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Age and gender differences in lower extremity kinematics in adult recreational soccer players

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Age and Gender Differences in Lower Extremity Kinematics
in Adult Recreational Soccer Players

by

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THESIS

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Dedication and Acknowledgments

I would like to dedicate this work to my parents for their support and encouragement in all of my endeavors.

Researchers in the UCSF Movement Analysis Lab and the Department of Physical Therapy that contributed to this work:

- Kathryn Hamel, Ph.D.
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- Nathan Swain

Table of Contents

List of Tables

List of Figures

Introduction

Athletic participation in the United States is soaring. Not only are more children and teens participating in sports, but the number of adults participating in athletics is also increasing. Sport activities at all ages are enjoyable, entertaining and important for prevention of health risks such as obesity, heart disease and diabetes, which have become major health epidemics in the United States. Despite the benefits of athletics, the risk for injury increases during sport participation and some injuries sustained can become debilitating later in life. Anterior cruciate ligament (ACL) and subsequent cartilage injury in athletes has been linked to osteoarthritis later in life.[1] Preventing injury keeps athletes healthy, yet it is impossible to truly prevent injury unless the risk factors for injury have been established. Extrinsic risk factors such as increased joint laxity[2], weak quadriceps and hamstring muscle strength[3] and decreased proprioception[4] during athletic maneuvers have been attributed to sports injury. In particular, these extrinsic risk factors are found to increase the risk for ACL injury in young females. Gender differences such as limb alignment and hormonal factors are also thought to contribute to injury in females.[5] Older athletes face even greater risks because of additional age-related changes. Changes in tissue properties, aerobic maximal capacity and muscle function are just a few of the many changes humans must face as they age.[6-9] Changes to our bodies as a result of age are expected, but the time these changes occur and their severity vary with each individual. Additionally, older athletes typically have increased exposure time participating in their risk associated sport, whereas younger athletes have less exposure.[5] It seems reasonable that more exposure would lead to an increase in risk for injury; however, risk factor studies have yielded conflicting results on the effect of age on injury and very few studies have examined athletes above the age of 30. Age-related changes as well as exposure and competition level as risk factors for injury during sport need to be further examined in older athletes.

According to a recent study of the Consumer Product Safety Commission, sports related injuries among 35-54 year olds have increased 33% from 1991 to 1998.[10] Moreover, the number of ACL reconstruction surgeries performed in the year 2000 on females age 30 is approximately the same as the number performed on females age 17.[11] The actual number of surgeries performed on these two age groups may be similar; however the number of athletes in each age group most likely differs greatly, with many more 17 year olds participating in athletics than 30 year olds. Since less female 30 year olds are participating in sports yet suffering the same amount of ACL injuries as 17 year olds, it seems reasonable that the risk for ACL injury at age 30 is much higher than younger athletes. Additionally, a significant increase in risk of overall injury in female athletes over the age of 25 in comparison with younger athletes was found in a prospective study of female soccer players (age range 14-39 years).[12] Another study has noted trends toward more muscle strains, severe ligament ruptures, and meniscal tears with increasing age.[13] Although evidence exists supporting the fact that injury seems to be problematic for older athletes, the focus of biomechanical studies are predominantly on college and high school athletes. Additionally, the focus of biomechanical studies is often focused on the knee and little consideration is given to other lower extremity joints (ankle and hip) that play a role in dynamic movements. Recent research suggests that the biomechanical interaction of the entire lower extremity may be an important contributor to the overall risk of non-contact ACL injury and studies have found an association between the coupled mechanical interrelationships of the hip and ankle with muscle activation.[14, 15] Other studies have demonstrated a major role of hip muscle activation in increasing quadriceps and hamstring muscle activation during running and jumping.[16] Neuromuscular control of the trunk, hip and ankle play an important role in dynamic movements of the knee and associated risk factors for injury should be identified. Additionally, more studies need to address and define the biomechanical and neuromuscular relationship between age, injury and ALL lower extremity joint kinematics.

In older athletes, age-related changes in conjunction with gender differences may affect risk factors for severe injuries such as ACL ruptures. Kinematic differences have been shown to exist in young athletes during landing, with males landing in more knee flexion and less knee abduction than females.[3, 4, 17-20] Additionally, the lack of knee flexion and increased knee valgus ("knock-kneed") in young females has also been shown to strain the ACL.[21] This lack of knee flexion may increase later in life due to tissue property changes and decreased range of motion and may increase an older athlete's susceptibility to injury. Despite the risk factors identified in young athletes, older athletes are also highly susceptible to severe injury, yet no studies to date have tried to examine landing characteristics of older athletes. If athletic competition is to continue into later decades of life, it is important to keep older athletes healthy and prevent as many severe injuries as possible by identifying risk factors for sports injury that may be specific to older athletes. Once the risk factors have been identified, intervention programs can be designed to reduce injury incidence, severity and medical costs.

The purpose of this exploratory pilot study was to analyze landing differences between older and younger, male and female recreational soccer players to determine if there were any age and gender kinematic differences in the hip, knee and ankle while performing drop jump and various soccer maneuvers. Additionally, the soccer maneuver and drop jump tasks were used to examine differences in lower extremity kinematics when visual focus was changed during a controlled and repeatable laboratory based maneuver. Lastly, identification of the tasks that place the lower extremity joints in the most injury susceptible position were analyzed. For this study, it was hypothesized that males would land with greater knee flexion than younger and older females. Additionally, it was hypothesized that females would land with greater knee abduction than both male groups. With respect to age, it was hypothesized that the older male and female groups would have less knee flexion than the younger groups. The soccer turning task was hypothesized to place the knee in the most injury susceptible position.

Literature Review:

Age and Gender Associated Risk Factors for Lower Extremity Injury

Introduction

Since the occurrence of Title IX in 1972, females have not only become more involved in sports, but they are also playing sports longer than their predecessors. With the introduction of professional leagues such as the Women's National Basketball Association (WNBA) and the Women's United Soccer Association (WUSA), female athletes are continuing to compete at high levels into their late 30's. Other women who competed at the high school and college level are also continuing to compete recreationally later in life by participating in local area and city leagues. With the published studies linking obesity to severe health problems such as diabetes and heart disease[22], a greater number of Americans both female and male are trying to become more physically active at all ages.

Although these trends are good for women and men as athletes and competitors, participation in sports at all ages has associated risks. Intrinsic gender differences such as limb alignment, hormonal factors and joint laxity are thought to contribute to an increased risk of knee injury in females, while age-related changes in tissue properties, maximal aerobic capacity and muscle function may put an older athlete at risk of injury. Extrinsic risk factors such as flexibility, muscle strength and body movement/position during athletic maneuvers have been linked to sports injury, most notably increased risk of anterior cruciate ligament (ACL) injury in young females.

Most biomechanical and neuromuscular risk factors have only been examined in young athletes; however, the number of injuries among older athletes is growing.

According to a recent study of the Consumer Product Safety Commission, sports related injuries among 35-54 year olds have increased 33% from 1991 to 1998.[10] According to a review by Yu and colleagues [11], the number of ACL reconstruction surgeries performed in the year 2000 on females age 30 is approximately the same as the number performed on females age 17. Despite the existing evidence supporting the fact that lower extremity injury is problematic for older athletes, the focus of lower extremity injury research is predominantly on college and high school athletes. Biomechanical and neuromuscular risk factors for lower extremity injury in older athletes need additional attention and the relationship between age and injury should be well defined.

Age as a Risk Factor for Injury and Age Associated Physiological Changes

As mentioned previously, the majority of neuromuscular control research in athletes is conducted on participants under the age of 25. However, risks for lower extremity injury in sport have been directly associated with age.[12, 23-26] Physiological changes that occur with age such as decrease in flexibility, muscle strength and increase in body fat may affect neuromuscular control mechanisms placing older athletes at a greater risk for injury.[7-9, 27, 28]

Age as an Intrinsic Risk Factor for Lower Extremity Injury in Sport

Older athletes typically have increased exposure time in their at risk activity in cumulative years, whereas younger athletes have less exposure. In the case of exposure, it seems reasonable that more exposure would lead to an increase in risk for injury.[12] However, risk factor studies have yielded conflicting results on the effect of age on injury and few studies have examined athletes above the age of 30.

Increased injury has been reported with increased age among athletes.[12, 23, 24] In a prospective study of 123 female soccer players (age range 14-39 years), Ostenberg and Roos [12] found a significant increased risk of overall injury in female athletes over 25 years of age in comparison with younger athletes (odds ratio=3.7). Approximately 80% of all injuries sustained were to the knee, foot, ankle, thigh, and back. During a prospective cohort study of 1512 athletes (mean age = 23) in Western Australia, female and male athletes aged 26-30 were found to be at a 55% increased risk of injury compared with athletes younger than 26 and older than 30 years.[23] In a study of injury incidence among indoor soccer players, Lindenfeld reported that men older than 25 years suffered the highest rate of all injuries considered as a group (incident rate (IR) = 7.9) compared with males in the age ranges 19-24 years (IR=3.8), 16-18 (IR = 4.9), 12-15 (IR=4.4), and younger than 12 years (IR=2.8).[24] For females, the highest rate of all injuries was in the 12-15 age range (IR=6.3) compared with those less than 12 years (IR =5.6), and those in ranges 16-18 years (IR =4.6), 19-24 years (IR=4.9), and older than 25 years (IR =5.1). The body parts most often injured were the ankle and the knee. Most recently, in prospective cohort study of 306 male soccer players (mean age = 24) in Iceland, Arnason and colleagues found that increasing age was a risk factor of injury in general (odds ratio=1.1 per year, P=0.05).[26] Age was also found to be a significant risk factor for hamstring strains (odds ratio=1.3 per year, P<0.001) and previous hamstring strains (odds ratio=11.6, P<0.001).

Age was not found to be an injury risk factor specifically among female soccer players in the following studies. Soderman and colleagues [29] did not find age to be a risk factor for injury in a study of female Swedish soccer players (mean (SD) age 20.6

(4.7) years). Chomiak[13] found a similar incidence of severe injury among soccer athletes aged 14-41 years. However, injury type in this study differed by age group. Chomiak noted that there was a trend toward more muscle strains, severe ligament ruptures, and meniscal tears with increasing age, whereas there were fewer minor joint sprains, contusions, and spinal fractures among older athletes.

It is difficult to compare findings of these studies because research methods differed in terms of the sports, age ranges, and types of injuries investigated. Furthermore, several of the studies focused on a narrow age range, which make it difficult to conclude the association between age and injury.

Age & Physiologic Changes

The aging process has been associated with decreased muscle mass[8, 27, 28], increased fat mass[7], decreased aerobic capacity[8], and decreased musculoskeletal flexibility[6, 9]. Most physiologic functions do not experience significant declines until after age 70; however, small decrements in certain systems typically begin at approximately 25 years of age.[8] Approximately 10% of muscle cross-sectional area is lost between the ages of 20 and 50, and VO_{2max} has been shown to decrease by approximately 10% per decade after age 25.[8] Joint range of motion has been shown to decrease with age and is thought to be related to a decrease in soft tissue compliance.[30] The combination of decrements in soft tissue tensile strength, increased stiffness with aging and decreased vasculature of certain tendons most likely play a major role in age related sports injuries such as Achilles tendon ruptures, meniscal tears and quadriceps tendon ruptures.

In a study of musculoskeletal and physiological changes in different aged soccer players, McHugh and colleagues studied 3 different age groups of soccer players.[9] The oldest group (mean age 35 years) had significantly less knee extension/flexion strength, significantly less lumbar flexion and hip rotation flexibility, and a longer time out of balance in single-limb stance than the 2 younger groups. The combined effects of small changes in certain musculoskletal and physiologic systems in older athletes could result in changes to neuromuscular control strategies of the lower extremities which may lead to an increased risk of injury.

Flexibility as a Risk Factor for Injury

Measures of flexibility vary greatly and include generalized and specific joint laxity, and muscle tightness.[5] There is a sparse amount of definitive research concerning flexibility and/or joint laxity as intrinsic risk factors for the development of joint or muscle injury. Debates about flexibility arise from lack of agreeable definitions and measurements and lack of scientific understanding about the determinants of flexibility.[31] Despite this, thorough studies have concluded that generalized joint laxity is a risk factor for lower extremity injury. The connection between muscle tightness and lower extremity injury is weak and more conclusive studies need to be performed to analyze a true connection between tightness and injury.

Generalized Joint Laxity

The relationship between generalized joint laxity and injury is becoming more conclusive. In a recent prospective study by Uhorchak, increased generalized joint laxity increased the risk for non-contact Anterior Cruciate Ligament (ACL) injuries in both men and women cadets ($P < 0.001$).[2] Generalized joint laxity was measured using a modified form of the Beighton method[32], which included: small finger metacarpophalangeal hyperextension (≥ 90° of extension), elbow hyperextension, knee hyperextension and the ability to touch the thumb to the volar aspect of the forearm. Subjects were considered to have generalized joint laxity if they had five or more of these signs (on a scale of 0-8, with 8 being the greatest laxity), indicating that excessive laxity was observed bilaterally and in at least three joints. The relative risk of sustaining an injury as a result of generalized joint laxity (≥ 5 regions) was 2.8 for both men and women. Men with laxity scores greater than or equal to 5 had a 3.1 relative risk and women with laxity scores greater than or equal to 5 had a 2.7 relative risk. Uhorchak's study was unique and significant because of the prospective design, large number of subjects enrolled (859 cadets, 739 men, 120 women), and the high level of control within this study (similar activity level, lifestyle of the subjects and ability to identify all injuries).

In a prospective study of 123 Swedish female soccer players, Ostenberg and Roos used a similar method to measure generalized joint laxity and determined that athletes who scored 4 and above (on a scale of 0-9, with 9 being the greatest laxity) were at a fivefold increased risk of sustaining an injury.[12] Similarly, Soderman also did a prospective study of 146 Swedish female soccer players and found that athletes with increased generalized joint laxity (score of 5 or more) were at 3.1 times the increased risk of traumatic leg injuries (95% CI = 1.19 to 8.01).[29] In addition, Soderman's study of the hyperextension of the knee joint alone was indicative of a 2.5 increase in risk of traumatic leg injuries (95% CI = 1.11-5.61).

Krivickas and Feinberg's prospective study of 201 college athletes determined that the rate of lower extremity injury was unrelated to ligamentous laxity in female athletes.[33] However, for men they determined that lower extremity injuries were associated with lower ligamentous laxity scores (P=0.008).

The majority of studies have concluded that generalized joint laxity is a risk factor for lower extremity injury and the difference in methods and injury classification may play a role in the different results of these studies.

Knee Joint Laxity

Several studies have shown a relationship between knee laxity and knee injury.[2, 13, 34, 35] The measurements of knee laxity vary greatly. Two methods are generally used to determine knee joint laxity. The first method consists of a trained doctor or therapist performing one or more of the following tests: Lachman, pivot shift, anterior drawer, posterior drawer and varus/valgus stress tests at 0° and 30°. Another method for knee laxity measurements is using the KT 1000 or KT 2000 arthrometer, which quantitatively assigns a value to anterior tibial translation.

In a prospective study of 398 Czech Republic soccer teams of varying skill levels and ages, previous knee injury and instability of the knee were found to predispose soccer players to subsequent major knee injury.[13] Knee laxity in this study was determined based on anterior drawer, Lachman, valgus and varus stress tests. Similarly, Ekstrand and Gillquist studied a senior male soccer division with 12 teams for a 1 year period and found that players with increased knee laxity, based on varus/valgus and anterior/posterior exam to be at significantly increased risk of injury.[34] Five out of seven players that sustained non-contact knee injuries in the study had pre-existing instability compared to 1 of the 11 knee collision injuries ($P<0.05$).

In a study by Rozzi and colleagues, knee joint laxity was tested using the KT 1000 arthrometer.[35] A significant difference in anterior tibial translation scores between female and male athletes was found, demonstrating that female athletes have more knee joint laxity than male athletes.

In the prospective study by Uhorchak, knee laxity tests using the KT-2000 arthrometer showed a significant difference between men and women at all KT-2000 loads.[2] In just the men, KT-2000 values were not concluded to be a significant risk factor for ACL injury, and in the women the values approached significance but lacked statistical power. According to the study, knee laxity alone may not be a significant risk factor for women, but it may increase risk for ACL injury when combined with other risk factors.

In a study by Huston, female athletes had less laxity than the knees of non-athletic controls ($P<.05$).[36] In addition, the knees of women were also looser than the knees of men as was also found in Uhorchak's study of cadets.

Knee laxity tests are very subjective and depend greatly on inter-rater reliability. Until more reliable and less subjective methods for determining knee laxity are developed, the relationship between knee joint specific laxity and injury will remain unclear. Murphy suggests a more reliable and less subjective method for measuring joint laxity by using radiographic based stressed measurements.[5] However, this is not common because of the cost and increased risk associated with these techniques.

Muscle Tightness

The findings of studies concerning muscle tightness are often confounded because of the various methods used to measure muscle tightness, diverse injury types, and a variety of sports with different inherent risks.[5] The most common measurement of muscle tightness is goniometer measurements of specific muscles. The sit and reach test is also used although it is considered by experts to be a nonspecific test.

In a prospective study of 146 male professional soccer players (after injury exclusion), the flexibility of the hamstring, quadriceps, adductor, and gastrocnemius muscles was measured with a goniometer on both sides.[37] Statistical significance was found between preseason hamstring muscle tightness and subsequent development of a hamstring injury (P=0.02). A relationship for quadriceps muscle tightness and the development of quadriceps muscle injuries was also found (P=0.047). For both muscles, the injured group showed a significantly lower mean flexibility. This study is weakened by the scarcity of injuries in some categories (i.e. calf strain) and failure to note the circumstances around surrounding the injury event (i.e. non-contact versus contact, overuse versus traumatic, etc.).

In a prospective study of 55 Division III collegiate female athletes, athletes whose hip extensors had a 15% greater range of motion on the right side, were 2.6 times more likely to get injured than athletes with less than a 15% imbalance.[38] Joint flexibility measurements were done actively with a goniometer and joints measured included the hip flexors (hamstrings), hip extensors, hip adductors, hip external rotators, knee flexors (quadriceps), and ankle dorsiflexors (gastrocnemius and soleus). A major weakness in this study is that there was no control for different types of sports or player position because of the relatively low sample size.

In a more recent prospective cohort study of male soccer players in Iceland with 249 players undergoing flexibility tests, Arnason and colleagues found decreased range of motion in the hip abductors to be a risk factor for groin (adductor) strains (odds ratio=0.9 [1°], P=0.05).[26] Hip abduction flexibility was measured with the player supine with one leg fixed in slight abduction outside the examination table. The other leg was placed on a sliding board and passively abducted using a 4kg load. The tension meter was placed proximal to the lateral malleolus at 90° angles to the lower leg and was visually controlled. The amount of abduction was measured using a goniometer. As with most prospective studies, the precision of the incidence rates is questionable since injury rates and exposure are often not accurately reported. In this study, not all of the selected players were able to be tested for flexibility (249 tested out of 306 selected) and not all of the coaches properly measured match participation and practice involvement.

Krivickas and Feinberg found a statistically significant correlation between flexibility and the development of injuries in male college athletes.[33] They introduced a new scale for assessing muscle tightness of hip flexors, hamstrings, quadriceps and gastrocnemius. There was also a significant relationship between increased iliopsoas tightness and overuse knee injury in men. No relation between muscle tightness and injury was found for women.

In Uhorchak's study, the sit and reach test was used to analyze flexibility and it was determined that there was no link between sit and reach scores and ACL injury in both men and women.[2]

In retrospective studies analyzed by Butler and Crowell, too much lower extremity stiffness of all components including tendons, muscles, ligaments, cartilage and bone may be associated with bony injuries, while too little stiffness of these components may be associated with soft tissue injuries.[39]

As can be seen, it is difficult to truly conclude that muscle tightness (or lack of) is an extrinsic risk factor for lower extremity injury. The different measurement methods and the different athletes tested (male only, female only, male and female) and sports with different inherent risks make comparison and conclusions between studies difficult.

