were not significant. Figure 8 shows the distributions of knee flexion angle scores at impact on landing tasks for male and female volleyball players.

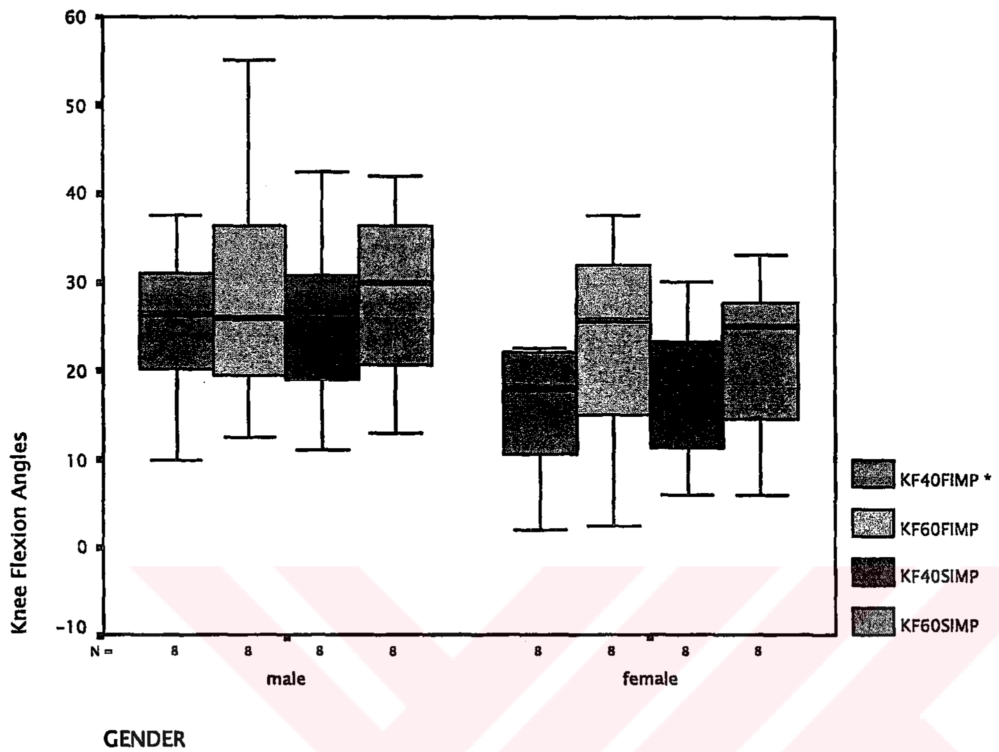


Figure 8. The distributions of knee flexion angle scores at impact on landing tasks for male and female volleyball players (*. Significantly different ($p<0.05$)).

Table XIII. Correlations Between the Male Volleyball Players' Leg Strength Parameters and Applied Body Forces

Variables (N=8)	R	P
FOR40/BW - Quadriceps	-.33	.42
FOR60/BW- Quadriceps	-.37	.37
SID40/BW - Quadriceps	-.46	.25
SID60/BW - Quadriceps	-.88	.00*
FOR40/BW - Hamstring	-.10	.82
FOR60/BW - Hamstring	-.67	.07
SID40/BW - Hamstring	-.39	.34
SID60/BW - Hamstring	-.79	.02*

*. Correlation is significant at the 0.05 levels

The results obtained through Pearson Product Moment Correlations between the male volleyball players' leg strength parameters and applied body forces. The significant negative relationships between the variables as follows; FOR60/BW - Quadriceps, and SID60/BW - Hamstring.