Muscle Strength and Imbalance

Forces developed by the contraction of muscles are important for quick and precise movement; however, it is unclear whether muscle contraction, evaluated in terms of strength is a risk factor for injury. Measurements of muscle strength in terms of hamstring to quadriceps strength ratio and peak torque generated about a specific joint are done using isokinetic dynamometers. Although these instruments provide important information, the tests are done with the subject seated (non-weight bearing) and cannot duplicate the speeds of physical activity and injury mechanism.[5]

Hamstring to Quadriceps Strength Ratio

In a prospective study of 146 Swedish female soccer players, muscle torques of the hamstrings and quadriceps were measured using 2 different isokinetic dynamometers at 90°/s.[29] Soderman found a decreased ratio of hamstring to quadriceps strength (H/Q ratio) to be related to a higher risk for traumatic leg injury (OR =0.95) and increased H/Q ratio to be a risk factor for overuse leg injury (OR = 1.13) in female soccer athletes. Similarly, in a study by Anderson and colleagues of 100 high school basketball players

(50 female, 50 male) the H/Q ratio at 60°/s was significantly higher for male players, indicating that the hamstring muscles in female players were relatively weaker than in males compared with the quadriceps muscles ($P<0.01$ with corrections for body weight).[40]

Peak Torque

Lephart and colleagues analyzed 15 female college athletes and 15 age and activity level matched male athletes.[3] Using a dynamometer at 60°/s, Lephart *et al.* found that females had significantly lower peak torque to body weight for knee extension ($p=0.011$) and flexion ($p=0.043$) than males. This relation to body weight is important in landing and women tended to land with less flexion than men; thereby increasing the demand on the quadriceps and may make females more susceptible to ACL injury. Similarly, Wojtys and Huston found that female control and athlete groups had weaker quadriceps and hamstring muscle strength at 60°/s testing compared with both male control and athlete groups even when normalized for body weight ($P<0.05$).[41] Their study consisted of 23 volunteers (10 men and 13 women) all with similar knee laxity. In another study by Wojtys and Huston of size matched athletes (24 in ACL risk sports and 28 in endurance athletes), male athletes had significantly larger knee flexor and extensor peak torques than did female athletes ($P<0.001$).[42] Anderson and colleagues demonstrated that at 60°/s and 240°/s, male high school basketball players were able to generate higher peak torques than the female players ($P<0.0001$).[40]

Despite the differences in peak torque generation in men and women, a link between peak torque and injury is still unclear. In Ostenberg and Roos' prospective study of female soccer players, quadriceps and hamstring muscle strength were tested using a dynamometer at angular velocities of 60°/s and 180°/s.[12] When comparing the injured group to the uninjured players, no difference was seen in isokinetic strength at both velocities. Also, Uhorchak prospectively tested athletes with a dynamometer at 60°/s and found no difference between the ACL injured and uninjured groups.[2] It was further mentioned in the study that peak torques were normalized to body weight. In the case of ankle injury, Beynnon found that ankle strength was not a risk factor for ankle injury in collegiate athletes.[43]

Many studies have demonstrated that the peak torque generated by men significantly differs from women. However, few studies have linked this difference to a risk for lower extremity injury. Since relatively few studies have linked H/Q ratio and peak torque to injury and 3 studies have shown that strength has no relation to lower extremity injury, additional research is needed to validate strength as a risk factor for lower extremity injury.

Biomechanical and Neuromuscular Risk Factors for Injury

An estimated 70% of ACL injuries are sports related and the majority of non-skiing ACL injuries (72%) are due to non-contact mechanisms in which the injured athlete is not hit or touched by another player.[44, 45] Static analysis has yielded significant risk factors for injury (i.e. generalized joint laxity[2, 12, 29] and ACL notch width[2]), however the nature of both ACL injuries are often dynamic in nature and the variety of dynamic studies makes them difficult to compare. Altered neuromuscular control strategies, altered movement patterns, and body positioning are believed to contribute to the increased of incidence of non-contact ACL injuries in female athletes.[11]

Cutting and Landing Risk for Injury

Gender differences exist when athletes perform athletic maneuvers, such as cutting and landing from a jump.[17] Malinzak and colleagues compared knee motion patterns between male and female recreational athletes (11 men {mean age 24.6} and 9 women {mean age 24.5}) in running, cutting and jumping tasks.[4] In this study, women tended to land with the knee in a more extended position in all selected athletic tasks, and therefore subject themselves to higher forces per body weight during the impact of landing. Females also demonstrated greater valgus angles than males at ground contact during all selected tasks, suggesting that the load on the ACL increase as knee valgus increases. Increasing the load on the ACL may also increase the risk for ACL injury.

McLean and colleagues examined the cutting maneuver in two separate studies.[18, 46] The first study involved thirty "state level" athletes (16 male and 14 female, mean age 19 years old).[18] Knee joint kinematic data was recorded for both the right and left leg and for eight running and eight cutting trials. Differences ($P<0.01$) were found between male and female maximum and minimum adduction/abduction values, with women tending to land and remain in a more abducted position than men during stance. Women also displayed significantly ($P<0.05$) larger coefficients of variation for external/internal knee rotation when compared with men. A strong relationship was found between level of experience and knee external/internal rotation variability ($P<0.01$) in the female group. Extreme variability in knee joint kinematics during complex movement tasks has been linked to low levels of conditioning and experience. The author suggests that increased variability in knee joint kinematics during sidestepping may increase the risk of injury with the possibility of an abnormal or potentially hazardous cut being more likely. Although differences were found between the two genders, no source of increased risk for non-contact ACL injury was found because maximum knee adduction/abduction values for both women and men during sidestep cutting were well within safe ranges of joint movement. In a more recent study by Mclean and colleagues, the cutting maneuver was again analyzed, but this time a stationary "defensive opponent" was placed 20cm behind the prescribed sidestep location.[46] Sixteen subjects (8 female and 8 male) preformed 10 trials without a defensive opponent and 10 trials with a defensive opponent. Approach speed was monitored and all subjects had to be within 4.5 to 5.5 m/s. Results showed that females had larger peak knee valgus and rear foot pronation angles and smaller peak hip flexion, hip abduction, hip internal rotation and knee flexion and internal rotation angles compared with males ($P<0.003$). The simulated defensive opponent resulted in increases in peak medial ground reaction force, hip flexion, hip abduction, knee flexion and knee valgus ($P<0.003$). Overall, significant gender differences were found in all joints. The authors point out that biomechanical interaction of the hip, knee and ankle (and not just the knee alone) may be important contributors to the overall risk of non-contact ACL injury during any maneuver. Although the methodology of this study is novel, the use of non-competitive athletes as subjects is questionable.

Huston and colleagues studied 20 height-matched subjects (10 male / 10 female) performing normalized drop landings from 3 heights.[19] Significant gender differences were found in knee angle at initial landing ($P<0.05$), with the largest difference occurring at the highest height of 60cm. Females landing with a straighter knee may potentially increase ACL strain, thereby increasing injury risk.[21]

Similarly, in a study by Lephart and colleagues, females had significant less knee flexion than males in two separate landing tasks consisting of single leg landing off a 20cm platform and a separate forward hop.[3] The 15 female subjects were division 1 athletes in various sports and the males were recreational athletes that were matched according to age and activity level.

Decker and colleagues recently published similar findings.[20] In the study of 21 (12 male / 9 female) recreational athletes performing a 60cm drop landing, the female group also demonstrated lower knee flexion and greater ankle plantar flexion angles at initial ground contact compared with the male group (both $P<0.05$).

In contrast to the above findings, Fagenbaum and Darling's study of 6 male and 8 female basketball players performing 3 different jump tasks found that women tended to land with 10° to 14° of greater knee flexion than men.[47] They flexed the knee more just before landing ($P=0.03$) and had greater knee flexion than men at ground contact ($P=0.032$). These conflicting findings suggest the possibility that recreational female athletes land differently than do elite female basketball players during controlled laboratory conditions and care needs to be made when choosing subjects and landing tasks for studies.

From the above studies it can be concluded that women tend to favor less knee flexion during landing with their ankles more dorsiflexed than men; thereby placing additional strain on the ACL and increasing the likelihood for ACL injury. The greater amount of knee flexion in men may protect men from ACL injuries.

Hamstring and Quadriceps Activation during Specific Tasks

Cowling and Steele report in a study of matched players (7 male and 11 female) receiving netball passes after accelerating for 3 steps, that no statistical significant differences existed between male and female joint angles during the final dominant limb stabilization posture.[48] In addition, males and females displayed similar quadriceps muscle activation during the final step. However, significant differences were found in the hamstring muscle activation pattern used by the 2 groups during the task. Males showed significant delay in the onset of semimembranosus compared to females. Cowling and Steele conclude that the synchrony in muscle activation may be more protective of the ACL in males than in females. This is in agreement with Colby and colleagues, where 15 college recreational athletes (9 men and 6 women) performed 4 movements (sidestep cutting, cross-cutting, stopping and landing from 0.4 meters) while knee angle and EMG activity of the leg muscles were recorded.[44] The results suggest that the levels of hamstring muscle activity are much lower than the levels of quadriceps activity and may not be sufficient to prevent anterior tibial displacement and subsequent ACL injury.

Malinzak and colleagues also demonstrated that female subjects had a lower activation for their hamstring muscle and a higher activation for their quadriceps muscle than male subjects in selected athletic tasks.[4] According to Malinzak, the combination of increased quadriceps activation and decreased hamstring activation of the female subjects increases the possibility of increased knee anterior shear force for female subjects while the male subjects recruited the hamstring muscle for initial knee stabilization. These data suggest that differences in knee motion patterns between genders may be caused by different lower extremity muscle activation patterns.[11]

In a unique study by Huston and Wojtys in which a device places anterior tibial translation on the lower extremity, the order of muscle recruitment for female athletes was significantly different than male athletes and controls.[36] According to the authors the female athletes relied more on the quadriceps and gastrocnemius muscles to resist anterior tibial translation. This again demonstrates that women athletes tend to favor firing the quadriceps before the hamstring, placing them at greater risk for anterior tibial translation and subsequent ACL injury.

Alternatively to the above findings, Fagenbaum and Darling found that there were no significant differences between men and women in hamstring muscle EMG activity before or during landing.[47] However, as mentioned before, this study had a low number of subjects (14) and all subjects were elite basketball players.

Muscle synchrony between the hamstring and quadriceps muscle groups plays an important role in neuromuscular motor control patterns that protect the lower extremity from injury. As described in the above studies, female hamstring activation may be delayed during dynamic tasks, thereby increasing their risk for ACL injury. Muscular control patterns in the lower extremity that may predispose men to Achilles tendon injuries need to be analyzed.

Knee Kinetics during Specific Tasks

Chappell and colleagues studied 20 college-age recreational athletes (10 women and 10 men) to compared differences in sexes in proximal anterior shear forces, knee flexion-extension, valgus/varus moments and knee flexion angles in 3 stop jump tasks.[49] The three tasks were (1) stop-jump forward, (2) stop-jump vertically and (3) stop-jump backward. The results showed that women had significantly greater peak proximal tibial anterior shear forces, greater knee extension moment, greater knee valgus moment and smaller flexion angle than did the men during the landing phase of the three stop-jump tasks. All three of these loading patterns in women tend to increase strain on the ACL and may lead to ACL injury. Additionally, these knee motion patterns between men and women may be associated with differences in lower extremity neuromuscular control.[11]

Conclusion

Injury prevention is an important goal for clinicians and researchers. The complications after injury can become debilitating later in life. ACL and subsequent cartilage injury in athletes may be linked to osteoarthritis later in life. Preventing injury keeps athletes healthy, yet it is impossible to prevent injury unless the risk factors have been established. Many intrinsic and extrinsic risk factors have been identified, yet agreement has been met on very few. There is a general consensus that being female, having reduced femoral intercondylar notch width and generalized joint laxity are risk factors for ACL injury. The lack of agreement on some risk factors is generally a result of different study methods, different sports studied, techniques used to measure the same risk factors, varying injury definitions and timing and frequency of data collection. Future studies should be well controlled and should also use a sufficient sample size including an adequate number of males and females of various ages.

The association between age, gender and risk for lower extremity injury needs to be further examined. Studies have linked increased age with injury, however, specific studies linking other factors such as gender, generalized joint laxity and neuromuscular control to age are lacking. Gender-specific neuromuscular control strategies at the knee and hip have been demonstrated in young athletes, yet little information is available regarding the use of different strategies at other joints such as the ankle and how these control strategies may change with age. Additionally, factors such as lower extremity flexibility may influence the biomechanical patterns and neuromuscular control strategies in older athletes. Identification of risk factors for lower extremity injury is important because preventing injury can prevent complications associated with injury later in life and can lead to a healthier generation of athletic participants of all ages. Once the risk factors have been identified, intervention programs can be designed to reduce injury incidence, severity and medical costs.

Methods:

Subjects

Seven younger male (Age: 24.1 ± 1.8 years, Height: 175.7 ± 7.9 cm, Weight: 165.9 ± 14.9 lbs), seven older male (39.1 ± 4.6 years, 176.1 ± 6.6 cm, 176.9 ± 15.2 lbs), seven younger female (23.3 ± 1.1 years, 164.9 ± 6.0 cm, 141.7 ± 11.1 lbs) and nine older female recreational soccer players (37 ± 3.4 years, 163 ± 8.3 cm, 141.7 ± 18.9 lbs) from communities surrounding the San Francisco area volunteered to participate in this study. All participants were currently playing recreational soccer at least 2 times per week and were skilled in soccer maneuvers. Subjects with a history of major lower extremity surgery, major fractures, or other musculoskeletal problems were excluded from the study. Additionally, subjects with a history of disease or arthritis that affected posture and/or lower extremity function were excluded. All subjects gave informed consent as stipulated by the Committee on Human Research at the University of California San Francisco prior to participation in the study.

Experimental Design & Protocol

Questionnaire

Subjects were asked to complete a medical and athletic history questionnaire. The medical history consisted of self-report of any diagnosis or symptoms of severe disease and current medication intake. The athletic history detailed the subject's past and current participation in soccer and other sports and any specific athletic activities such as weight training in which they routinely participated. Additionally, the type of shoe, playing surface and soccer position were listed. Additional questionnaire items assessed whether the player did any stretching or warming up / cooling down before and after soccer games.

Selected Athletic Tasks

The subject warmed up by jogging on the treadmill at a self-selected pace for 5 minutes. Following the warm-up, each subject completed multiple trials of four athletic tasks. The subjects were allowed to practice each task until comfortable. Three clean trials of each of the five tasks were collected. A clean trial was defined as a trial in which all marker coordinates were captured with no more than 5 consecutive missing frames of individual marker data. All tasks were block randomized for each subject using a random number generator. The four individual tasks are described below:

Drop Jump

This task consisted of stepping off a 62cm plyometric platform (ATAFA Sporting Goods) onto a landing platform. The platform was located 11cm from the force plate and slightly to the right of the force plate (Figure 1). Subjects were instructed to fold their arms across their chest and step off the box without jumping up or stepping down and to land as naturally as possible. The right foot landed on the force place and the other foot landed next to the force plate on the landing platform.

Step Right, Cut Left

A 30.5cm platform was placed 11cm posterior to the force plate and to the left side of the force plate (Figure 2). The subject was then instructed to step onto the center of the force plate (marked with an X) with their right foot. After contact, the subject then cut to the left approximately 45° following a line of tape directed 45° from the center of the force plate. Each subject was instructed to perform the task as fast as they felt comfortable and as if they were performing an evasive soccer maneuver.

Soccer Turning with Soccer Ball

The subject was placed 3 step lengths from the force plate. A size 5 soccer ball was placed near the left side of the force plate on the platform (Figure 3). Subjects started with their right foot and after 3 steps landed on the force plate with their right foot and then with the left foot, rolled the ball toward their back and did a 180° turn facing where they started. After they rolled the ball, the subject would continue approximately 3 steps. Each subject was instructed to perform the task as fast as they felt comfortable and as if they were performing an evasive soccer maneuver.

Soccer Heading with Soccer Ball

The subject was placed 1 step length away from the force plate. A size 5 soccer ball was hung from the ceiling 25.4cm above the measured height of the subject (Figure 4). The subject was then instructed to take one step, plant and jump up and head the soccer ball as if in a soccer game. The subjects were instructed to head the soccer ball as if they were participating in a soccer game.

Kinematics

A total of 16 spherical reflective markers were secured to the subject's right lower extremity. The subject was fitted for an indoor soccer shoe with 4 pre-attached markers (Reebok Tenari II) (Figure 5). Three clusters of four markers attached to rigid molded plastic (Figure 6) were firmly attached to the right hip, thigh and shank using double-sided tape and self-adherent wrap (3M Coban™) (Figure 7). Digital photographs of each subject in their normal stance were taken in the frontal (Figure 7) and sagittal plane (Figure 8).

3D marker coordinates were captured at 240 Hz with a 6 camera motion analysis system (Falcon Analog System, Motion Analysis Corp., Santa Rosa, CA). Touch down and toe off of the right foot for three of the six selected tasks were monitored with a force plate (type 9286A, Kistler Instrument, Corp., Amherst, NY) which sampled ground reaction forces at 600 Hz. For the Heading and Drop Jump tasks, touch down only was monitored with the force plate.

Twelve anatomical landmark locations were identified with a pointer containing two mounted large spherical markers (Figure 9). The distance from the center of the farthest marker to the tip of the pointer was 500mm. This was done in accordance with the technique developed by Capozzo and colleagues [50] and enabled the calculation of the relevant lower extremity anatomical landmarks with respect to the marker clusters. During the experiment, the tip of the pointer was placed onto the anatomical landmarks so that the markers on the pointer and the relevant body segment marker clusters were visible to the cameras. The anatomical landmarks that were measured then defined the anatomical axes locations in each body segment.

The following twelve anatomical landmarks were identified with the pointer on the lower extremity: (Figure 10, Figure 11)

1. Medial Malleolus
2. Lateral Malleolus
3. Foot Heel
4. Foot Toe
5. Shoe Heel
6. Shoe Toe
7. Medial Tibial Condyle
8. Lateral Tibial Condyle
9. Right Anterior Superior Iliac Spine
10. Left Anterior Superior Iliac Spine
11. Right Posterior Superior Iliac Spine
12. Left Posterior Superior Iliac Spine

Joint Kinematics Calculations

Coordinate data from the kinematic trials and anatomical landmarks were inputted into "MARey", a MATLAB software package for kinematic analysis. [51] Marker trajectories were filtered at 17 Hz using a fourth order low-pass Butterworth filter. Joint angular position and velocities were calculated from the filtered 3D marker coordinate data. The joint kinematics were calculated using the Joint Coordinate System methodology for the ankle (dorsi/plantarflexion), knee (flexion/extension, abduction/adduction, internal/external rotation), and hip (flexion/extension).[52]

Stance phase of the step right, cut left and soccer turning tasks was determined using analog touchdown and toe-off data. The frame at touchdown was determined when the first ground reaction vertical forces were greater than or equal to 20 Newtons. Touchdown for the drop jump and soccer heading tasks were also calculated this way. The frame at toe-off for the step right, cut left task and soccer turning task was determined when the first vertical ground reaction forces after touchdown were less than or equal to 20 Newtons. The joint angle curves from touchdown to toe off were then normalized to 100 data points using the polynomial interpolation function in Matlab. Data for the soccer heading and drop jump tasks was extracted from touchdown to maximum knee flexion and also normalized to 100 data points using the polynomial interpolation function in Matlab. After normalization to the stance phase, the joint angle curves for all 3 trials within each task were averaged across each subject. Group averages for young males, older males, young females and older females were averaged for each variable.

Statistics:

One-way analyses of variance were used assess the effect of group (young male, older male, young female, older female) on each dependent kinematic variable. Statistical significance was set to a value of $p \leq 0.05$. Because of the exploratory nature of the study, no adjustment was made for the use of multiple comparisons. If the one-way ANOVA achieved statistical significance, post hoc multiple comparisons between groups were analyzed using the Tukey method with statistical significance also set to a value of $p \leq 0.05$.

The following kinematic dependent variables were analyzed in each of the four tasks:

1. Touchdown Ankle Dorsiflexion / Plantarflexion Joint Angle
2. Maximum Ankle Dorsiflexion / Plantarflexion Joint Angle
3. Time to Maximum Ankle Dorsiflexion / Plantarflexion Joint Angle
4. Maximum Ankle Dorsiflexion / Plantarflexion Joint Angular Velocity
5. Time to Maximum Ankle Dorsiflexion / Plantarflexion Joint Angular Velocity
6. Touchdown Knee Adduction/Abduction Joint Angle
7. Maximum Knee Adduction/Abduction Joint Angle
8. Time to Maximum Knee Adduction/Abduction Joint Angle
9. Maximum Knee Adduction/Abduction Joint Angular Velocity
10. Time to Maximum Knee Adduction/Abduction Joint Angular Velocity
11. Touchdown Knee Internal/External Rotation Joint Angle
12. Maximum Knee Internal/External Rotation Joint Angle
13. Time to Maximum Knee Internal/External Rotation Joint Angle
14. Maximum Knee Internal/External Rotation Joint Angular Velocity
15. Time to Maximum Knee Internal/External Rotation Joint Angular Velocity
16. Touchdown Knee Flexion/Extension Joint Angle
17. Maximum Knee Flexion/Extension Joint Angle
18. Time to Maximum Knee Flexion/Extension Joint Angle
19. Maximum Knee Flexion/Extension Joint Angular Velocity
20. Time to Maximum Knee Flexion/Extension Joint Angular Velocity
21. Touchdown Hip Flexion/Extension Joint Angle
22. Maximum Hip Flexion/Extension Joint Angle
23. Time to Maximum Hip Flexion/Extension Joint Angle
24. Maximum Hip Flexion/Extension Joint Angular Velocity
25. Time to Maximum Hip Flexion/Extension Joint Angular Velocity

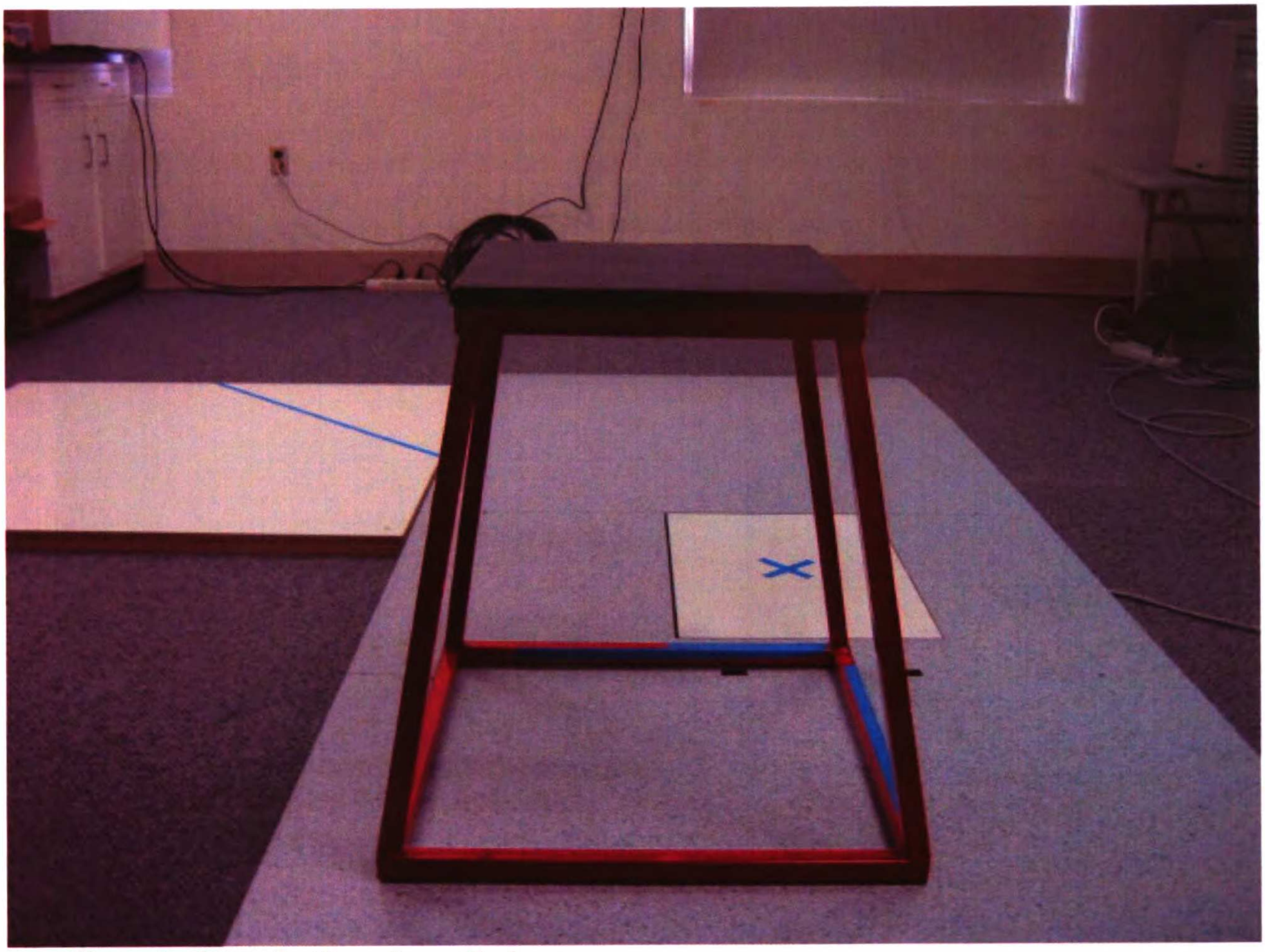

Figure 1: Setup for Drop Jump Task

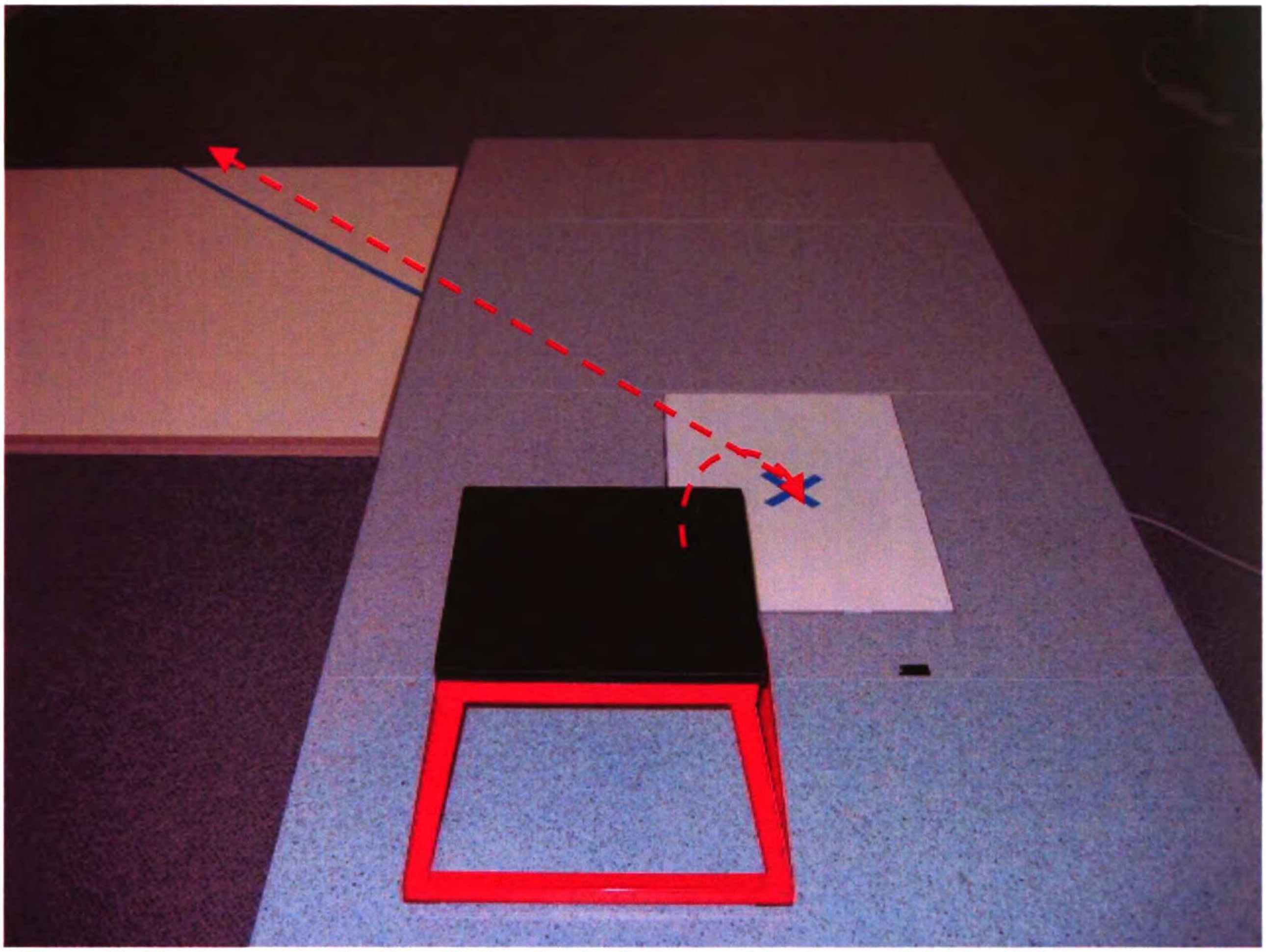

Figure 2: Platform setup for Step Right, Cut Left Task and Pathway of Subject Right Lower Extremity Movement

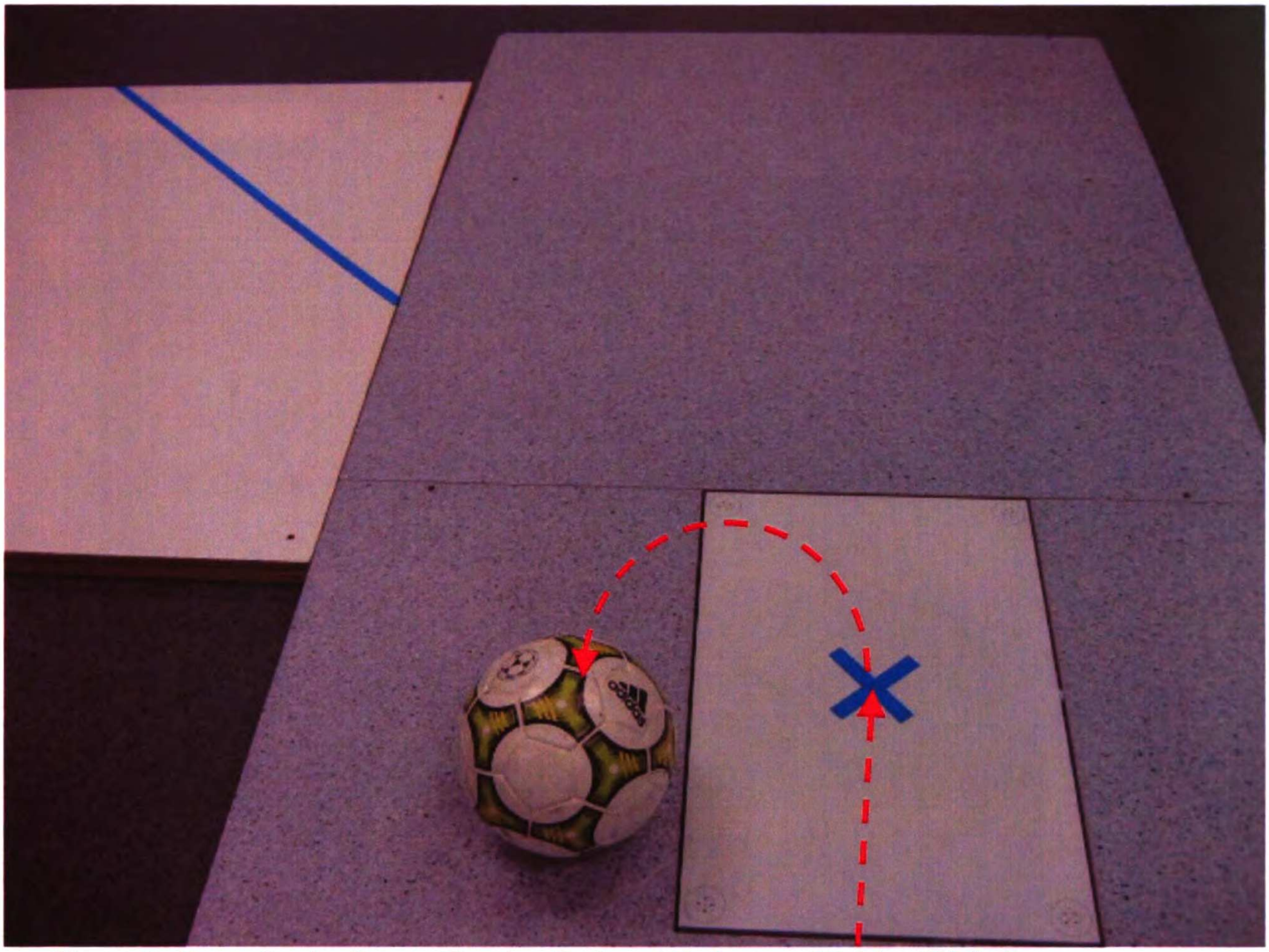

Figure 3: Setup for the Soccer Turning Task and Pathway of Subject Right Lower Extremity Movement

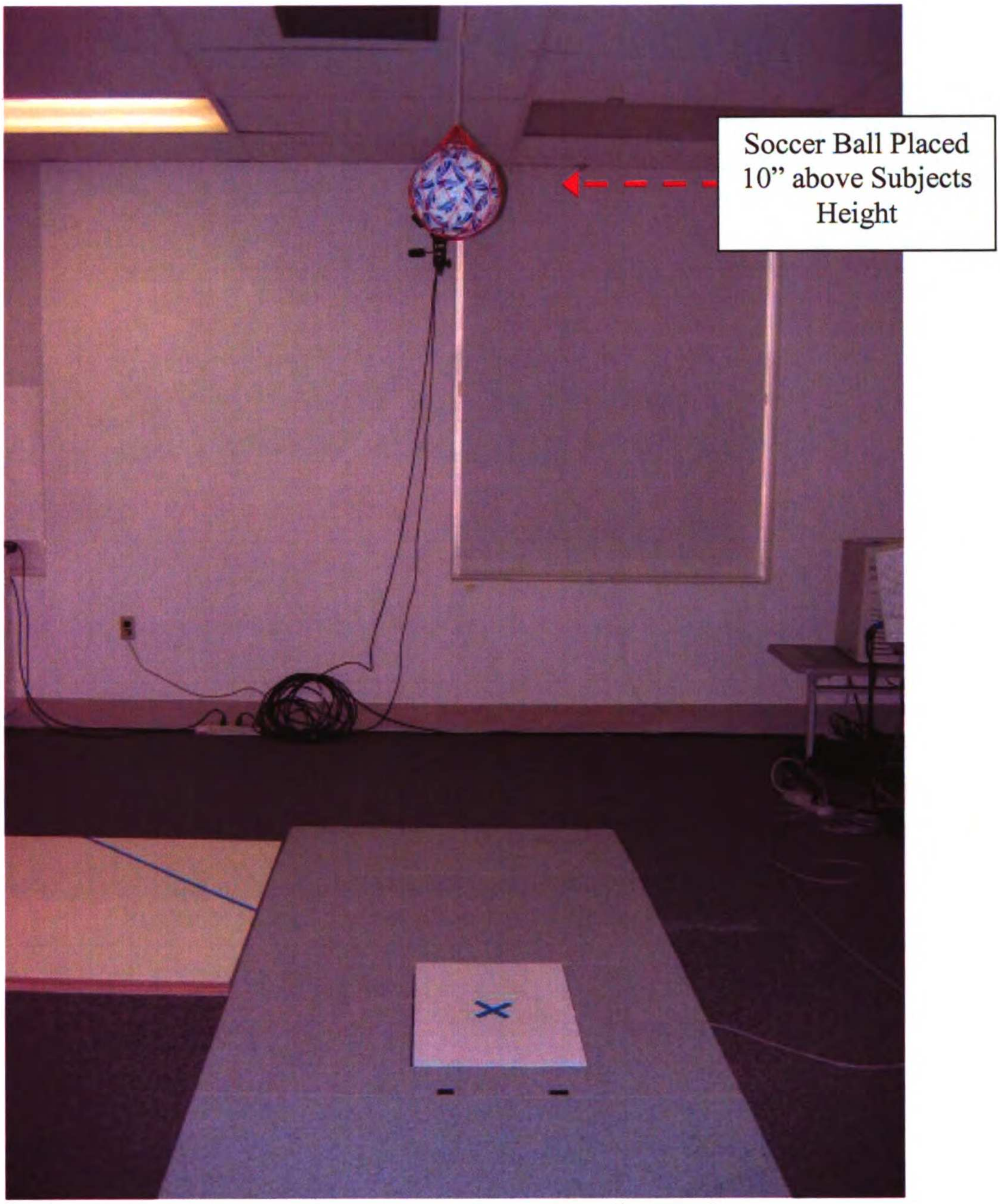

Figure 4: Setup for the Soccer Heading Task

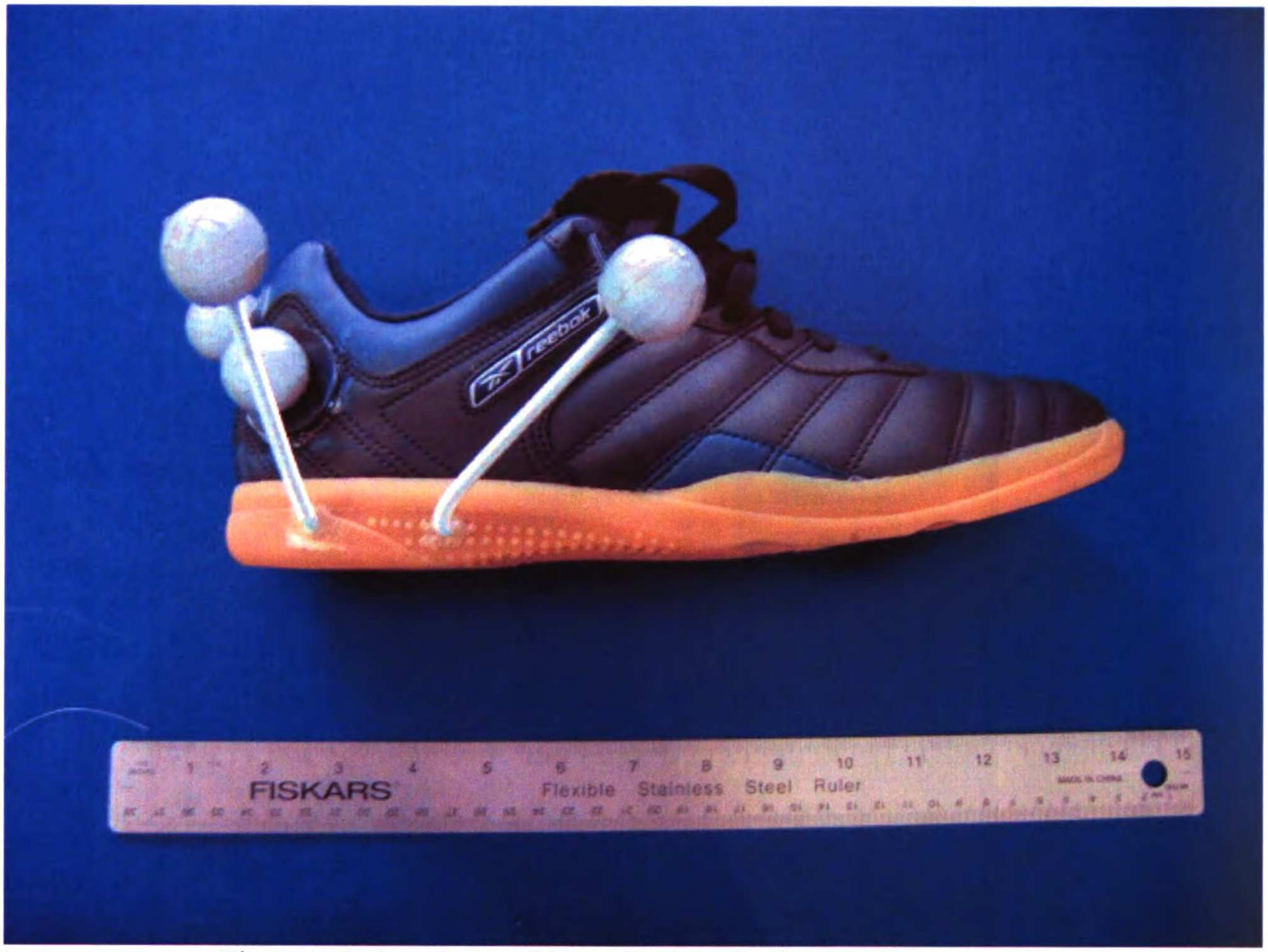

Figure 5: Indoor Soccer Shoe with 4 Reflective Markers

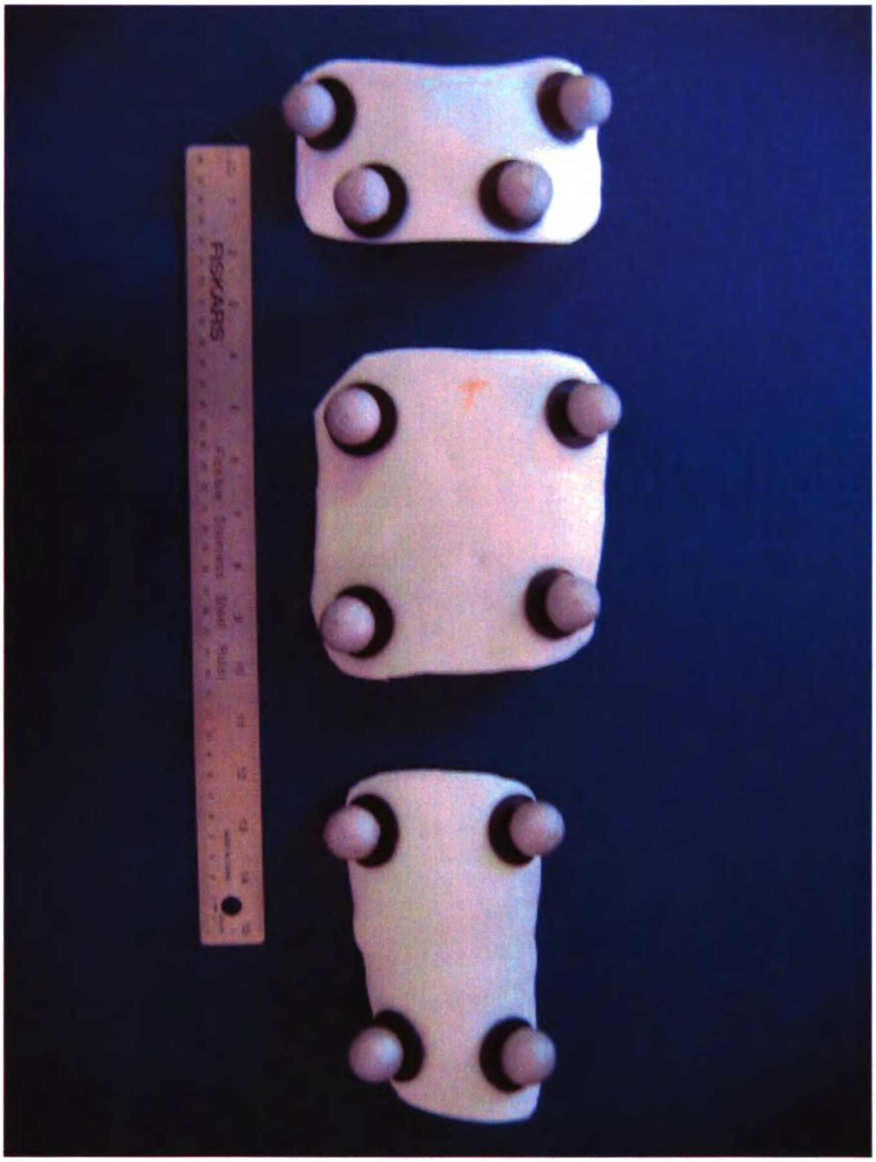

Figure 6: (From Top to Bottom)
Hip Marker Cluster, Thigh Marker Cluster, Shank Marker Cluster