Table XIV. Correlations Between the Female Volleyball Players' Leg Strength Parameters and Applied Body Forces

Variables (N=8)	R	P
FOR40/BW - Quadriceps	.42	.29
FOR60/BW- Quadriceps	-.39	.33
SID40/BW - Quadriceps	.41	.31
SID60/BW - Quadriceps	.49	.21
FOR40/BW - Hamstring	.88	.00*
FOR60/BW - Hamstring	.23	.59
SID40/BW - Hamstring	.58	.13
SID60/BW - Hamstring	.59	.13

*. Correlation is significant at the 0.05 levels

The results obtained through Pearson Product Moment Correlations between the female volleyball players' leg strength parameters and applied body forces. The significant positive relationship was observed between FOR40/BW and Hamstring muscles.

CHAPTER V

DISCUSSION

In this present study, male and female volleyball players' landing differences from 2 different heights (40 cm and 60 cm) and two different directions (forward and sideward) were investigated. After that leg strength variables of the subjects' were used to establish relations between strength variables and landing differences, which were used to identify increased risk for anterior cruciate ligament injuries in female players.

Results of the current study suggested that male and female players displayed different knee flexion angles in their landing tasks (Table II). Males displayed greater knee flexion angle in all landing tasks. Significant difference at knee flexion angle was only observed at the 40 cm forward landing task between male and female players. Because of the time taking applicability nature of this experiment, a relatively small number of subjects were included into the study and they were university team players not professionals. In addition, measurements of this study were performed in the laboratory, because we could not place the laboratory equipments into volleyball court. The main hypothesis of this study was to test for differences between groups of male and female volleyball players; detailed examination of individual subject differences was not addressed in this study.

Self and Paine (2001) in their study demonstrated similar findings to the present study in terms of average knee flexion angle degree in male subjects.

The results of the current study were consistent with the study of Devita and Skelly (1992). They also revealed gender differences in knee flexion angles when performing landing maneuvers. Moreover, in current study landins were performed from two different heights (40 cm and 60 cm) and subjects were also landed on two different (forward and sideward) directions. However, Cowling and Steele (2001) suggested that males and females displayed similar knee flexion angles during the landing tasks, this contrary findings may be explained by measurement differences of the landing tasks because subjects landed on a force platform after receiving a chest-height netball pass and also subjects were not netball players.

Chappell et al. (2002) compared knee kinetics in stop-jump task, followed by the kinematic study by Malinzak et al. (2001). This study recruited 34 college-aged healthy recreational athletes and gender differences in knee flexion angles were determined in three stop-jump tasks. Females had significantly smaller knee flexion angles than males during landing. Measurement methods of that study were different from the current study but the concept was similar.

One of the findings of the current study, knee flexion angle at impact on 40 cm forward landing task was significantly higher in male volleyball players than female volleyball players (Table XII). Male volleyball players were touching the floor in a more flexed knee position. They were also maintaining a more flexed knee position to absorb the ground reaction force following landing. Males had furthermore higher knee flexion angles during landing, however, differences were statistically not significant.

The data from Lephart et al. (2002) suggested that biomechanical variables differ between genders during landing activities. This finding is in accordance with findings of the current study. Males demonstrated a greater amount of knee flexion subsequent to impact then females. The absence of this controlled knee flexion in females may be related to the weaker quadriceps and hamstring strength, resulting in abrupt stiffening of the knee. These factors need to be considered in relation to the occurrence of ACL injuries in female athletes.

A recent study by Huston et al. (2001) investigated gender differences in knee angle when landing from a drop-jump of 20, 40, and 60 cm onto a concrete floor. Significant gender differences in knee flexion angles were found at the ground impact during landing ($p<.05$). The largest difference in knee angle occurred when landing from a height of 60 cm and then 40 cm. This finding is consistent with the present study. Moreover, in the present study the largest difference was observed during landing from the 40 cm forward and then 60 cm forward landing tasks. Discomfort of subjects in 60 cm landing tasks may be the reason for this difference. Cowling and Steele (2001) in a similar study found that there was a tendency for males to display greater knee flexion angles at initial contact but they could not find any statistically significant difference ($p>.05$) between male and female knee joint angles during landing.

Shapiro et al. (2001) also investigated male and female biomechanical differences in landing maneuvers from 27 cm and 53 cm heights. However, the result of the investigation did not support the previous studies for the hypothesis that there were significant differences in knee flexion at impact because there were some differences but not sufficient to confirm the hypothesis.

This present study demonstrated that male players had reached a greater hip flexion in landing tasks (Table III). Specifically, if reduced hip flexion postures are used to conduct landing (common to volleyball spikes) then the quadriceps' high compensatory knee extensor torques, acting in combination with large transferred ground reaction forces, may excessively accelerate the tibia anteriorly from beneath the femur, hence, ACL injury may be incurred (Ball et al., 1999). However, Cowling and Steele (2001) did not revealed the difference in hip flexion angle between two group ($p>.05$), therefore they concluded that gender did not alter the landing kinematics used by the subjects in their study. Although greater hip flexion thought as a potential adventage, excessive trunk flexion can hinder performance. As the trunks moves forward the body's center of the gravity moves in front of the base of support at landings potentially (Straub, 2002) leading to an unstable landing.

In this investigation, male and female players showed similar ankle flexion angles during landing tasks (Table IV). Shapiro et al. (2001) also observed similar small differences in their study. This may suggest that for these studied groups the male and female players were tended to perform the similar ankle flexion techniques in landing tasks.

Results of this investigation also provided support for the hypothesis that there were significant differences in applied body forces on force plate between male and female players in all four landing tasks (Table V). Female volleyball players applied higher forces then male players in landing maneuvers. The difference in applied body forces for both groups in landing maneuvers can be explained by the higher knee flexion angles in all maneuvers. When the forces correlated with the knee flexion angles for both group, there was a high and negative correlation in male players, especially between the 40 cm forward landing and the applied forces in same landing (Table VII). This result can be explained as the increase in knee flexion angles causes decrease in the applied body forces in landing maneuvers. This is compatible with the earlier idea that less knee flexion results in higher peak GRFs. In another word, the data comfirms that a landing strategy in which the player lands with taller posture may result in increased peak GRFs. Dufek and Bates (1990) claimed that softer landings were beneficial in decreasing peak GRFs upon ground contact. Additionally, the same negative relation was also found for female players, however, not as high as in male counterparts. These data compare favorably to values reported by other investigators. To compare the forces to other studies, it is necessary to normalize them to body weight.

McNair and Prapavessis (1999) studied to set a normative data of vertical ground reaction forces during landing from a jump and observed that there were no significant differences ($p>0.05$) across gender, activity levels, and type of sport played. In regard to gender, mean peak vertical GRFs were 4.6 body weights (SD: 1.7) and 4.2 (SD: 1.4) for males and females respectively. However, in this study subjects were the recreational sport performers and subjects jumped from a box 30 cm high to land on a force plate. Measurement procedure and the characteristics of the subjects should be considered for the comparison of the results to the present study.

Zhang et al. (2000) investigated the energy dissipation of lower extremity joints during drops of 32, 62, and 103 cm heights. The subjects were instructed to use three different self-selected landing strategies based on knee joint range of motion (soft, normal, and stiff). Normal landing of the subjects was close to our current study landing tasks. Peak ground reaction force to body weight measurements reached 6.72 times body weight. Self and Paine (2000) also investigated drop landing from 30.5 cm high box and normal landing scores of their subjects were reached the 4.29 times body weight. Additionally, studies about the PGRF were also concluded in Table 15.

Table 15. Peak ground reaction force values from various studies

Author	Activity	PGRF/BW (Male – Female)
Current Study	Drops from	
	For40/BW	3.3 – 4.6
	For60/BW	3.9 – 5.7
	Sid40/BW	3.6 – 5.1
	Sid60/BW	4.4 – 6.2
McNair and Prapavessis (1999)	Jumps from 30 cm	4.6 – 4.2
Self and Paine (2000)	Natural (self-selected)	
	Drop from 30.5 cm	4.2 –
Zhang, Dufek, Bates (2000)	Average across 32 cm, 62, and 103 cm	
	Normal landing	6.7 –