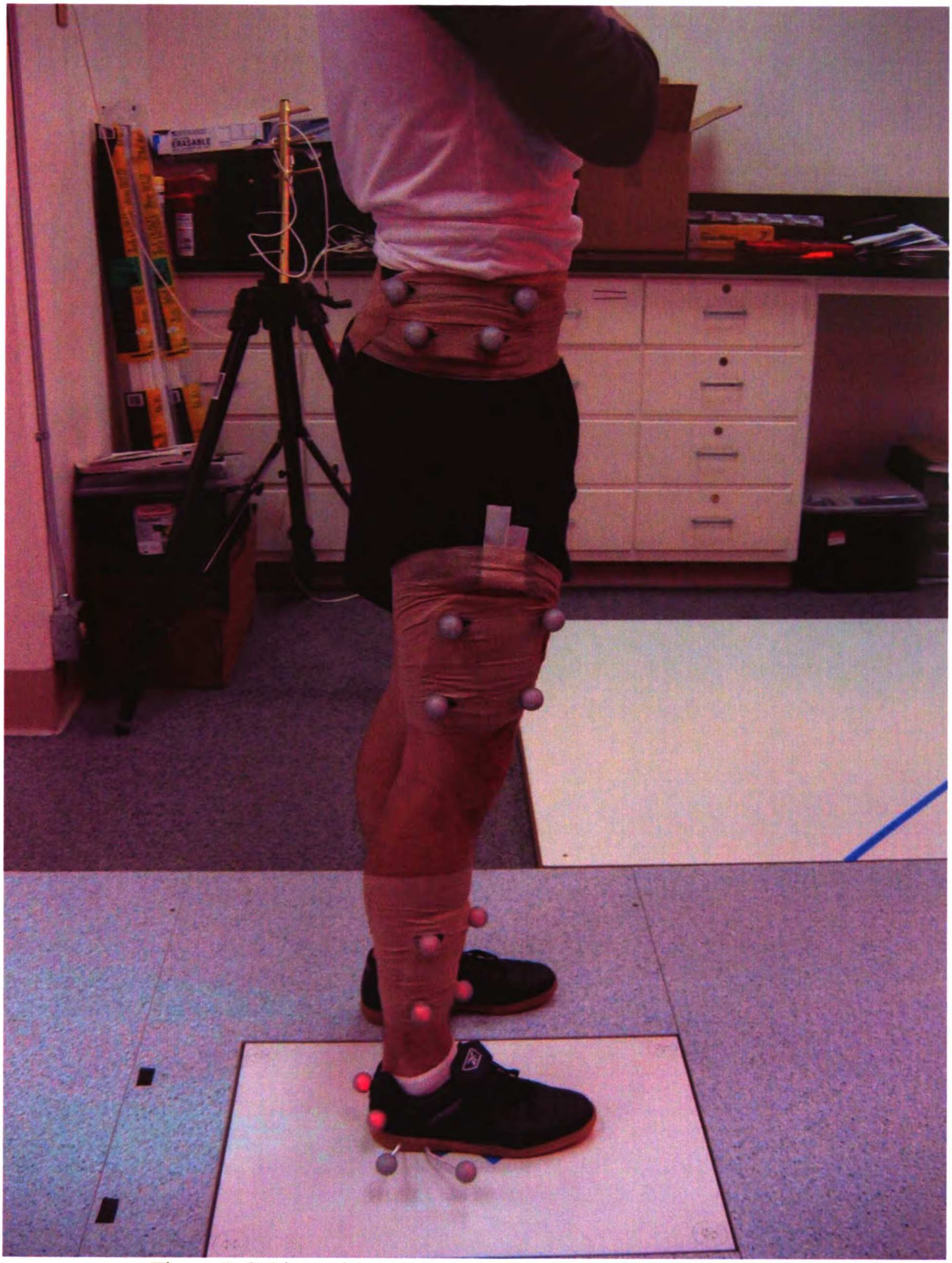

Figure 7: Subject with complete marker set (Sagittal Plane)

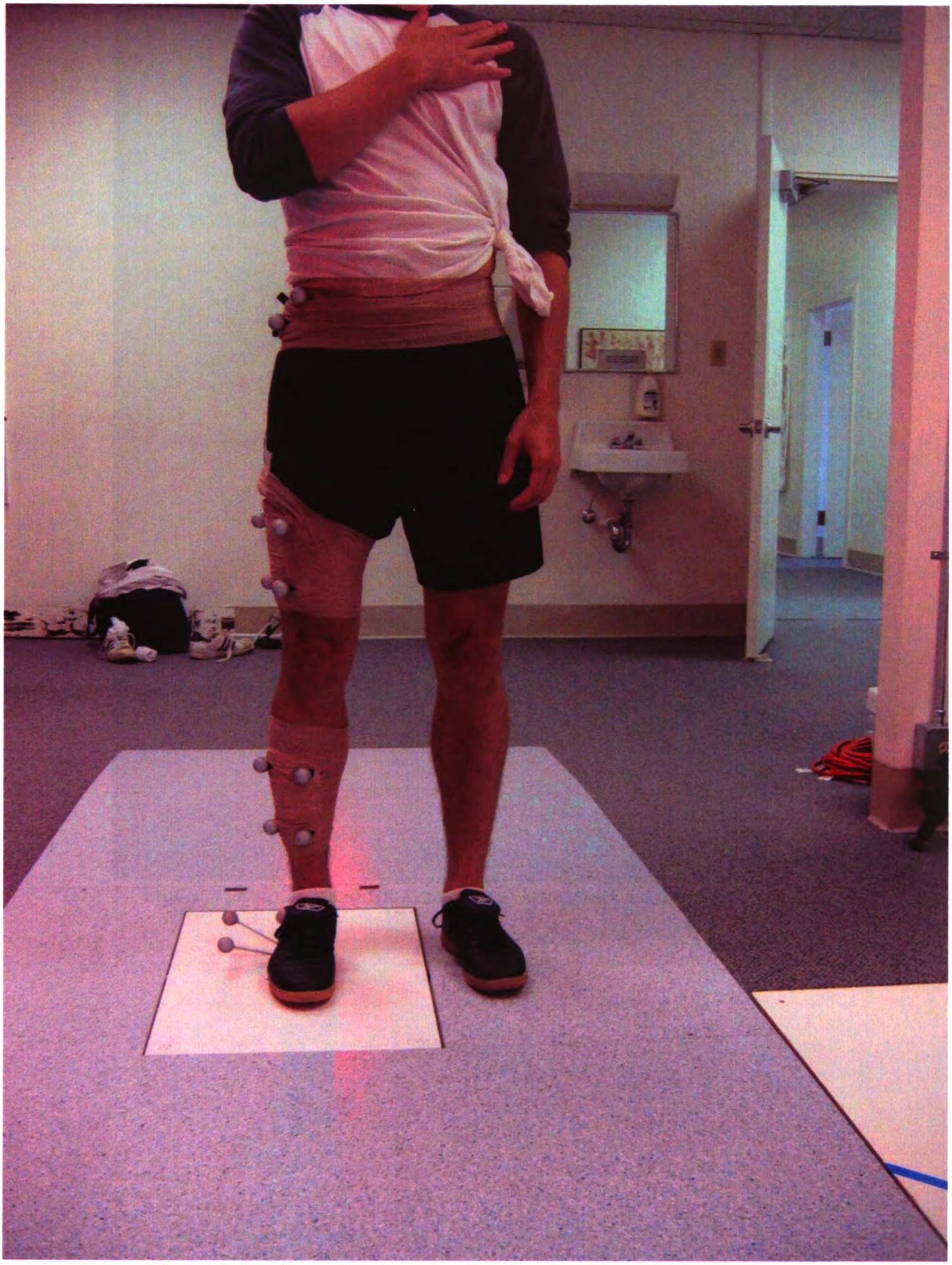

Figure 8: Subject with Complete Marker Set (Frontal Plane)

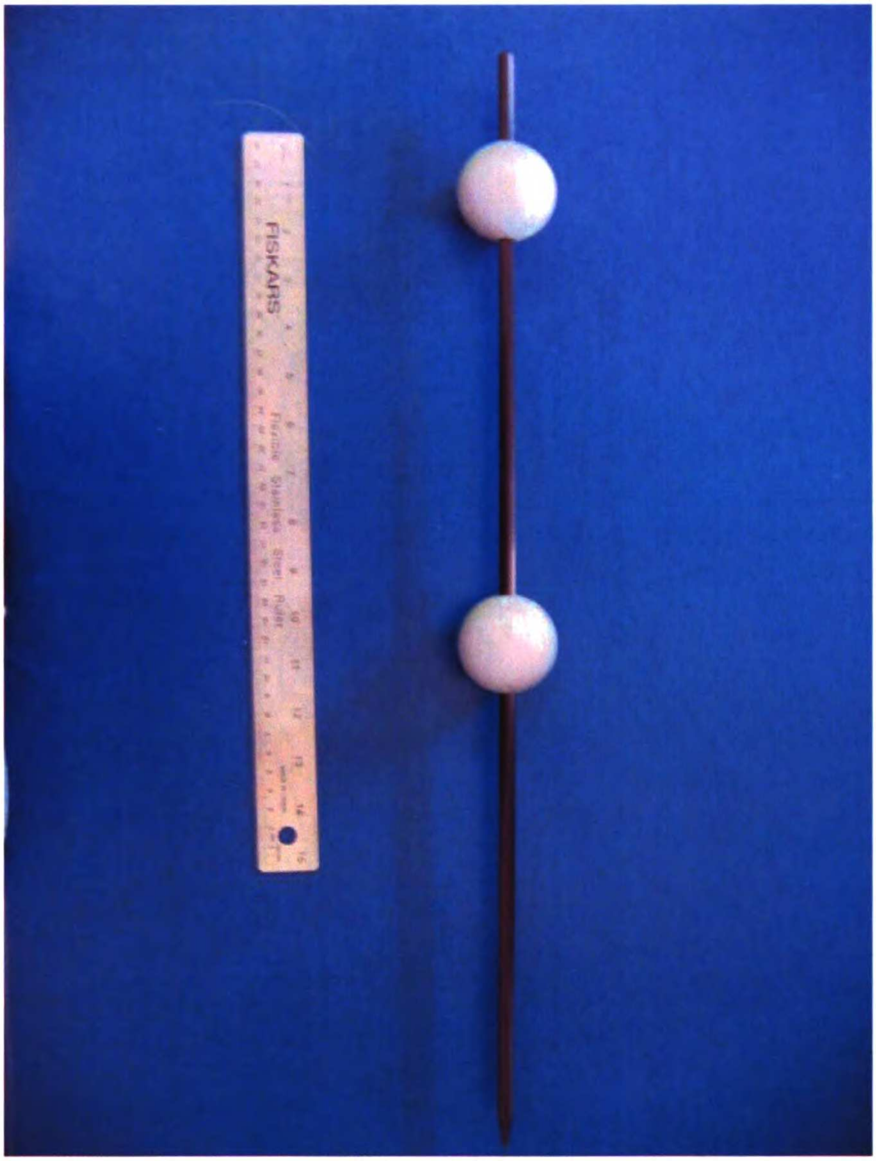

Figure 9: Pointer Used for Anatomical Landmark Calibration

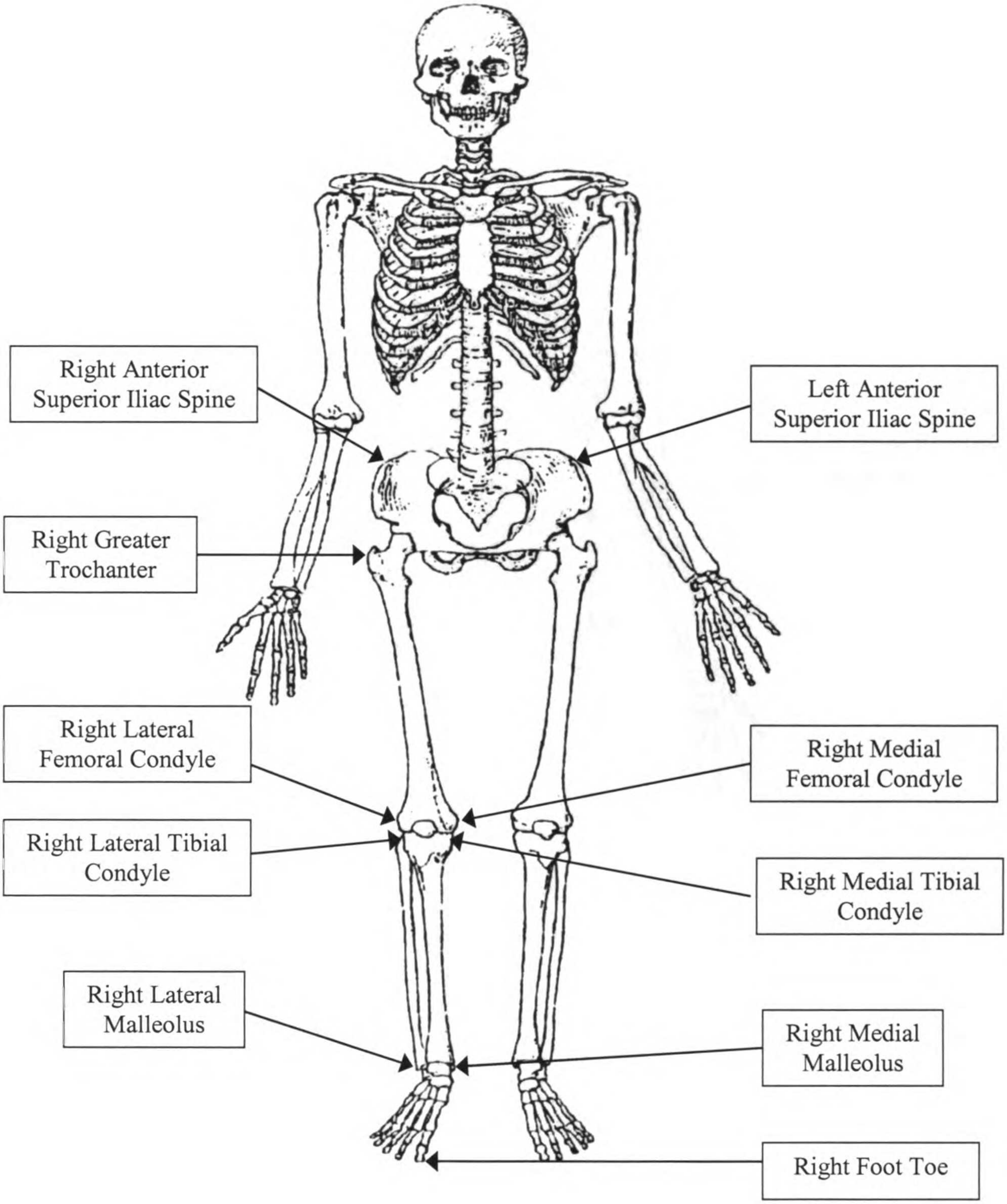

Figure 10: Anterior Anatomical Landmark Locations

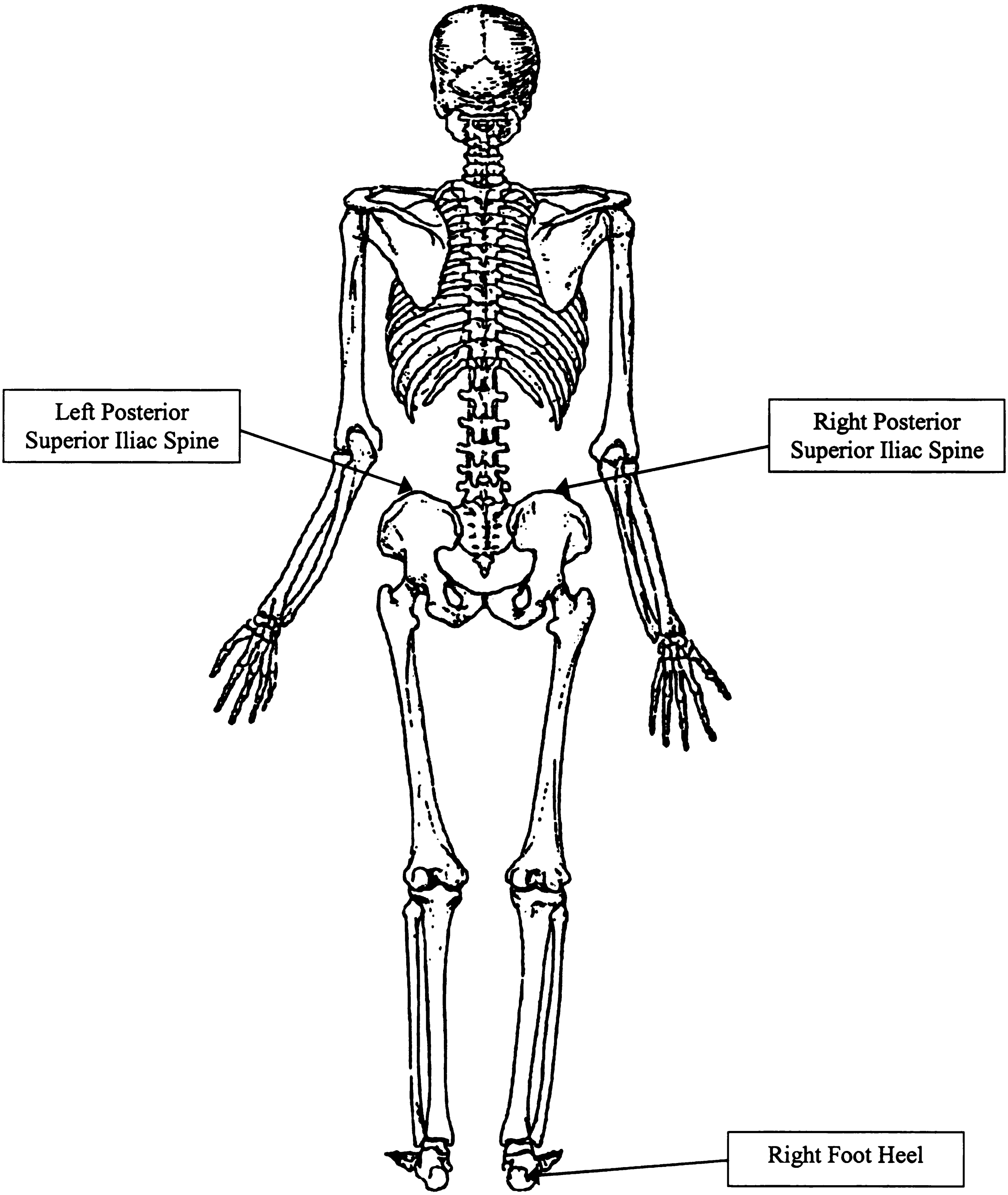

Figure 11: Posterior Anatomical Landmark Locations

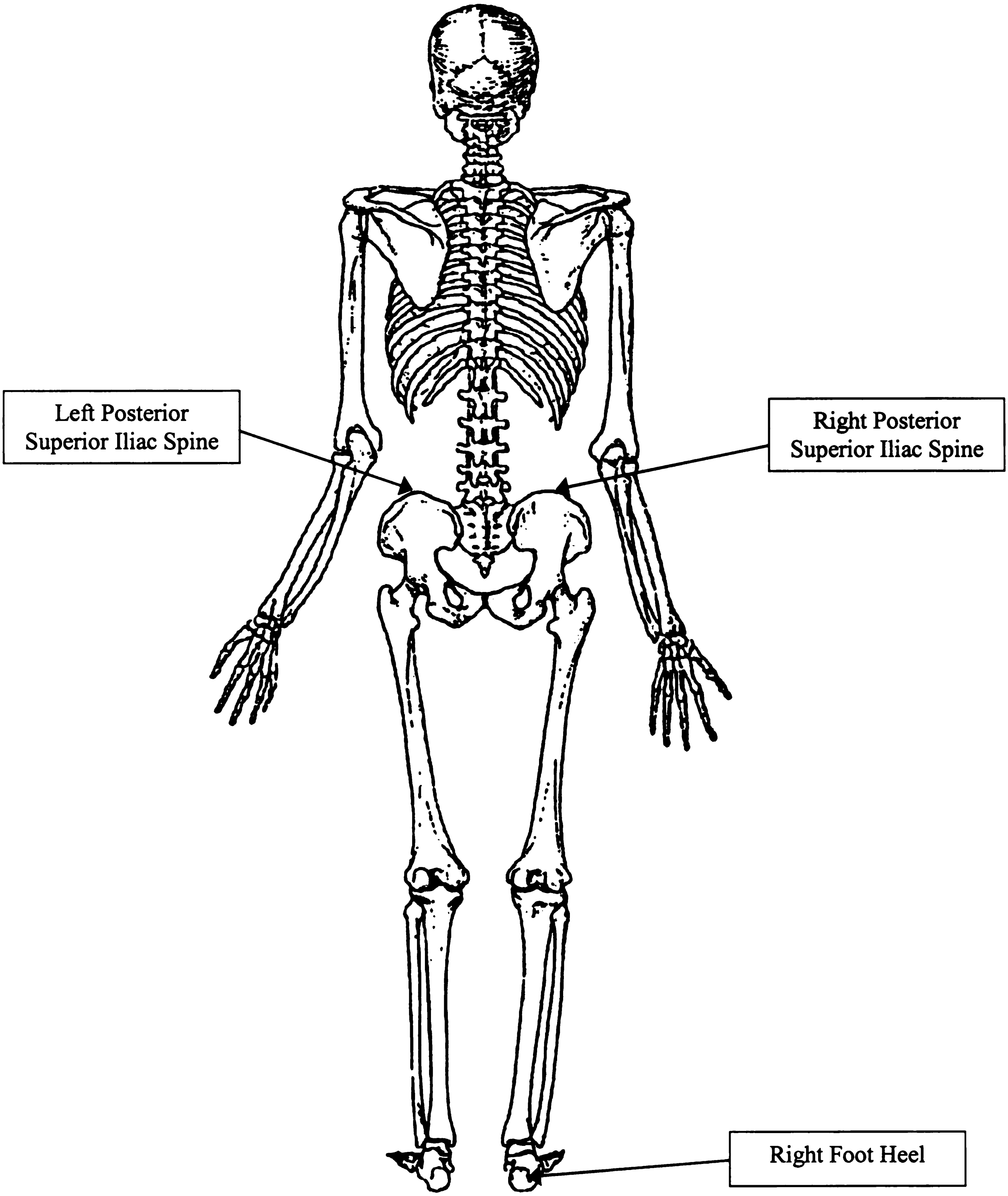

Figure 11: Posterior Anatomical Landmark Locations

Results:

Subject Characteristic Results

Thirty subjects participated in all portions of the study (questionnaire, and selected athletic tasks). Group subject averages of age, height, weight, current soccer participation and years of soccer experience are presented in Table 1. One-way ANOVA *P* values are presented for each variable. Statistically significant Adjusted *P* values (calculated using Tukey method) are shaded if Adjusted $P \leq 0.05$ for pairwise comparisons between the four groups. The four groups and respective abbreviations are as follows: Young Males (YM), Older Males (OM), Young Females (YF), and Older Females (OF).