The data from this study suggest that stabilization times obtained by means of the force platform did not differ between genders during landing maneuvers (Table VI). Lephart et al. (2002) also supported that there were no significant differences found between groups for the stabilization times for landing tasks. It was mentioned that female volleyball players had higher applied forces to the force plates then males. If stabilization times were not different, this means, joints and the muscles of the tendons of female players' were subjected to higher loads than male players. As the body adopts a moreflexible state it functions as a damped spring resulting in increased time for deceleration. Newton's second law, increased time for deceleration concurrently decreases the peak GRF. These factors need to be considered in relation to the incidence of knee injuries in female players.

Investigators have found that quadriceps and hamstring muscle strength has an important influence on anterior tibial translation. The quadriceps muscle, an ACL antagonist, may generate forces in excess of those required to cause ACL failure (Woo et al., 1991). Contraction of the hamstring muscles counteracts the quadriceps muscle force and helps to control anterior tibial translation (Renström et al., 1986). A balance of force between the quadriceps and hamstring muscle is important for normal knee function. Huston and Wojtys (1996) found that female athletes had weaker quadriceps and hamstring muscles, even with corrections for body weight. Current study results, like Huston and Wojtys (1996), Anderson et al. (2001) and Lephart et al. (2002) showed that female players have weaker quadriceps and hamstring muscles when corrections were made for body weight

(Table IX). These results suggested that the levels of hamstring activity might not be sufficient enough to prevent anterior tibial displacement.

The present studies results also demonstrated that there was a positive and high correlation between knee flexion angles and quadriceps peak torque to body weight and between knee flexion angles and hamstring peak torque to body weight in male players (Table X). Between knee flexion angle at impact and quadriceps peak torque to body weight positive high correlation was also observed. However, at impact knee flexion angles could not be related with the hamstring strength. Neither quadriceps strength nor hamstring strength were related to knee flexion angles in female players.

Female athletes must attain good physical condition before participating in volleyball to prevent injury. Weight training coupled with an endurance-training program is only part of the necessary components to improve muscle function. The female athlete not only needs to be strong, but her muscle reaction time needs to be as quick as possible. Plyometrics and agility-type exercises, such as running through cones, and single leg jumps are proven methods to significantly improve muscle reaction time (Wojtys et al., 1996). The hamstring muscles have been shown to protect the anterior cruciate ligament from excessive strain therefore female athletes tent to become quadriceps dominant with sports, special emphasis must be placed on hamstring exercises for strength and functional limb control (Huston et al., 2000). The jump-training program is strongly recommended and should be incorporated into the training program for females who participate in sports that require jumping. Bahr et al. (1997) who reported a decrease in injury rate in volleyball players after a multifaced approach that included training in approach, take off and landing. Hewett et al. (1999) reported the results of a randomized prospective application of training program; knee injury rates were .43 per 1000 exposures in an untrained group and .12 per 1000 exposures in trained group.

In summary, result of these investigations provided support for the hypothesis that there are significant differences in knee, hip flexion angles, applied body forces, quadriceps and hamstring muscle strength between male and female volleyball players. These differences confirm that during landings male and female players were performing different techniques for stability on landing. Theoretically, a female player with an anterior cruciate ligament injury may be an individual whose has significantly weaker quadriceps and hamstring muscle strength, and these weaknesses may result in an abrupt stiffening of the knee. These factors need to be considered related to the occurrence of anterior cruciate ligament injuries in the female players.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. Knee flexion angles, at impact and hip flexion angles of the female volleyball players were lower than their male counterparts but ankle flexion angles were similar.

2. Applied body forces of the female players measured from the force plate were significantly higher than male players.

3. A significant difference was found in quadriceps and hamstring peak torque to body weight between female and male players. Males had a greater peak torque for both muscle groups.

4. There was a significant negative relationship between male players' knee flexion angles and applied body forces on the force plate. Greater knee flexion was related with the lower body forces.

5. Knee flexion angles and at impact showed positive and high relationships with quadriceps and hamstring peak torque to body weight in males but female players did not demonstrated any relations between these parameters.

5.2 Recommendations

1. It is recommended that a similar study should be carried out with a larger number of subjects.

2. Studies should be designed to examine the subject in the field with relatively normal training and competitive environment.

3. Further research studies on complex knee, hip and ankle joint motion and their relations between each other are needed.

REFERENCES

Açıkada, C. (1991). Biyomekanikte Kinetik ve Kinematik Analiz. Hacettepe Journal of Sport Sciences. 2(1): 10-26.

Anderson, A.F., Dome, D.C., Gautam, S. Awh, M.H. & Rennirt, G.W. (2001). Correlation of Anthropometric Measurements, Strength, Anterior Cruciate Ligament Size, and Intercondylar Notch Characteristics to Sex Differences in Anterior Cruciate Ligament Tear Rates. The American Journal of Sports Medicine. 29(1): 58-66.

Arendt, E. & Dick, N. (1995). Knee Injury Patterns Among Men and Women in Collegiate Basketball and Soccer. NCAA Data and Review of Literature. 23: 694-701.

Arnold, C.A. & Boland, A. (2000). Anterior Cruciate Ligament Injuries in Women. (Online). Article from healthcare.partners.org

Bahr, R., Lian, O., & Bahr, I.A. (1997). A Twofold reduction in the Incidence of Acute Sprains in Volleyball After the Introduction of an Injury Prevention Program: A Prospective Cohort Study. Scandinavian Journal of Medicine and Science and Sports (Abstract). 7: 172-177.

Ball, K.A., Brooks-Hill, A.L., Richards, D., Marks, P. & Evans, R.J. (1999). Lack of Hip Flexion: A Mechanism for ACL Injury. Medicine and Science in Sports and Exercise (Abstract). 31(5): S295.

Bobbert, M.F., Huijing, P.A. & Van Ingen Schenau, G.J. (1987). Drop Jumping. II. The Influence of Dropping Height on the Biomechanics of Drop Jumping. Medicine and Science in Sports and Exercise. 19(4): 339-346.

Bobbert, M.F. & Zandwijk, P.V. (1999). Dynamics of Force and Muscle Stimulation in Human Vertical Jumping. Medicine and Science in Sports and Exercise. 31(2): 303-310.

Boden B.P, Dean G.S., Feagin J.A. & Garrett W.E. (2000). Mechanisms of Injuries to the Anterior Cruciate Ligament. Orthopedics. 23(6): 573-8.

Boden, B.P., Griffin, L.Y. & Garrett, W.E. (2000). Etiology and Prevention of Noncontact ACL Injury. The Physician and Sportsmedicine. 28: 53-60.

Briner, W.W. & Benjamin, H.J. (1999). Managing Acute and Overuse Disorders. The Physician and Sportsmedicine. 27(3): 58-65.

Chappell, J.D., Yu, B., Kirkendall, D.T. & Garrett, W.E. (2002). A Comparison of Knee Kinetics Between Male and Female Recreational Athletes in Stop-Jump Tasks. American Journal of Sports Medicine. 30(2): 261-267.

Colby, S., Francisco, A., Finch, M., Beutler, A. & Garret, W. (2000). Electromyographic and Kinematic Analysis of Cutting Maneuvers: Implications for Anterior Cruciate Ligament Injury. American Journal of Sports Medicine. 28(2): 1234-1240.

Cowling, E.J & Steele, J.R. (2001). Is Lower Limb Muscle Synchrony During Landing Affected by Gender? Implications for Variations in ACL Injury Rates. Journal of Electromyography and Kinesiology. 11: 263-268

Devita, P. & Skelly, W.A. (1992). Effect of Landing Stiffness on Joint Kinetics and Energetics in the Lower Extremity. Medicine and Science in Sports and Exercise. 24(1): 108-115.