Table 1: Subject Characteristic Results

Characteristic	Group & Gender (*n*)	Mean ± SD	Min.	Max.	GLM *P*	Adjusted *P* (Pairwise Comparisons) YM	OM	YF	OF
Age	YM (*n*=7)	24.1 ± 1.8	21	26	0.000[a]		0.00	0.95	0.00
	OM (*n*=7)	39.1 ± 4.6	33	45		0.00		0.00	0.52
	YF (*n*=7)	23.3 ± 1.1	22	25		0.95	0.00		0.00
	OF (*n*=9)	37.0 ± 3.4	32	44		0.00	0.52	0.00	
Height (cm)	YM (*n*=7)	175.7 ± 7.9	163.9	185.2	0.002[b]		1.00	0.05	0.01
	OM (*n*=7)	176.1 ± 6.6	171.5	190.5		1.00		0.04	0.01
	YF (*n*=7)	164.9 ± 6.0	154.3	174.0		0.05	0.04		0.95
	OF (*n*=9)	163.0 ± 8.3	150.3	174.5		0.01	0.01	0.95	
Weight (lbs)	YM (*n*=7)	165.9 ± 14.9	150.0	187.5	0.000[b]		0.55	0.04	0.02
	OM (*n*=7)	176.9 ± 15.2	152.0	191.0		0.55		0.00	0.00
	YF (*n*=7)	141.7 ± 11.1	129.0	161.0		0.04	0.00		1.0
	OF (*n*=9)	141.7 ± 18.9	122.0	170.0		0.02	0.00	1.0	
Current Soccer Participation (Hours Per Week)	YM (*n*=7)	6.4 ± 6.2	2.0	20.0	0.408				
	OM (*n*=7)	4.3 ± 1.3	2.0	6.0					
	YF (*n*=7)	3.6 ± 2.2	1.0	7.0					
	OF (*n*=9)	4.3 ± 3.0	1.5	10.0					
Years of Playing Soccer	YM (*n*=7)	10.4 ± 5.90	2.0	16.0	0.037		0.06	1.00	0.48
	OM (*n*=7)	21.4 ± 11.5	4.0	38.0		0.06		0.07	0.57
	YF (*n*=7)	10.6 ± 4.80	6.0	17.0		1.00	0.07		0.50
	OF (*n*=9)	17.2 ± 12.0	3.0	31.0		0.48	0.57	0.50	

[a] Statistically significant at the $P \leq 0.05$ level between genders
[b] Statistically significant at the $P \leq 0.05$ level between young and old

As expected, subject recruiting criteria yielded statistical differences between age between both the younger and older male and females. Additionally, statistical significance between gender, height and weight were also found, with males being taller and weighing statistically more than females. No difference in soccer playing exposure per week was found demonstrating that all groups played soccer on average about the same number of hours per week. Lastly, although differences existed within groups for years of soccer playing experience, no individual post hoc pairwise comparisons between groups were statistically significant.

Task Kinematics Results

Kinematic variable result descriptions and statistical findings are described below for each of the four athletic tasks: Drop Jump, Step Right, Cut Left, Soccer Turning and Soccer Heading. Figures 12 through 31 illustrate the group average joint angle range of motion for the ankle, knee and hip for the stance phase of each task. Figures 32 through 36 show the subject averages for all four tasks for each kinematic joint angle variable. Statistical findings between group kinematic variables are presented in Tables 2 through 5 complete with group means, *P* values from one-way ANOVA statistical analysis and Adjusted *P* values from post hoc analysis. Adjusted *P* values are shaded if post hoc pairwise comparisons were statistically significant at $P \leq 0.05$. Subject 3, an older male was excluded from the knee adduction/abduction variables due to incorrect knee anatomical landmark identification. Table 6 summarizes all significant statistical differences between groups for all tasks. In summary, the older males had the most significantly different kinematic variables compared with the other groups with 7 out of 10 total variations. Depending on the task, the older men differed independently from each of the other 3 groups in at least one kinematic variable. Besides the older males, no other group had significant differences between all the other groups. Three significant ankle and/or hip kinematic findings were between young males and young females, with no significant differences in any knee kinematics. No differences existed between the older females and both young gender groups in any of the selected tasks.

Drop Jump Task Result Summary (Figures 12-16, Table 2, 6)

As mentioned previously, the joint angles for the drop jump task were plotted to maximum knee flexion.

In the sagittal plane, as the subjects descended from the larger platform they landed on the force plate with their ankles in plantarflexion (Figure 12). At touchdown, there was a significant difference in ankle angle between groups (P = 0.046). Post-hoc comparisons demonstrated a trend toward less plantarflexion at touchdown in the young males (-26.4 ± 9.0°) compared to the young females (-37.2 ± 6.3°), (Adjusted *P* = 0.06). After touchdown, the rate of increase in dorsiflexion is linear until about 30% of stance. During the last 70% of stance, dorsiflexion increased much slower and peaked around 65 to 90% of stance. Older males reached max dorsiflexion around 67% stance; earlier than all other groups but significantly sooner than young females who reached max around 90% stance (Adjusted *P*=0.020). Maximum dorsiflexion/plantarflexion ankle angular velocity for the drop jump occurred in the first 10% of stance for all groups. The maximum ankle angular velocity differed in young females (1521.2±125.1) and young males (1163.1±214.1), (Adjusted *P*=0.014) with young females having significantly higher ankle joint angular velocities. Knee flexion at touchdown was approximately 22° for all groups and then linearly increased until about 50% stance (Figure 13). During the second 50% of stance, knee flexion increased at a slower rate until maximum flexion at 100% stance. Although graphically it appears that the older women had reduced maximum knee flexion angles (Figure 13), there were no significant differences between groups. Maximum knee flexion joint angular velocity was similar for all groups at approximately 800°/s. Maximum knee flexion angular velocity occurred on average sooner for the young females at 16% stance than all other groups, which achieved peak knee flexion angular velocity at approximately 25% of the stance phase. However, this difference was not statistically significant.

In the frontal plane, subjects tended to land in knee abduction (Figure 14). Although not statistically significant, the young females on average landed in the least knee abduction around -4.5°. All other groups averaged -8° to -9.5° abduction at landing. As the subjects continued into knee flexion, all groups transitioned to slight adduction and then returned to approximately neutral at maximum knee flexion. Knee adduction/abduction angular velocity was highest in the young males at 327.7±88.6°/s, compared to all other groups which had similar velocities ({OM} 266.6±76.2°/s, {YF} 247.1±87.9°/s, {OF} 280.9±67.2°/s). However, no statistical significance was found (P = 0.229).

In the transverse plane of the knee, the young females and older males tended to land in knee external rotation, while the older females and young males landed in internal rotation (Figure 15). After landing, the subjects all transitioned to internal rotation in about the first 20% of stance and then remained in internal rotation until maximum knee flexion. Internal/External max joint angular velocity was very similar between all groups.

For the hip, all subjects landed in 25-40° of hip flexion with flexion increasing until maximum around 95% stance (Figure 16). Young females had significantly higher hip flexion at touchdown (39.1±13.2°) compared with young males (24.9±8.0°), (Adjusted P=0.033). There were no significant differences in maximum hip flexion or hip flexion velocity between groups.

Step Right, Cut Left Task Result Summary (Figures 17-21, Table 3, 6)

As subjects descended from the smaller platform, all groups landed in ankle plantarflexion (Figure 17). Significant differences were found for ankle plantarflexion at touchdown between young males and young females, with young females touching down in more plantarflexion (-37.7±5.5°) than young males (-25.6±6.4°), (Adjusted P=0.004). After touchdown, dorsiflexion peaked at approximately 27° while the subjects absorbed the landing. Maximum dorsiflexion then transitions to plantarflexion around 55% stance as the subject transitions to push off the force plate. Ankle joint angular velocity was higher in the females than the males but not statistically significant, with young females having the highest ankle velocities (972.5±64.5°/s). Ankle joint angular velocity peaked around 7 to 8% of stance for all groups during the transition at landing from plantarflexion to dorsiflexion.

In the sagittal plane of the knee, all subjects landed in slight knee flexion at touchdown (Figure 18). Knee flexion continued to increase after touchdown peaking around 60° at 45% stance. After peak knee flexion, the knee began to decrease flexion as the subject toed off the platform. Maximum knee flexion angular joint velocity occurred around 20% of stance for all groups except the young females who reached peak knee flexion angular velocity at approximately 14% of stance. There were no significant differences between groups for any of the sagittal plane knee kinematic dependent variables.

Frontal plane knee abduction between groups varied on average during the step right, cut left task. All subjects on average tended to touch down in knee abduction (Figure 19). After landing, abduction increased and then decreased toward knee adduction around 50% stance. The young females on average peaked in 5.5° of knee adduction, while all other groups peaked in knee abduction. After peak around 50% stance, the knee returned to abduction as the subject toed off from the force plate. Maximum knee adduction/abduction angular velocity was similar for all groups and reached maximum around 30% stance as the subjects absorbed the landing.

Internal rotation in the transverse plane of the knee also varied between groups. Young males tended to touch down in internal rotation, while the other three groups landed in knee external rotation at touchdown (Figure 20). After touchdown, all subjects transitioned to more knee internal rotation as they landed on the force platform and then returned to external rotation as they toed off the force plate. Maximum internal rotation occurred at approximately 50% of the stance phase. Max knee internal/external angular velocity peaked around 15% of stance in all groups as the subjects absorbed the landing from touchdown to greater internal rotation.

At the hip, all subjects landed in hip flexion with a trend towards the men landing on average in less hip flexion than the women (Figure 21), ($P = 0.138$). After touchdown, subjects remained in slight hip flexion and then quickly transitioned to maximum hip flexion from 20% to approximately 40% stance. There was a trend towards greater maximum hip flexion in females compared to males ($P = 0.116$). After maximum hip flexion, the subjects began to extend as they begin to transition their body weight returning to neutral hip joint angles at toe off. Maximum hip flexion angular velocity was reached around 20% stance as the subjects slowed their hip motion from touchdown.

Soccer Turning Task Result Summary (Figures 22-26, Table 4, 6)

All groups landed in ankle plantarflexion with the older males landing in the least plantarflexion during touchdown on the force plate (Figure 22). After touchdown, subjects transition from plantarflexion toward dorsiflexion linearly until about 20% of stance. From 20 to 80% of stance ankle angle remains relatively constant around neutral as the subject changes direction and then linearly decreases back to plantarflexion from 80 to 100% of stance. Around 75% of stance, the subjects begin to transition to back to plantarflexion quickly and then slightly dorsiflex as they toe off from the force plate. Ankle joint angular velocity was higher in the females than the males but not statistically different, with young females having the highest ankle velocities (595.8±208.7°/s). Ankle joint angular velocity peaks around 4 to 18% of stance for all groups during the transition at touchdown landing from plantarflexion to dorsiflexion.

In the sagittal plane of the knee, all subjects landed in slight knee flexion (approx. 20°) at touchdown (Figure 23). Knee flexion continued to increase after touchdown peaking around 30° of stance. Maximum knee flexion was significantly higher in the older males compared with the older females (Adjusted P=0.039). After peak knee flexion, the knee began to decrease flexion gradually until about 75% of stance where it rapidly decreased from 80 to 100% of stance as the subject toed off the force plate. Maximum knee flexion angular joint velocity reached maximum around 6% of stance and was smaller for the young males (405.7±96.3°/s) compared with all other groups ({OM}521.4±99.6 °/s, {YF}481.5±95.0°/s, {OF}437.1±77.1°/s) although not statistically significant (*P*=0.103).

In the frontal plane, all subjects on average tended to touch down in knee abduction (Figure 24). After touchdown, knee abduction increased for the older males and young females and slightly decreased in the young males and older females. Knee abduction on average reached maximum in the females around 12% of stance and later, althought not statistically significant, in the males at 22% of stance. The young females on average peaked in slight knee adduction, while all other groups peaked in knee abduction. After peaking, the knee returned to more abduction than touchdown until about 75 to 85% of stance. After reaching maximum abduction, the subjects abduction decreased as the subject toed off of the force plate. Maximum knee adduction/abduction angular velocity was similar for all groups.

Internal rotation in the transverse plane of the knee also varied between groups. The older males touched down on average in external rotation (-3.5°) while all other groups touched down in internal rotation (Figure 25). At touchdown, knee internal/external rotation significantly differed between older males and younger males (Adjusted *P*=0.016), with younger males in more internal (+) knee rotation (13.1±16.2°) than the older males who on average landed in external (-) knee rotation (-3.5±9.4°). After touchdown, all subjects transitioned to maximum internal rotation around 15% of stance. Peak knee internal rotation significantly differed between older and younger males, with younger males (25.8±1.6°) having more internal rotation than the older males (10.8±6.1°), (Adjusted *P*=0.012). After peaking in internal rotation, subjects gradually increased external rotation from 20% until 95% of stance reaching the minimum around 95% of stance. Max knee internal/external angular velocity was similar for all groups and peaked from 6 to 16% of stance as the subjects slowed themselves from touchdown to greater internal rotation and switched directions with the soccer ball.

For the hip, all subjects landed in hip flexion with the young males tending to land in less hip flexion (30°) than all other groups (38°) but not statistically different. (Figure 26) After touchdown, subjects remained in slight hip flexion and then transitioned to maximum hip flexion from 37% to approximately 56% stance. After the initial flexion increase, subjects remained in higher hip flexion until about 70% of stance when the subjects began to rapidly extend (stand upright) after the subjects changed direction with the soccer ball. There were no significant differences in hip angular velocity between groups.

Soccer Heading Task Result Summary (Figures 27-31, Table 5, 6)

As mentioned previously, the joint angles for the soccer heading task were plotted to maximum knee flexion. In the sagittal plane, as the subjects descended from their heading jump they landed with their ankles in plantarflexion (Figure 27). There were no significant differences in any ankle joint angle dependent variables. After touchdown, the rate of increase in dorsiflexion is linear until about 40% of stance. During the last 60% of stance, dorsiflexion increased much slower and peaked earlier for the males than the females, with the older males peaking the earliest (65% of stance) and the young females peaking last (83% of stance), (not significantly different). There was a trend toward a significant difference in maximum dorsiflexion/plantarflexion ankle angular velocity ($P = 0.115$), with greater values for the young males and lowest for the older males.

Knee flexion at touchdown was about 21° for the male groups and about 17° for the females groups. Flexion gradually increased after touchdown until maximum knee flexion for all groups (Figure 28). Maximum angular knee flexion velocity was lower for older males compared with all other groups (Adjusted P=0.016{YM}, 0.011{YF}, 0.005{OF}).

In the frontal plane of the knee, subjects tended to land in knee abduction (Figure 29). There were no significant differences between groups for any of the frontal plane knee angle variables. The young females on average landed in the least knee abduction around -4.5°. All other groups averaged -7° to -9.5° abduction at landing. As the subjects continued into knee flexion, the male and older female group's knee abduction decreased and was the least around 70% stance. After touchdown, the young females reached the least abduction (slight adduction) earlier than the other groups around 64% stance. After peaking, all groups returned to abduction angles that were slightly higher than at touchdown. Knee adduction/abduction angular velocity was similar for all groups (~200°/s).

In the transverse plane of the knee, the young males tended to land in internal rotation while the other three groups landed in external rotation (Figure 30). After landing, the subjects all transitioned to increased internal rotation then remained in elevated internal rotation until maximum knee flexion. Internal/External max joint angular velocity was very similar between all groups and the percent stance of occurrence was later on average for the younger males but not statistically different from the other groups.

For the hip, all subjects landed in various amounts of hip flexion with flexion increasing until maximum around 85% stance (Figure 31). Older females had significantly higher hip flexion at touchdown compared with older males (Adjusted P=0.027). Also, the older females maximum flexion values were significantly higher than the older males (Adjusted P=0.025). Maximum hip joint angular velocity reached maximum around 50% stance and tended to be lower in the older males and younger females.

Task Comparison Result Summary (Figures 32-36)

Average joint angles for all subjects were plotted comparing all tasks in order to determine which task places the knee at the most risk for injury. The soccer heading and drop jump tasks were plotted to 50% stance (maximum knee flexion) and the soccer turning and step right, cut left tasks were plotted to 100 % stance for direct comparison.

Ankle plantarflexion values were similar for the drop jump, heading and step right, cut left tasks at touchdown (Figure 32). These three tasks also reach similar maximum ankle dorsiflexion values (about 25°). The soccer turning task had the least average peak ankle dorsi/plantarflexion and on average the subject's ankles remained in plantarflexion during the entire stance phase.

Knee ad/abduction values for the tasks are also similar for the drop jump, heading and step right, cut left tasks at touchdown (about -8°), (Figure 33). The soccer heading and step right, cut left tasks have similar minimum knee abduction values (about -2°). The drop jump was the only task on average that placed the knee in adduction at 1°. The soccer turning task placed the knee into the least adduction overall and toward the end of the stance phase, placed the knee into the most abduction (or valgus) of all tasks.

For knee internal/external rotation, the soccer turning task placed the knee into maximum internal rotation earlier in stance than the other three tasks (about 20% stance), (Figure 34). The soccer heading task placed the knee into internal rotation at about 35% stance. The drop jump subjects peaked in internal rotation at the same time as peak knee flexion (around 50% stance). Also, the step right, cut left task placed the knee into the most internal rotation of all tasks at 50% stance. Both the soccer turning task and the step right, cut left task placed the knee into external rotation during the last 10-20% of the stance phase. The knee remained in internal rotation during both the drop jump and the heading tasks. The total internal/external range of motion at the knee during the stance phase of each task was also the greatest for the soccer turning task.

Knee flexion results for all subjects were as expected with the drop jump having the greatest values, followed by the soccer heading task, the step right, cut left task and lastly the soccer turning task (Figure 35). Similar to the knee flexion averages, the hip flexion averages were also the highest for the drop jump and soccer heading tasks (Figure 36). The drop jump had the greatest hip flexion at about 70° of knee flexion. The soccer heading task peak hip flexion was about 45°. The step right, cut left peaked at about 40° of hip flexion, while the soccer turning task peaked the latest (about 75% stance) at a little over 40° of hip flexion. After peak hip flexion, the step right, cut left task, the subjects returned to neutral hip position sooner than the soccer turning task.