Dufek, J.S. & Bates, B.T. (1990). The Evaluation and Prediction of Impact Forces During Landings. Medicine and Science in Sports and Exercise. 22: 370-377.

Dufek, J.S. & Zhang, S. (1996). Landing Models for Volleyball Players: A Longitudinal Evaluation. Journal of Sports Medicine and Physical Fitness. 36: 35-42.

Egland, R.G. (2000). A Comparison of Landing Strategies in Volleyball Players Based on Quadriceps Strength. ProQuest Digital Dissertation [online]. AAT 9988918.

Ferretti, A., Papandrea, P., Conteduca, F., & Mariani, P.P. (1992). Knee Ligament Injuries in Volleyball Players. American Journal of Sports Medicine. 20(2): 203-207.

Goodwin-Gerberich, S.G., Luhmann, S., & Finke, C. (1987). Analysis of Severe Injuries Associated with Volleyball activities. The Physician and Sportsmedicine. 15(8): 75-79.

Griffin, J.W., Tooms, R.E., Zwaag, R.V., Bertorini, T.E. & O'Toole, M.L. (1993). Eccentric Muscle Performance of Elbow and Knee Muscle Groups in Untrained Men and Women. Medicine and Science in Sports and Exercise. 25: 936-944.

Hewett, T.E. (2000). Neuromuscular and Hormonal Factors Associated with Knee Injuries in Female Athletes: Strategies for Intervention. Sports Medicine. 29: 313-327.

Hewett, T.E., Lindenfeld, T.N., Riccobene, J.V. & Noyes, F.R. (1999). The Effect of Neuromuscular Training on the Incidence of Knee Injury in Female Athletes: A Prospective Study. American Journal of Sports Medicine. 27(6): 699-706.

Huston, L.J. & Wojtys, E.M. (1996). Neuromuscular Performance Characteristics in Elite Female Athletes. American Journal of Sports Medicine. 24: 427-436.

Huston, L.J., Greenfield, M.L.V. & Wojtys, E.M. (2000). Anterior Cruciate Ligament Injuries in the Females Athlete: Potential Risk Factors. Clinical Orthopaedics and Related Research. 372: 50-63.

Huston, L.J., Vibert, B., Ashton-Miller, J.A. & Wojtys, E.M. (2001). Gender Differences in Knee Angle When Landing from a Drop-Jump. The American Journal of Knee Surgery (Abstract). 14(4): 215-220.

Kovács, I., Tıhanyi, J., Devita, P., Rácz, L., Barrier, J. & Hortobágyi, T. (1999). Foot Placement Modifies Kinematics and Kinetics During Drop Jumping. Medicine and Science in Sports and Exercise. 31(5): 708-716.

Lephart, S.M., John, P. & Ferris, C.M. (2002). Neuromuscular Contributions to Anterior Cruciate Ligament Injuries in Females. Current Opinion in Rheumatology. 14: 168-173.

Lephart, S., Ferris, C., Riemann, B., Myers, J., & Fu, F. (2002). Gender Differences in Strength and Lower Extremity Kinematics During Landing. Clinical Orthopaedics and Related Research. 401: 162-169.

Madigan, M.L. (2001). Changes in Lower Extremity Landing Biomechanics Resulting from Fatigue. ProQuest Digital Dissertation [online]. ATT 3013553.

Maffulli, N., Yu, B., Kirkendall, D.T. & Garrett, W.E. (2002). Anterior Cruciate Ligament Injuries in Female Athletes: Anatomy, Physiology, and Motor Control. Sports Medicine and Arthroscopy Review. 10: 58-68.

Malinzak, K.C., Colby, S.M. & Kirkendall, D.T. (2001). A Comparison of Knee Motion Patterns between Men and Women in Selected Athletic Tasks. Clinical Biomechanics. 16: 438-445.

McLean, S.G., Neal, R.J., Myers, P.T. & Walters, M.R. (1999). Knee Joint Kinematics During the Sidestep Cutting Maneuver: Potential for Injury in Women. Medicine and Science in Sports and Exercise. 31(7): 959-968.

McNair, P.J. & Prapavessis, H. (1999). Normative Data of Vertical Ground Reaction Forces During Landing from a Jump. Journal of Science and Medicine in Sport (Abstract). 2(1): 86-88.

McNitt-Gray, J.L. (1993). Kinetics of the Lower Extremities During Drop Landings from Three Heights. Journal of Biomechanics. 26(9): 1037-1046.

McNitt-Gray, J.L., Hester, D.M.E., Mathiyakom, W. & Munkasy, B.A. (2001). Mechanical Demand and Multijoint Control During Landing Depend on Orientation of the Body Segments Relative to the Reaction Force. Journal of Biomechanics. 34: 1471-1482.

Messina, D.F., Farney, W.C. & Delee, J.C. (1999). The Incidence of Injury in Texas High School Basketball. A Prospective Study Among Male and Female Athletes. American Journal of Sports Medicine. 27: 294-299.

Moeller, J.L. & Lamb, M.M. (1997). Anterior Cruciate Ligament Injuries in Female athletes: Why Are Women More Susceptible? The Physician and Sportsmedicine. 25(4):

Neptune, R.R., Wright, I.C. & Van Den Bogert, A.J. (1999). Muscle Coordination and Function During Cutting Movements. Medicine and Science in Sports and Exercise. 31(2): 294-302.

Renström P., Arms, S.W., & Stanwyck, T.S. (1986). Strain within the Anterior Cruciate Ligament during Hamstring and Quadriceps Activity. American Journal of Sport Medicine. 14: 83-87.

Santello, M. & McDonagh, M.J. (1998). The Control of Timing and Amplitude of EMG Activity in Landing Movements in Humans. Experimental Physiology. 83(6): 857-874.

Schafle, M.D, Requa, R.K, & Patton, W.L. (1990). Injuries in the 1987 National Amateur Volleyball Tournament. American Journal of Sports Medicine. 18(6): 624-631.

Schnirring, L. (1999). Training Programs May Lower Women's ACL Injury Risk. The Physician and Sporsmedicine. 27: 15-16.

Self, B.P. & Paine, D. (2001). Ankle Biomechanics During Four Landing Techniques. Medicine and Science in Sports and Exercise. 33: 1338-1344.

Shapiro, R., Yates, J., McClay, I. & Ireland, M.L. (2001). Male-Female Biomechanical Differences in Selected Landing Maneuvers. Clinical Biomechanics (Keynote presentation). 16: 956-957.

Solomonow, M., Barrata, R., Zhou, B.H., Shoji, H., Bose, W., Beck, C. & D'Ambrosia, R. (1987). The Synergistic Action of the Anterior Cruciate Ligament and Thigh Muscles in Maintaining Joint Stability. American Journal of Sports Medicine. 15(3): 207-213.

Sterner, R.L. (2001). A Kinetic and Kinematic Analysis of the Drop Jump Following a Functional Fatigue Protocol. ProQuest Digital Dissertation [online]. AAT 3019074.

Straub, S.J. (2002). Skill Level Differences in Lower Extremity Kinematics and Neuromuscular Characteristics of Female Gymnasts During Drop Landings. ProQuest Digital Dissertation [online]. AAT 3057117.

Tillman, M.D., Smith, K.R., Bauer, J.A., Cauraugh, J.H., Falsetti, A.B. & Pattishall, J.L. (2002). Differences in Three Intercondylar Notch Geometry Indices Between Males and Females: A Cadever Study. The Knee. 9: 41-46.

Woo, S.Y.L., Hollis, J.M. & Adams, D.J. (1991). Tensile Properties of the Human Femur-Anterior Cruciate Ligament-Tibia Complex. The Effects of Specimen Age and Orientation. American Journal of sport Medicine. 19: 217-225.