Drop Jump Task Results

Table 2: Drop Jump Task Kinematics

Drop Jump Variable	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons) YM	OM	YF	OF
ANKLE DORSI / PLANTAR FLEXION							
Touchdown Dorsi (+) / Plantar (-) Flexion (*Deg*)	YM (*n*=7)	-26.4 ± 9.0	0.046		0.991	0.060	0.347
	OM (*n*=7)	-27.6 ± 8.2		0.991		0.111	0.525
	YF (*n*=7)	-37.2 ± 6.3		0.060	0.111		0.678
	OF (*n*=9)	-32.9 ± 6.8		0.347	0.525	0.678	
Maximum Dorsi (+) / Plantar (-) Flexion (*Deg*)	YM (*n*=7)	28.1 ± 6.5	0.790				
	OM (*n*=7)	27.3 ± 6.9					
	YF (*n*=7)	24.8 ± 6.9					
	OF (*n*=9)	26.5 ± 4.9					
% Stance at Maximum Dorsi/Plantar Flexion	YM (*n*=7)	83.6 ± 11.1	0.028		0.124	0.834	0.986
	OM (*n*=7)	66.7 ± 20.1		0.124		0.020	0.181
	YF (*n*=7)	89.8 ± 7.8		0.834	0.020		0.609
	OF (*n*=9)	81.2 ± 13.2		0.986	0.181	0.609	
Maximum Ankle Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	1163.1 ± 214.1	0.010		0.912	0.014	0.091
	OM (*n*=7)	1234.4 ± 264.3		0.912		0.061	0.315
	YF (*n*=7)	1521.2 ± 125.1		0.014	0.061		0.722
	OF (*n*=9)	1414.0 ± 186.9		0.091	0.315	0.722	
% Stance at Maximum Ankle Joint Angular Velocity	YM (*n*=7)	9.6 ± 4.0	0.369				
	OM (*n*=7)	10.2 ± 4.3					
	YF (*n*=7)	7.1 ± 3.7					
	OF (*n*=9)	10.4 ± 3.8					
KNEE FLEXION / EXTENSION							
Touchdown Knee Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	22.0 ± 3.9	0.947				
	OM (*n*=7)	22.6 ± 10.1					
	YF (*n*=7)	23.6 ± 6.0					
	OF (*n*=9)	22.7 ± 5.6					
Maximum Knee Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	97.2 ± 21.3	0.468				
	OM (*n*=7)	102.4 ± 22.4					
	YF (*n*=7)	101.2 ± 20.5					
	OF (*n*=9)	89.1 ± 8.5					
% Stance at Maximum Knee Flexion	YM (*n*=7)	100	N/A				
	OM (*n*=7)	100					
	YF (*n*=7)	100					
	OF (*n*=9)	100					
Maximum Knee Flexion/Extension Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	843.5 ± 112.2	0.555				
	OM (*n*=7)	778.9 ± 114.5					
	YF (*n*=7)	786.5 ± 69.7					
	OF (*n*=9)	787.5 ± 77.9					

Drop Jump Variable (*cont.*)	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons)			
				YM	**OM**	**YF**	**OF**
% Stance at Maximum Knee Flexion/Extension Joint Angular Velocity	YM (*n*=7)	24.8 ± 10.8	0.137				
	OM (*n*=7)	27.4 ± 8.8					
	YF (*n*=7)	15.9 ± 6.8					
	OF (*n*=9)	25.4 ± 10.9					
KNEE ADDUCTION / ABDUCTION							
Touchdown Knee Adduction (+) / Abduction (-) (*Deg*)	YM (*n*=7)	-9.1 ± 5.5	0.484				
	OM (*n*=6)	-8.0 ± 7.4					
	YF (*n*=7)	-4.8 ± 8.0					
	OF (*n*=9)	-9.5 ± 4.6					
Maximum Knee Adduction (+) / Abduction (-) (*Deg*)	YM (*n*=7)	2.4 ± 6.7	0.725				
	OM (*n*=6)	4.1 ± 8.5					
	YF (*n*=7)	6.7 ± 8.5					
	OF (*n*=9)	3.1 ± 6.9					
% Stance at Maximum Knee Adduction (+) / Abduction (-)	YM (*n*=7)	73.4 ± 11.5	0.413				
	OM (*n*=6)	65.7 ± 11.3					
	YF (*n*=7)	60.6 ± 19.2					
	OF (*n*=9)	65.2 ± 13.1					
Maximum Knee Adduction / Abduction Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	327.7 ± 88.6	0.229				
	OM (*n*=6)	266.6 ± 76.2					
	YF (*n*=7)	247.1 ± 87.9					
	OF (*n*=9)	280.9 ± 67.2					
% Stance at Maximum Knee Adduction / Abduction Joint Angular Velocity	YM (*n*=7)	49.7 ± 23.3	0.188				
	OM (*n*=6)	35.6 ± 20.1					
	YF (*n*=7)	33.5 ± 14.3					
	OF (*n*=9)	50.7 ± 16.7					
KNEE INTERNAL / EXTERNAL ROTATION							
Touchdown Knee Internal (+) / External (-) Rotation (*Deg*)	YM (*n*=7)	6.6 ± 13.5	0.160				
	OM (*n*=7)	-6.6 ± 11.1					
	YF (*n*=7)	-1.5 ± 10.0					
	OF (*n*=9)	0.2 ± 7.7					
Maximum Knee Internal (+) / External (-) Rotation (*Deg*)	YM (*n*=7)	24.9 ± 12.6	0.083				
	OM (*n*=7)	11.3 ± 7.9					
	YF (*n*=7)	13.9 ± 11.3					
	OF (*n*=9)	17.6 ± 7.5					
% Stance at Maximum Knee Internal (+) / External (-) Rotation	YM (*n*=7)	74.0 ± 27.1	0.604				
	OM (*n*=7)	56.4 ± 28.0					
	YF (*n*=7)	57.4 ± 28.0					
	OF (*n*=9)	58.9 ± 28.1					

Drop Jump Variable (*cont.*)	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons) YM	OM	YF	OF
Maximum Knee Internal / External Rotation Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	421.4 ± 140.3	0.190				
	OM (*n*=7)	387.2 ± 118.9					
	YF (*n*=7)	393.1 ± 42.2					
	OF (*n*=9)	511.5 ± 159.4					
% Stance at Maximum Knee Internal / External Rotation Joint Angular Velocity	YM (*n*=7)	7.1 ± 5.8	0.910				
	OM (*n*=7)	6.7 ± 2.9					
	YF (*n*=7)	8.8 ± 9.0					
	OF (*n*=9)	8.8 ± 8.8					
HIP FLEXION / EXTENSION							
Touchdown Hip Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	24.9 ± 8.0	0.033		0.925	0.043	0.164
	OM (*n*=7)	28.1 ± 9.0		0.925		0.151	0.456
	YF (*n*=7)	39.1 ± 13.2		0.043	0.151		0.838
	OF (*n*=9)	35.1 ± 6.9		0.164	0.456	0.838	
Maximum Hip Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	62.0 ± 19.9	0.175				
	OM (*n*=7)	73.0 ± 18.9					
	YF (*n*=7)	86.9 ± 27.1					
	OF (*n*=9)	74.6 ± 14.5					
% Stance at Maximum Hip Flexion	YM (*n*=7)	92.0 ± 6.5	0.425				
	OM (*n*=7)	93.6 ± 10.3					
	YF (*n*=7)	94.2 ± 6.4					
	OF (*n*=9)	97.6 ± 3.3					
Maximum Hip Flexion/Extension Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	506.7 ± 188.0	0.800				
	OM (*n*=7)	545.9 ± 111.5					
	YF (*n*=7)	578.6 ± 132.1					
	OF (*n*=9)	557.4 ± 116.8					
% Stance at Maximum Hip Flexion/Extension Joint Angular Velocity	YM (*n*=7)	28.2 ± 8.7	0.328				
	OM (*n*=7)	29.1 ± 7.6					
	YF (*n*=7)	32.9 ± 14.4					
	OF (*n*=9)	37.0 ± 9.7					

Drop Jump Joint Angle Kinematics Figures

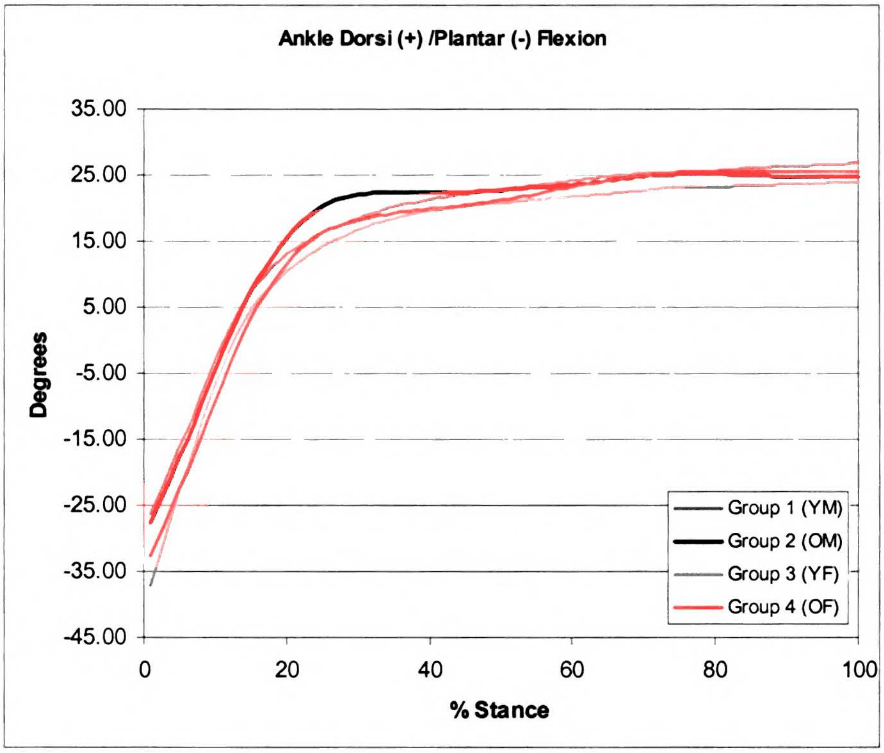

Figure 12: Drop Jump Sagittal Plane Group Ankle Joint Angles

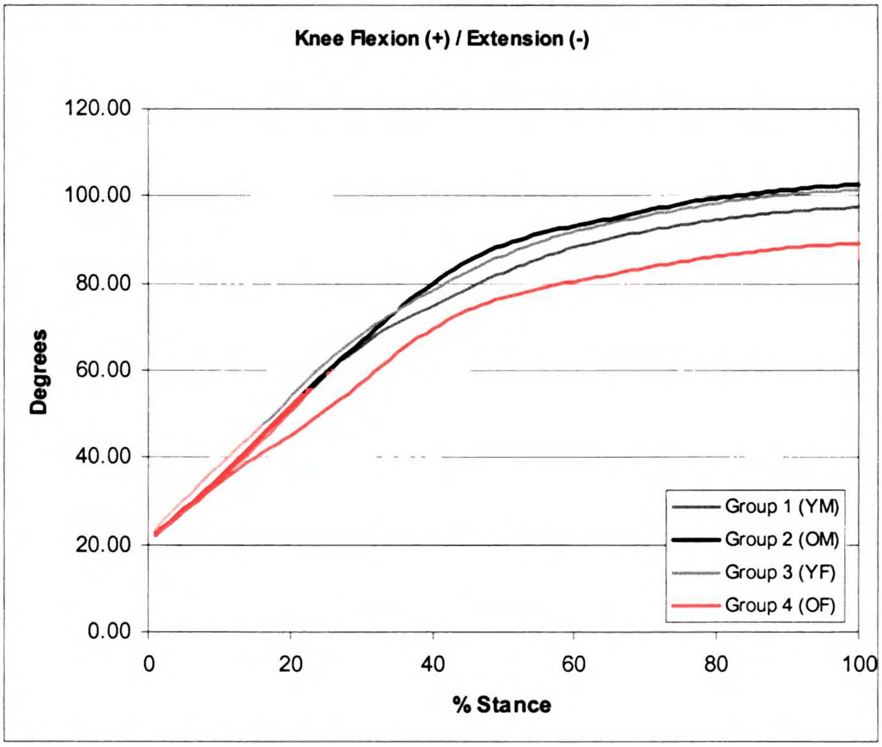

Figure 13: Drop Jump Sagittal Plane Group Knee Joint Angles

Drop Jump Joint Angle Kinematics Figures (*cont.*)

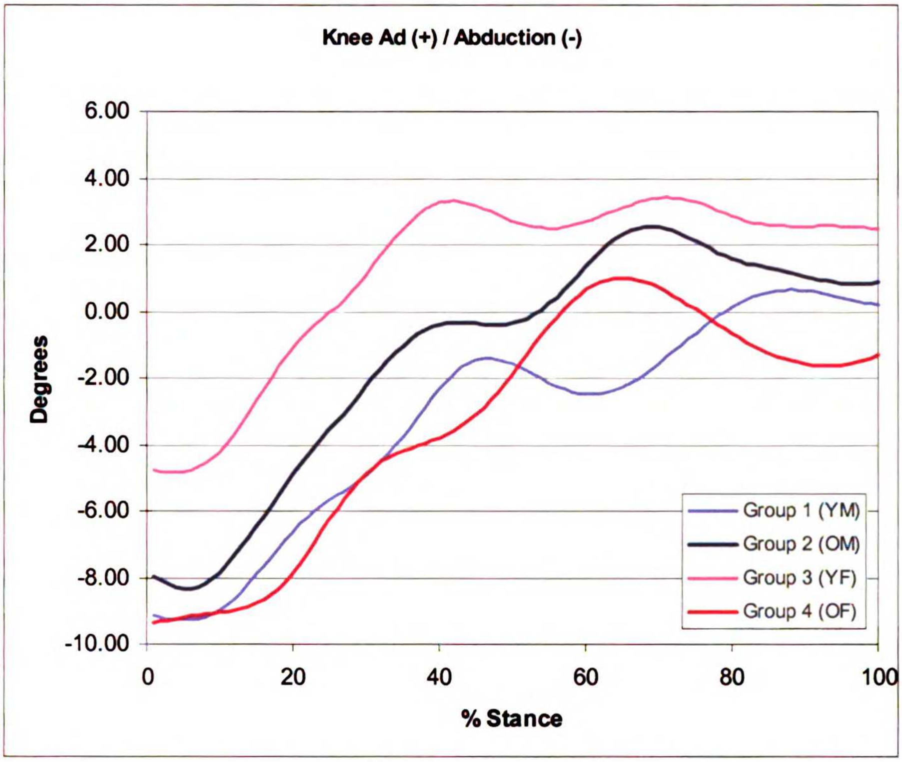

Figure 14: Drop Jump Frontal Plane Group Knee Joint Angles

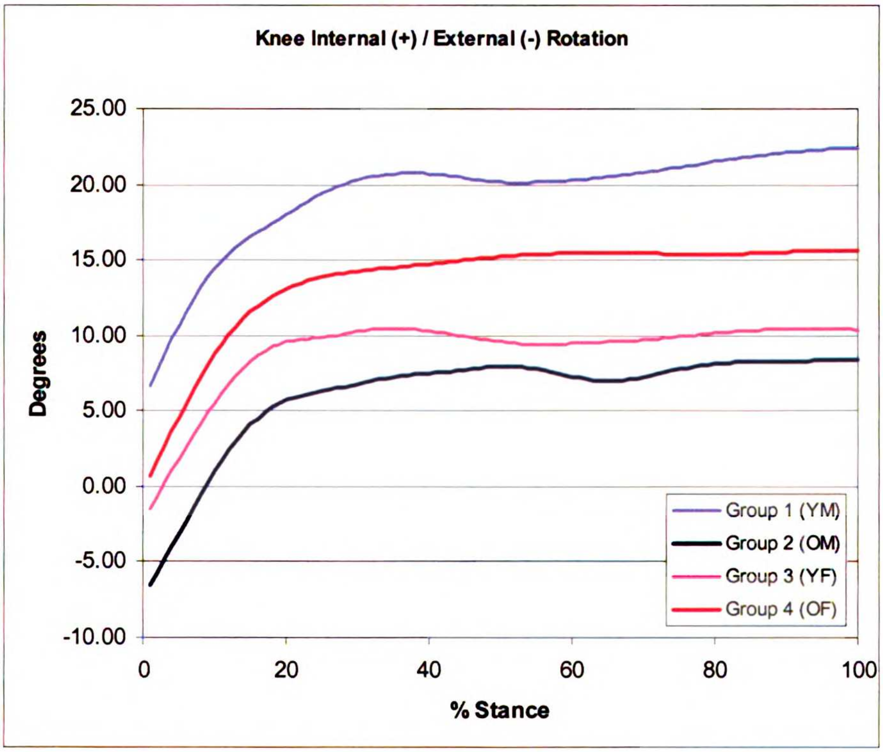

Figure 15: Drop Jump Transverse Plane Group Knee Joint Angles

Drop Jump Joint Angle Kinematics Figures (*cont.*)

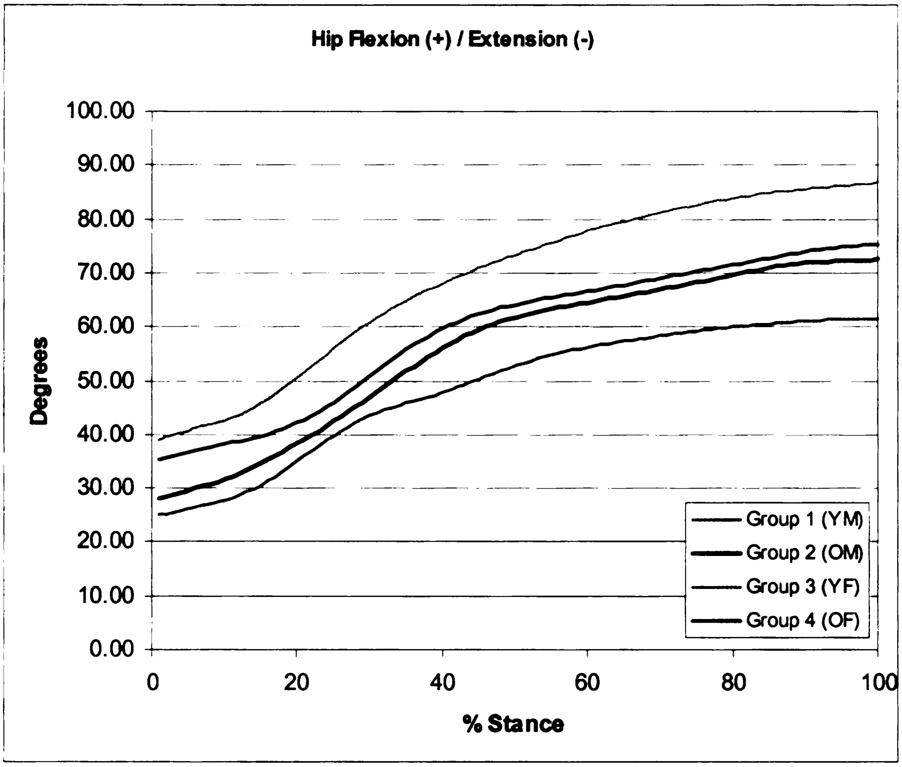

Figure 16: Drop Jump Sagittal Plane Group Hip Joint Angles

Step Right, Cut Left Task Results

Table 3: Step Right, Cut Left Task Kinematics

Step Right, Cut Left Variable	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons) YM	OM	YF	OF
ANKLE DORSI / PLANTAR FLEXION							
Touchdown Dorsi (+) / Plantar (-) Flexion (*Deg*)	YM (*n*=7)	-25.6 ± 6.4	0.006		0.705	0.004	0.204
	OM (*n*=7)	-27.7 ± 4.4		0.705		0.063	0.867
	YF (*n*=7)	-37.7 ± 5.5		0.004	0.063		0.160
	OF (*n*=9)	-32.8 ± 5.8		0.204	0.867	0.160	
Maximum Dorsi (+) / Plantar (-) Flexion (*Deg*)	YM (*n*=7)	30.5 ± 6.1	0.504				
	OM (*n*=7)	27.9 ± 4.7					
	YF (*n*=7)	27.4 ± 5.6					
	OF (*n*=9)	29.9 ± 7.6					
% Stance at Maximum Dorsi/Plantar Flexion	YM (*n*=7)	52.4 ± 3.4	0.740				
	OM (*n*=7)	55.5 ± 8.5					
	YF (*n*=7)	55.3 ± 6.3					
	OF (*n*=9)	55.6 ± 7.1					
Maximum Ankle Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	842.8 ± 101.0	0.187				
	OM (*n*=7)	842.7 ± 139.5					
	YF (*n*=7)	972.5 ± 64.5					
	OF (*n*=9)	939.8 ± 101.3					
% Stance at Maximum Ankle Joint Angular Velocity	YM (*n*=7)	8.4 ± 1.5	0.433				
	OM (*n*=7)	8.0 ± 1.2					
	YF (*n*=7)	7.0 ± 2.2					
	OF (*n*=9)	7.3 ± 1.6					
KNEE FLEXION / EXTENSION							
Touchdown Knee Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	18.5 ± 5.0	0.258				
	OM (*n*=7)	16.1 ± 5.1					
	YF (*n*=7)	18.0 ± 5.2					
	OF (*n*=9)	13.1 ± 6.0					
Maximum Knee Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	59.7 ± 6.9	0.606				
	OM (*n*=7)	58.0 ± 9.1					
	YF (*n*=7)	62.7 ± 8.2					
	OF (*n*=9)	61.4 ± 6.0					
% Stance at Maximum Knee Flexion	YM (*n*=7)	47.1 ± 2.5	0.920				
	OM (*n*=7)	46.8 ± 3.4					
	YF (*n*=7)	47.0 ± 4.1					
	OF (*n*=9)	45.5 ± 7.0					
Maximum Knee Flexion/Extension Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	469.0 ± 101.1	0.775				
	OM (*n*=7)	464.9 ± 83.6					
	YF (*n*=7)	499.3 ± 41.0					
	OF (*n*=9)	529.0 ± 112.1					

Step Right, Cut Left Variable (*cont.*)	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons) YM	OM	YF	OF
% Stance at Maximum Knee Flexion/Extension Joint Angular Velocity	YM (*n*=7)	19.2 ± 4.7	0.179				
	OM (*n*=7)	20.0 ± 6.4					
	YF (*n*=7)	20.0 ± 9.2					
	OF (*n*=9)	13.7 ± 6.3					
KNEE ADDUCTION / ABDUCTION							
Touchdown Knee Adduction (+) / Abduction (-) (*Deg*)	YM (*n*=7)	-9.6 ± 6.1	0.639				
	OM (*n*=6)	-8.9 ± 6.9					
	YF (*n*=7)	-5.4 ± 9.1					
	OF (*n*=9)	-9.2 ± 5.3					
Maximum Knee Adduction (+) / Abduction (-) (*Deg)*	YM (*n*=7)	-1.9 ± 7.1	0.308				
	OM (*n*=6)	-0.3 ± 8.6					
	YF (*n*=7)	5.5 ± 10.8					
	OF (*n*=9)	-1.6 ± 6.4					
% Stance at Maximum Knee Adduction (+) / Abduction (-)	YM (*n*=7)	49.0 ± 13.0	0.853				
	OM (*n*=6)	54.4 ± 23.4					
	YF (*n*=7)	50.6 ± 7.9					
	OF (*n*=9)	53.1 ± 8.8					
Maximum Knee Adduction / Abduction Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	204.0 ± 28.7	0.756				
	OM (*n*=6)	206.3 ± 61.4					
	YF (*n*=7)	214.6 ± 40.8					
	OF (*n*=9)	212.3 ± 51.2					
% Stance at Maximum Knee Adduction / Abduction Joint Angular Velocity	YM (*n*=7)	26.3 ± 3,8	0.485				
	OM (*n*=6)	37.7 ± 30.0					
	YF (*n*=7)	26.6 ± 10.2					
	OF (*n*=9)	33.43 ± 12.6					
KNEE INTERNAL / EXTERNAL ROTATION							
Touchdown Knee Internal (+) / External (-) Rotation (*Deg*)	YM (*n*=7)	4.1 ± 17.3	0.204				
	OM (*n*=7)	-8.7 ± 9.3					
	YF (*n*=7)	-4.8 ± 13.6					
	OF (*n*=9)	-4.6 ± 9.4					
Maximum Knee Internal (+) / External (-) Rotation (*Deg)*	YM (*n*=7)	28.1 ± 13.5	0.065				
	OM (*n*=7)	13.8 ± 7.0					
	YF (*n*=7)	16.9 ± 11.0					
	OF (*n*=9)	19.4 ± 7.9					
% Stance at Maximum Knee Internal (+) / External (-) Rotation	YM (*n*=7)	47.4 ± 6.0	0.777				
	OM (*n*=7)	45.6 ± 10.7					
	YF (*n*=7)	52.1 ± 13.1					
	OF (*n*=9)	50.7 ± 9.6					

Step Right, Cut Left Variable (*cont.*)	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons) YM	OM	YF	OF
Maximum Knee Internal / External Rotation Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	331.5 ± 54.6	0.982				
	OM (*n*=7)	306.5 ± 81.9					
	YF (*n*=7)	319.7 ± 73.2					
	OF (*n*=9)	358.4 ± 141.0					
% Stance at Maximum Knee Internal / External Rotation Joint Angular Velocity	YM (*n*=7)	17.4 ± 5.4	0.880				
	OM (*n*=7)	13.7 ± 5.6					
	YF (*n*=7)	15.9 ± 10.7					
	OF (*n*=9)	14.7 ± 10.7					
HIP FLEXION / EXTENSION							
Touchdown Hip Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	26.8 ± 10.2	0.138				
	OM (*n*=7)	26.9 ± 9.8					
	YF (*n*=7)	37.1 ± 10.8					
	OF (*n*=9)	33.0 ± 8.8					
Maximum Hip Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	35.9 ± 12.4	0.116				
	OM (*n*=7)	39.0 ± 11.3					
	YF (*n*=7)	51.3 ± 17.7					
	OF (*n*=9)	47.4 ± 9.7					
% Stance at Maximum Hip Flexion	YM (*n*=7)	36.4 ± 10.6	0.615				
	OM (*n*=7)	41.9 ± 9.6					
	YF (*n*=7)	37.9 ± 7.2					
	OF (*n*=9)	35.9 ± 9.6					
Maximum Hip Flexion/Extension Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	226.6 ± 124.2	0.596				
	OM (*n*=7)	283.4 ± 128.9					
	YF (*n*=7)	279.9 ± 105.1					
	OF (*n*=9)	293.1 ± 86.8					
% Stance at Maximum Hip Flexion/Extension Joint Angular Velocity	YM (*n*=7)	27.6 ± 6.7	0.320				
	OM (*n*=7)	22.3 ± 2.9					
	YF (*n*=7)	21.5 ± 9.7					
	OF (*n*=9)	21.6 ± 6.8					

Step Right, Cut Left Joint Angle Kinematics Figures

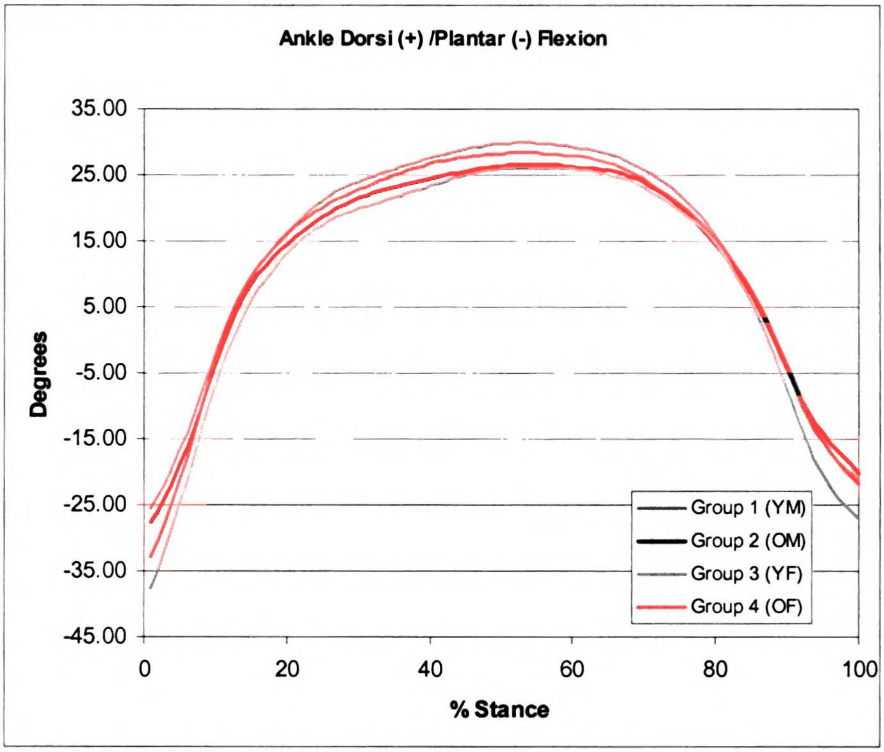

Figure 17: Step Right, Cut Left Sagittal Plane Group Ankle Joint Angles

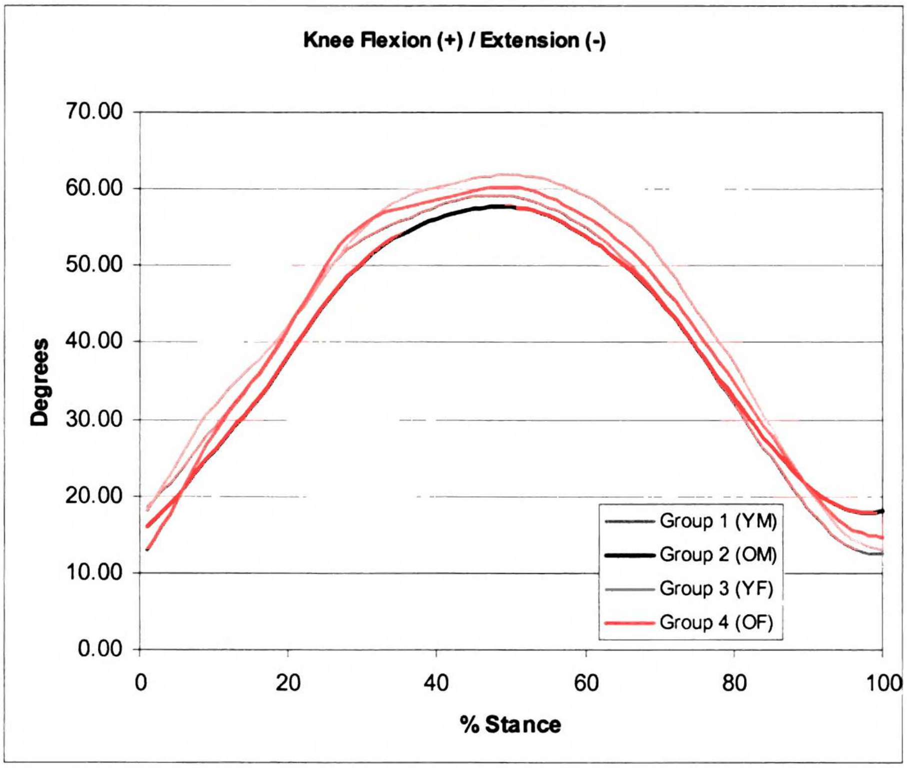

Figure 18: Step Right, Cut Left Sagittal Plane Group Knee Joint Angles

Step Right, Cut Left Joint Angle Kinematics Figures (*cont.*)

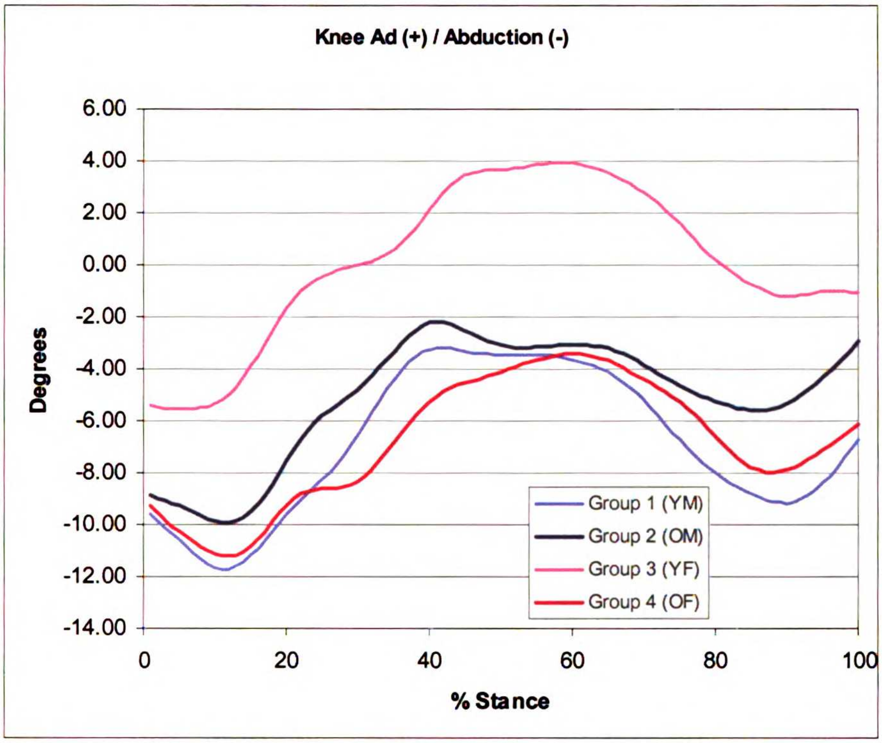

Figure 19: Step Right, Cut Left Frontal Plane Group Knee Joint Angles

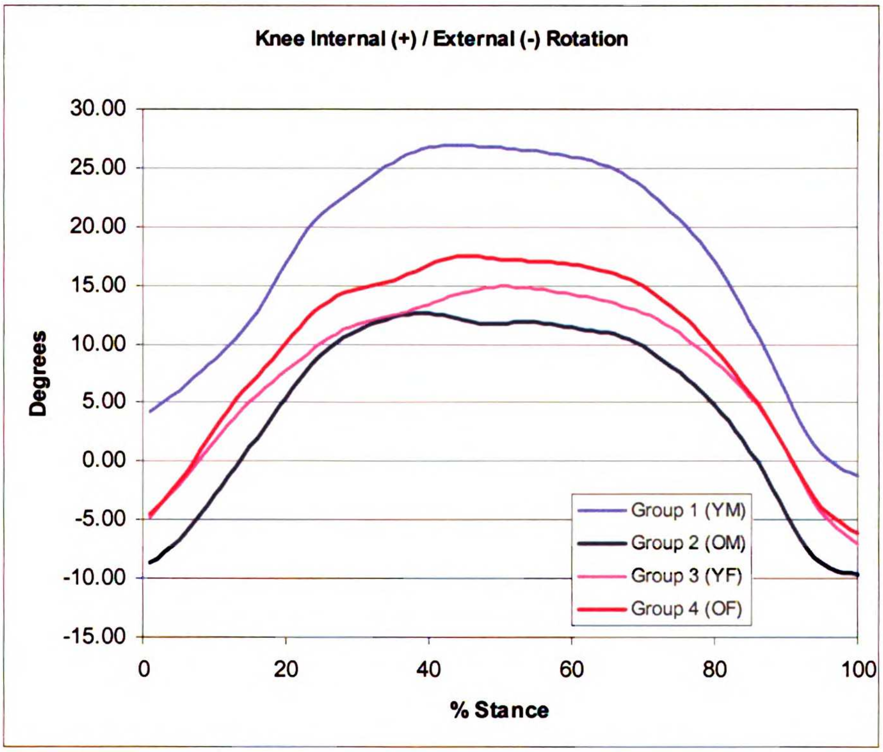

Figure 20: Step Right, Cut Left Transverse Plane Group Knee Joint Angles

Step Right, Cut Left Joint Angle Kinematics Figures (*cont.*)

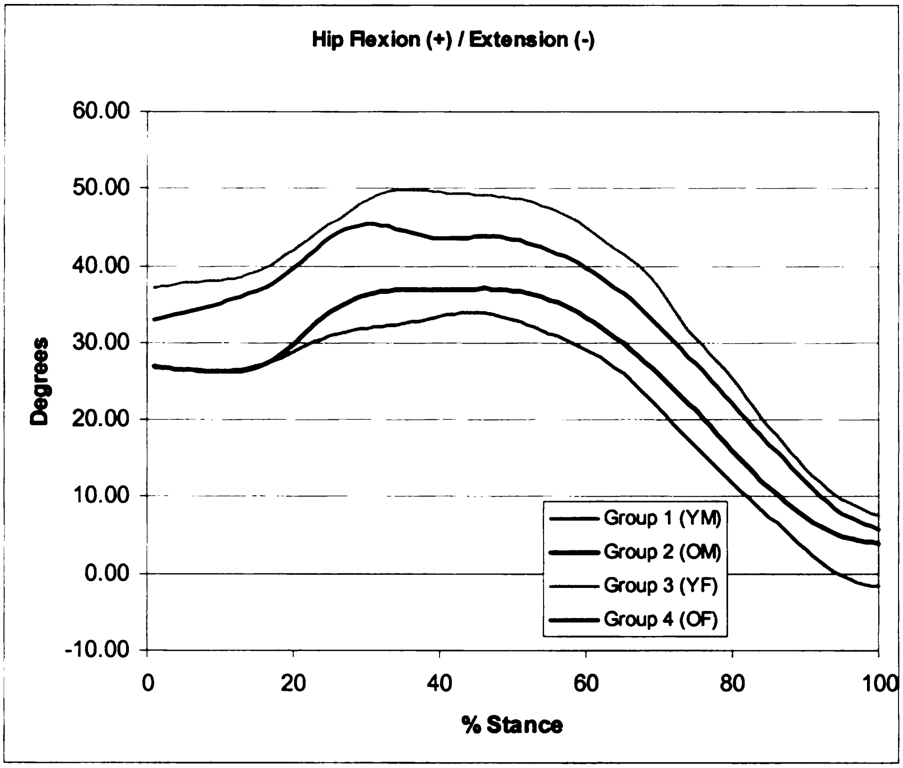

Figure 21: Step Right, Cut Left Sagittal Plane Group Hip Joint Angles

Soccer Turning Task Results

Table 4: Soccer Turning Task Kinematics

Soccer Turning Variable	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons) YM	OM	YF	OF
ANKLE DORSI / PLANTAR FLEXION							
Touchdown Dorsi (+) / Plantar (-) Flexion (*Deg*)	YM (*n*=7)	-25.5 ± 13.7	0.490				
	OM (*n*=7)	-16.2 ± 16.6					
	YF (*n*=7)	-25.7 ± 17.5					
	OF (*n*=9)	-28.2 ± 13.6					
Maximum Dorsi (+) / Plantar (-) Flexion (*Deg*)	YM (*n*=7)	6.1 ± 8.9	0.798				
	OM (*n*=7)	2.3 ± 4.3					
	YF (*n*=7)	4.3 ± 7.9					
	OF (*n*=9)	3.5 ± 8.1					
% Stance at Maximum Dorsi/Plantar Flexion	YM (*n*=7)	46.4 ± 25.3	0.820				
	OM (*n*=7)	46.8 ± 19.6					
	YF (*n*=7)	50.1 ± 18.1					
	OF (*n*=9)	41.8 ± 27.7					
Maximum Ankle Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	496.0 ± 174.0	0.536				
	OM (*n*=7)	430.4 ± 144.1					
	YF (*n*=7)	595.8 ± 208.7					
	OF (*n*=9)	519.6 ± 229.0					
% Stance at Maximum Ankle Joint Angular Velocity	YM (*n*=7)	4.5 ± 1.7	0.387				
	OM (*n*=7)	10.6 ± 6.5					
	YF (*n*=7)	18.2 ± 36.0					
	OF (*n*=9)	4.25 ± 2.1					
KNEE FLEXION / EXTENSION							
Touchdown Knee Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	20.3 ± 4.8	0.753				
	OM (*n*=7)	20.2 ± 3.1					
	YF (*n*=7)	18.6 ± 3.1					
	OF (*n*=9)	18.0 ± 7.1					
Maximum Knee Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	55.6 ± 6.2	0.062		0.317	0.997	0.742
	OM (*n*=7)	63.1 ± 3.1		0.317		0.231	**0.039**
	YF (*n*=7)	54.7 ± 5.0		0.997	0.231		0.858
	OF (*n*=9)	50.4 ± 10.9		0.742	**0.039**	0.858	
% Stance at Maximum Knee Flexion	YM (*n*=7)	33.1 ± 19.1	0.751				
	OM (*n*=7)	30.4 ± 9.8					
	YF (*n*=7)	31.0 ± 11.7					
	OF (*n*=9)	26.1 ± 12.5					
Maximum Knee Flexion/Extension Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	405.7 ± 96.3	0.103				
	OM (*n*=7)	521.4 ± 99.6					
	YF (*n*=7)	481.5 ± 95.0					
	OF (*n*=9)	437.1 ± 77.1					

Soccer Turning Variable (*cont.*)	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons) YM	OM	YF	OF
% Stance at Maximum Knee Flexion/Extension Joint Angular Velocity	YM (*n*=7)	7.7 ± 2.0	0.072				
	OM (*n*=7)	7.4 ± 2.6					
	YF (*n*=7)	5.7 ± 2.8					
	OF (*n*=9)	4.9 ± 2.0					
KNEE ADDUCTION / ABDUCTION							
Touchdown Knee Adduction (+) / Abduction (-) (*Deg*)	YM (*n*=7)	-6.9 ± 8.2	0.566				
	OM (*n*=6)	-6.4 ± 6.5					
	YF (*n*=7)	-2.7 ± 9.5					
	OF (*n*=9)	-8.2 ± 5.5					
Maximum Knee Adduction (+) / Abduction (-) (*Deg*)	YM (*n*=7)	-4.0 ± 7.5	0.395				
	OM (*n*=6)	-2.1 ± 8.8					
	YF (*n*=7)	2.0 ± 9.9					
	OF (*n*=9)	-4.7 ± 5.9					
% Stance at Maximum Knee Adduction (+) / Abduction (-)	YM (*n*=7)	23.4 ± 34.1	0.588				
	OM (*n*=6)	21.1 ± 18.5					
	YF (*n*=7)	11.7 ± 8.2					
	OF (*n*=9)	13.3 ± 5.8					
Maximum Knee Adduction / Abduction Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	156.2 ± 56.1	0.939				
	OM (*n*=6)	139.6 ± 44.5					
	YF (*n*=7)	139.9 ± 59.6					
	OF (*n*=9)	154.2 ± 31.2					
% Stance at Maximum Knee Adduction / Abduction Joint Angular Velocity	YM (*n*=7)	11.5 ± 1.9	0.593				
	OM (*n*=6)	16.7 ± 15.5					
	YF (*n*=7)	7.9 ± 2.9					
	OF (*n*=9)	18.22 ± 25.0					
KNEE INTERNAL / EXTERNAL ROTATION							
Touchdown Knee Internal (+) / External (-) Rotation (*Deg*)	YM (*n*=7)	13.1 ± 16.2	0.021		0.016	0.463	0.813
	OM (*n*=7)	-3.5 ± 9.4		0.016		0.280	0.059
	YF (*n*=7)	4.9 ± 8.6		0.463	0.280		0.887
	OF (*n*=9)	8.4 ± 7.6		0.813	0.059	0.887	
Maximum Knee Internal (+) / External (-) Rotation (*Deg*)	YM (*n*=7)	25.8 ± 1.6	0.014		0.012	0.086	0.369
	OM (*n*=7)	10.8 ± 6.1		0.012		0.749	0.187
	YF (*n*=7)	14.2 ± 9.3		0.086	0.749		0.726
	OF (*n*=9)	18.6 ± 8.2		0.369	0.187	0.726	
% Stance at Maximum Knee Internal (+) / External (-) Rotation	YM (*n*=7)	15.8 ± 7.1	0.327				
	OM (*n*=7)	22.3 ± 12.7					
	YF (*n*=7)	16.9 ± 4.2					
	OF (*n*=9)	16.6 ± 5.7					