Wojtys, E.M., Huston, L.J., Taylor, P.D. & Bastian, S.D. (1996). Neuromuscular Adaptations in Isokinetic, Isotonic, and Agility Training Programs. American Journal of Sports Medicine. 24: 187-192.

Zhang, S.N., Bates, B.T. & Dufek, J.S. (2000). Contributions of Lower Extremity Joints to Energy Dissipation During Landings. Medicine and Science in Sports and Exercise. 32: 812-819.

Zelisko, J.A., Noble, H.B. & Porter, M. (1982). A Comparison Men's and Women's Professional Basketball Injuries. American Journal of Sports Medicine. 10(5): 297-299.

APPENDICES

APPENDIX A

MIDDLE EAST TECHNICAL UNIVERSITY
MECHANICAL ENGINEERING DEPARTMENT
BIOMECHANICS LABORATORY EXPERIMENT SHEET

File Name: Date:..........................

I. PERSONAL INFORMATION

Name :

Age :

Gender :

Mass (kg) :

Stature (m) :

Clinical Status : Normal / Patient

Clinical Remarks :

Referred by :

II. MEASUREMENTS

ASIS – ASIS Distance :

Right Leg Length :

Left Leg Length :

Right Knee Width :

Left Knee Width :

Right Ankle Width :

Left Ankle Width :

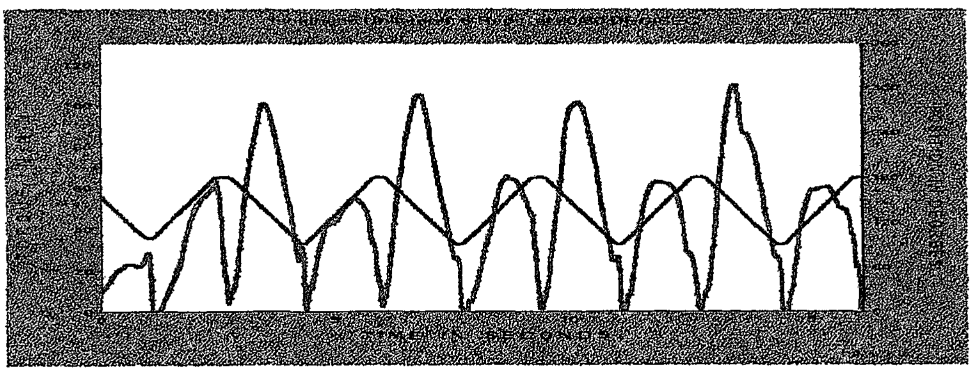
BIOMECHANICS LABORATORY – MECHANICAL ENGINEERING DEPARTMENT D-02 TEL: 2105210

APPENDIX B

Comprehensive Evaluation

Name:	Session: 4.12.2002	Windowing: None
ID: 123	Involved: None	Protocol: IsokineticUnilateral
Birth Date:	Clinician:	Pattern: Exten/Flex
Ht:	Referral:	Mode: Isokinetic
Wt: 65.4	Joint: Knee	Contraction: CON/CON
Gender: Female	Diagnosis:	GET: 23 N-M at 90 Degrees

Side Right		EXTENSION 60 DEG/SEC	FLEXION 60 DEG/SEC
# OF REPS: 5			
PEAK TORQUE	N-M	110.0	65.5
PEAK TQ/BW	%	168.2	100.2
TIME TO PK TQ	MSEC	630.0	1030.0
ANGLE OF PK TQ	DEG	144.0	147.0
CIEFF.OF VAR.	%	39.9	7.3
MAX. REP. TOT. WORK	J	105.0	70.1
AVG. POWER	WATT	57.3	36.2
ACCELERATION TIME	MSEC	80.0	120.0
DECELERATION TIME	MSEC	120.0	240.0
ROM	DEG	89.7	
AVG.PEAK TQ	N-M	89.3	61.8
AGON/ANTAG RATIO	%	59.5	G: 62.0



APPENDIX C

JOINT ANGLES