Soccer Turning Variable (*cont.*)	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons) YM	OM	YF	OF
Maximum Knee Internal / External Rotation Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	341.5 ± 50.7	0.504				
	OM (*n*=7)	375.6 ± 101.8					
	YF (*n*=7)	322.3 ± 108.2					
	OF (*n*=9)	368.9 ± 119.1					
% Stance at Maximum Knee Internal / External Rotation Joint Angular Velocity	YM (*n*=7)	8.0 ± 2.3	0.694				
	OM (*n*=7)	11.7 ± 15.6					
	YF (*n*=7)	6.5 ± 2.4					
	OF (*n*=9)	16.5 ± 29.3					
HIP FLEXION / EXTENSION							
Touchdown Hip Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	30.2 ± 6.3	0.214				
	OM (*n*=7)	38.6 ± 7.1					
	YF (*n*=7)	39.2 ± 12.0					
	OF (*n*=9)	38.1 ± 9.4					
Maximum Hip Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	40.3 ± 10.7	0.193				
	OM (*n*=7)	52.5 ± 6.8					
	YF (*n*=7)	50.8 ± 13.4					
	OF (*n*=9)	47.7 ± 9.7					
% Stance at Maximum Hip Flexion	YM (*n*=7)	37.9 ± 24.1	0.232				
	OM (*n*=7)	46.7 ± 16.4					
	YF (*n*=7)	55.9 ± 14.6					
	OF (*n*=9)	33.1 ± 31.4					
Maximum Hip Flexion/Extension Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	172.8 ± 46.1	0.416				
	OM (*n*=7)	193.8 ± 76.4					
	YF (*n*=7)	236.1 ± 89.6					
	OF (*n*=9)	209.6 ± 59.5					
% Stance at Maximum Hip Flexion/Extension Joint Angular Velocity	YM (*n*=7)	21.6 ± 28.2	0.321				
	OM (*n*=7)	15.2 ± 8.1					
	YF (*n*=7)	9.0 ± 3.7					
	OF (*n*=9)	9.8 ± 3.6					

Soccer Turning Joint Angle Kinematics Figures

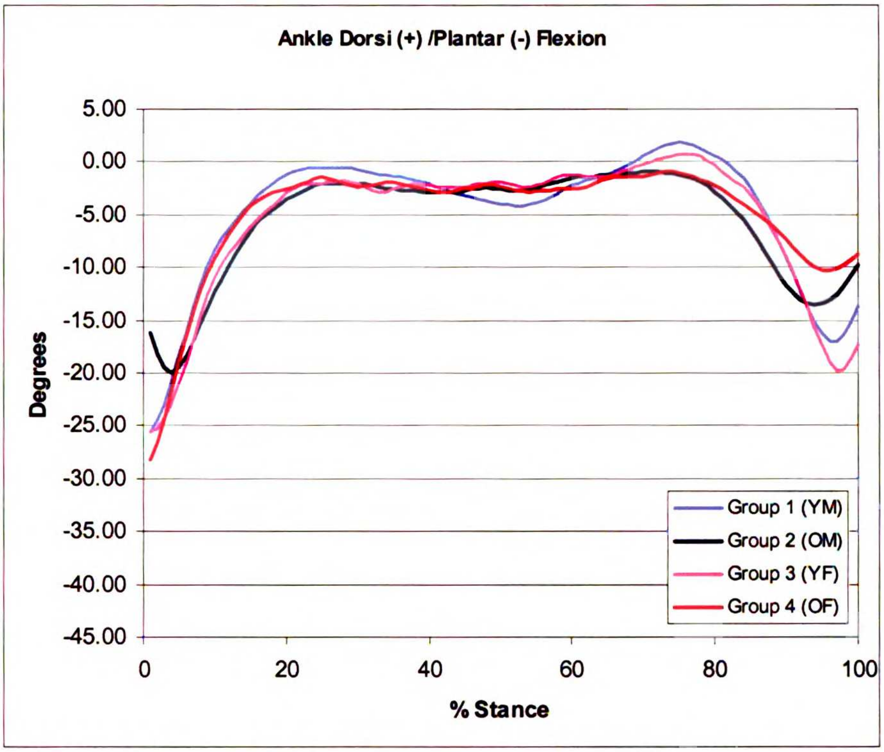

Figure 22: Soccer Turning Sagittal Plane Group Ankle Joint Angles

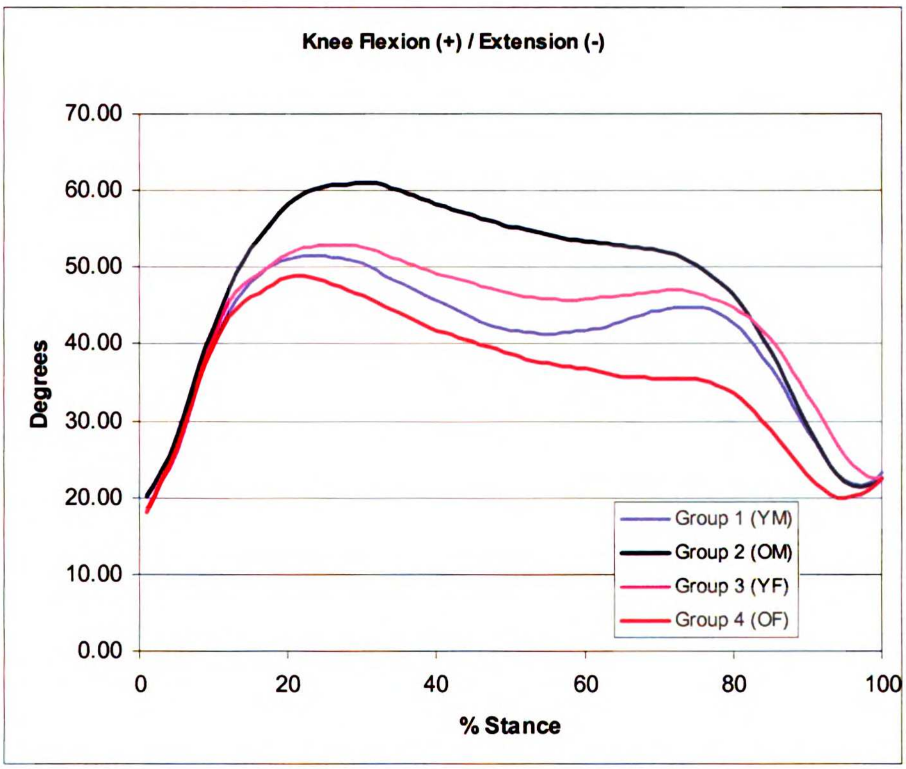

Figure 23: Soccer Turning Sagittal Plane Group Knee Joint Angles

Soccer Turning Joint Angle Kinematics Figures (*cont.*)

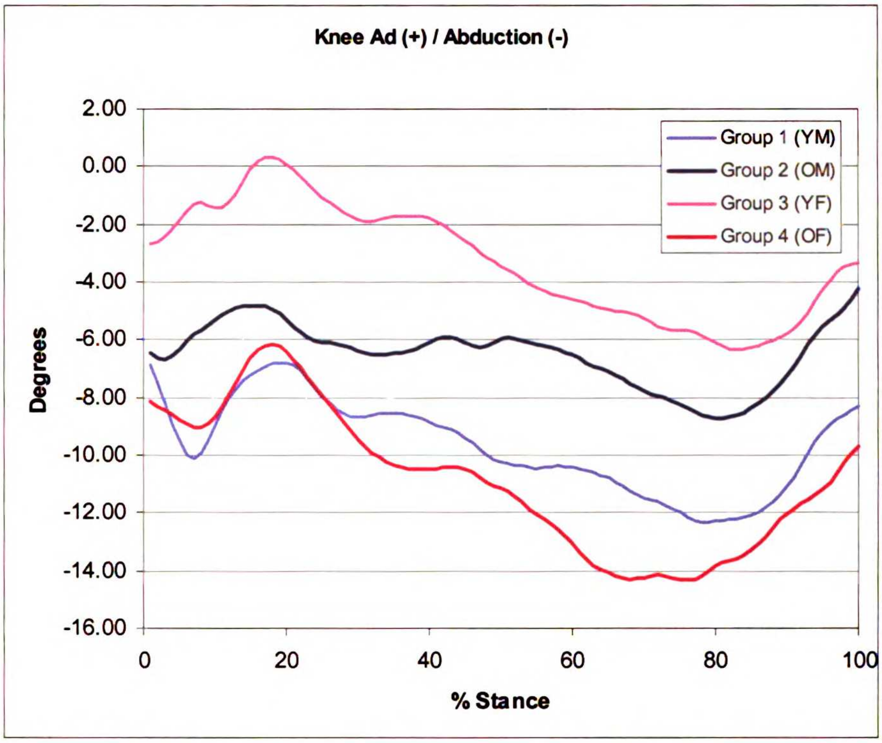

Figure 24: Soccer Turning Frontal Plane Group Knee Joint Angles

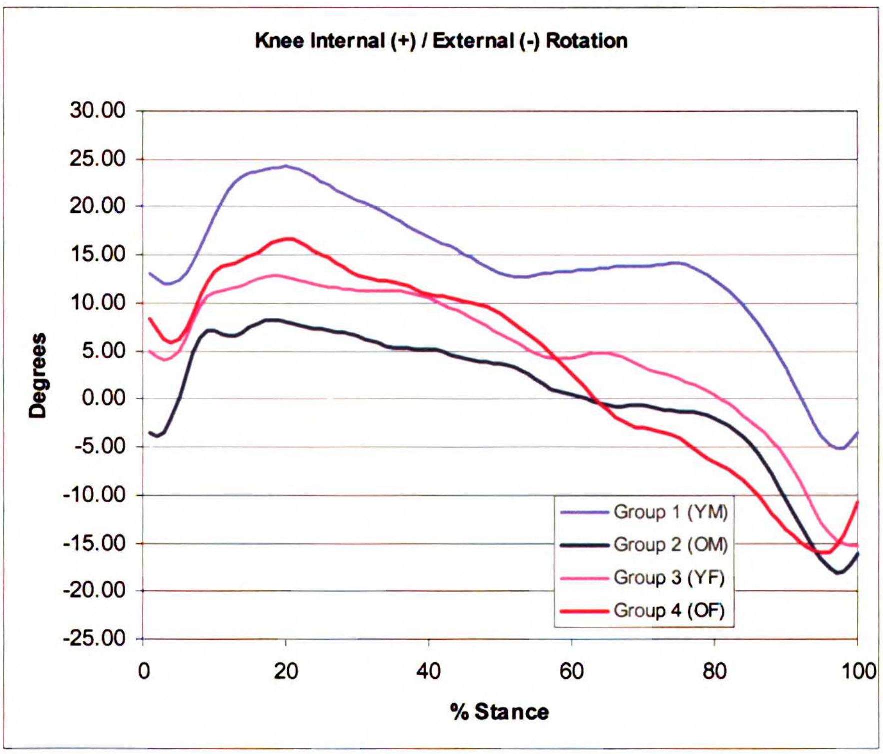

Figure 25: Soccer Turning Transverse Plane Group Knee Joint Angles

Soccer Turning Joint Angle Kinematics Figures (*cont.*)

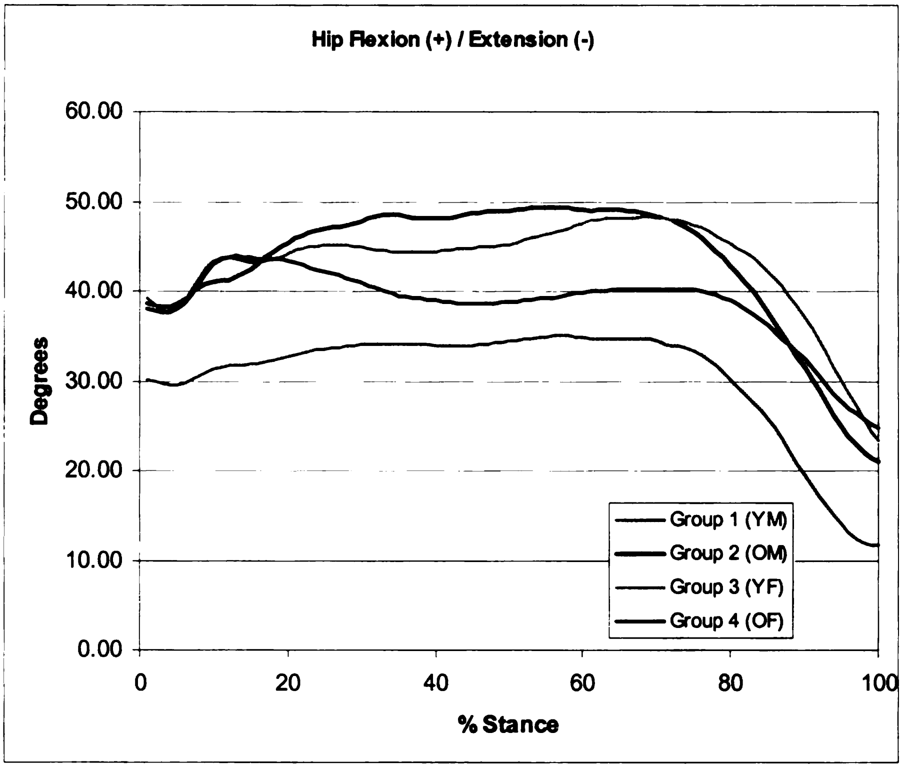

Figure 26: Soccer Turning Sagittal Plane Group Hip Joint Angles

Soccer Heading Task Results

Table 5: Soccer Heading Task Kinematics

Soccer Heading Variable	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons)			
				YM	OM	YF	OF
ANKLE DORSI / PLANTAR FLEXION							
Touchdown Dorsi (+) / Plantar (-) Flexion (*Deg*)	YM (*n*=7)	-33.7 ± 7.2	0.251				
	OM (*n*=7)	-31.5 ± 7.0					
	YF (*n*=7)	-39.0 ± 5.5					
	OF (*n*=9)	-34.9 ± 7.6					
Maximum Dorsi (+) / Plantar (-) Flexion (*Deg*)	YM (*n*=7)	21.5 ± 5.5	0.890				
	OM (*n*=7)	24.0 ± 4.8					
	YF (*n*=7)	22.6 ± 6.6					
	OF (*n*=9)	22.7 ± 5.6					
% Stance at Maximum Dorsi/Plantar Flexion	YM (*n*=7)	79.2 ± 20.1	0.169				
	OM (*n*=7)	65.0 ± 11.9					
	YF (*n*=7)	83.0 ± 18.7					
	OF (*n*=9)	81.2 ± 13.8					
Maximum Ankle Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	1272.6 ± 297.2	0.115				
	OM (*n*=7)	1009.1 ± 185.4					
	YF (*n*=7)	1164.6 ± 103.9					
	OF (*n*=9)	1187.5 ± 164.2					
% Stance at Maximum Ankle Joint Angular Velocity	YM (*n*=7)	14.0 ± 5.3	0.102				
	OM (*n*=7)	19.2 ± 2.5					
	YF (*n*=7)	14.3 ± 5.3					
	OF (*n*=9)	15.0 ± 3.5					
KNEE FLEXION / EXTENSION							
Touchdown Knee Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	20.9 ± 3.3	0.559				
	OM (*n*=7)	20.7 ± 10.7					
	YF (*n*=7)	16.3 ± 3.9					
	OF (*n*=9)	18.8 ± 6.3					
Maximum Knee Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	73.8 ± 10.9	0.979				
	OM (*n*=7)	71.8 ± 14.5					
	YF (*n*=7)	74.0 ± 16.8					
	OF (*n*=9)	74.4 ± 10.0					
% Stance at Maximum Knee Flexion	YM (*n*=7)	100	N/A				
	OM (*n*=7)	100					
	YF (*n*=7)	100					
	OF (*n*=9)	100					
Maximum Knee Flexion/Extension Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	674.0 ± 88.2	0.003		**0.016**	0.999	0.990
	OM (*n*=7)	532.4 ± 74.5		**0.016**		**0.011**	**0.005**
	YF (*n*=7)	680.3 ± 63.4		0.999	**0.011**		0.999
	OF (*n*=9)	686.7 ± 93.1		0.990	**0.005**	0.999	

Soccer Heading Variable (*cont.*)	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons)			
				YM	OM	YF	OF
% Stance at Maximum Knee Flexion/Extension Joint Angular Velocity	YM (*n*=7)	30.3 ± 18.1	0.393				
	OM (*n*=7)	30.0 ± 16.0					
	YF (*n*=7)	18.1 ± 10.2					
	OF (*n*=9)	22.4 ± 16.6					
KNEE ADDUCTION / ABDUCTION							
Touchdown Knee Adduction (+) / Abduction (-) (*Deg*)	YM (*n*=7)	-8.9 ± 5.1	0.454				
	OM (*n*=6)	-7.3 ± 6.7					
	YF (*n*=7)	-4.3 ± 8.8					
	OF (*n*=9)	-9.2 ± 5.1					
Maximum Knee Adduction (+) / Abduction (-) (*Deg*)	YM (*n*=7)	-1.13 ± 7.6	0.674				
	OM (*n*=6)	-0.85 ± 9.6					
	YF (*n*=7)	2.9 ± 10.0					
	OF (*n*=9)	-2.20 ± 6.7					
% Stance at Maximum Knee Adduction (+) / Abduction (-)	YM (*n*=7)	75.7 ± 19.9	0.674				
	OM (*n*=6)	77.5 ± 16.5					
	YF (*n*=7)	64.4 ± 24.8					
	OF (*n*=9)	71.3 ± 21.0					
Maximum Knee Adduction / Abduction Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	229.2 ± 63.8	0.637				
	OM (*n*=6)	186.2 ± 74.7					
	YF (*n*=7)	200.0 ± 71.5					
	OF (*n*=9)	195.4 ± 49.7					
% Stance at Maximum Knee Adduction / Abduction Joint Angular Velocity	YM (*n*=7)	58.3 ± 15.8	0.418				
	OM (*n*=6)	46.4 ± 11.2					
	YF (*n*=7)	47.3 ± 13.1					
	OF (*n*=9)	52.0 ± 15.5					
KNEE INTERNAL / EXTERNAL ROTATION							
Touchdown Knee Internal (+) / External (-) Rotation (*Deg*)	YM (*n*=7)	7.5 ± 11.9	0.075				
	OM (*n*=7)	-3.1 ± 4.8					
	YF (*n*=7)	-4.0 ± 10.1					
	OF (*n*=9)	-3.2 ± 8.3					
Maximum Knee Internal (+) / External (-) Rotation (*Deg*)	YM (*n*=7)	24.0 ± 10.9	0.046		0.062	0.068	0.227
	OM (*n*=7)	11.2 ± 4.1		0.062		1.000	0.835
	YF (*n*=7)	11.4 ± 11.9		0.068	1.000		0.856
	OF (*n*=9)	15.0 ± 7.6		0.227	0.835	0.856	
% Stance at Maximum Knee Internal (+) / External (-) Rotation	YM (*n*=7)	72.8 ± 18.5	0.341				
	OM (*n*=7)	68.0 ± 20.0					
	YF (*n*=7)	56.1 ± 19.4					
	OF (*n*=9)	63.0 ± 12.5					

Soccer Heading Variable (*cont.*)	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons) YM	OM	YF	OF
Maximum Knee Internal / External Rotation Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	392.3 ± 120.3	0.341				
	OM (*n*=7)	322.6 ± 84.1					
	YF (*n*=7)	335.5 ± 113.0					
	OF (*n*=9)	422.7 ± 151.2					
% Stance at Maximum Knee Internal / External Rotation Joint Angular Velocity	YM (*n*=7)	22.8 ± 17.6	0.761				
	OM (*n*=7)	17.5 ± 11.5					
	YF (*n*=7)	15.7 ± 11.5					
	OF (*n*=9)	17.4 ± 11.2					
HIP FLEXION / EXTENSION							
Touchdown Hip Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	26.2 ± 7.5	0.030		0.905	0.824	0.122
	OM (*n*=7)	21.9 ± 8.2		0.905		0.429	0.027
	YF (*n*=7)	31.7 ± 17.1		0.824	0.429		0.514
	OF (*n*=9)	40.2 ± 12.4		0.122	0.027	0.514	
Maximum Hip Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	40.8 ± 11.9	0.018		0.913	0.398	0.109
	OM (*n*=7)	34.6 ± 6.8		0.913		0.136	0.025
	YF (*n*=7)	55.8 ± 28.7		0.398	0.136		0.907
	OF (*n*=9)	61.8 ± 15.9		0.109	0.025	0.907	
% Stance at Maximum Hip Flexion	YM (*n*=7)	81.0 ± 32.1	0.932				
	OM (*n*=7)	87.2 ± 15.8					
	YF (*n*=7)	85.4 ± 13.9					
	OF (*n*=9)	86.5 ± 11.5					
Maximum Hip Flexion/Extension Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	335.1 ± 95.6	0.157				
	OM (*n*=7)	275.2 ± 84.2					
	YF (*n*=7)	369.6 ± 107.7					
	OF (*n*=9)	370.9 ± 67.9					
% Stance at Maximum Hip Flexion/Extension Joint Angular Velocity	YM (*n*=7)	52.3 ± 14.4	0.908				
	OM (*n*=7)	47.5 ± 10.4					
	YF (*n*=7)	46.6 ± 26.0					
	OF (*n*=9)	50.1 ± 10.3					

Soccer Heading Joint Angle Kinematics Figures

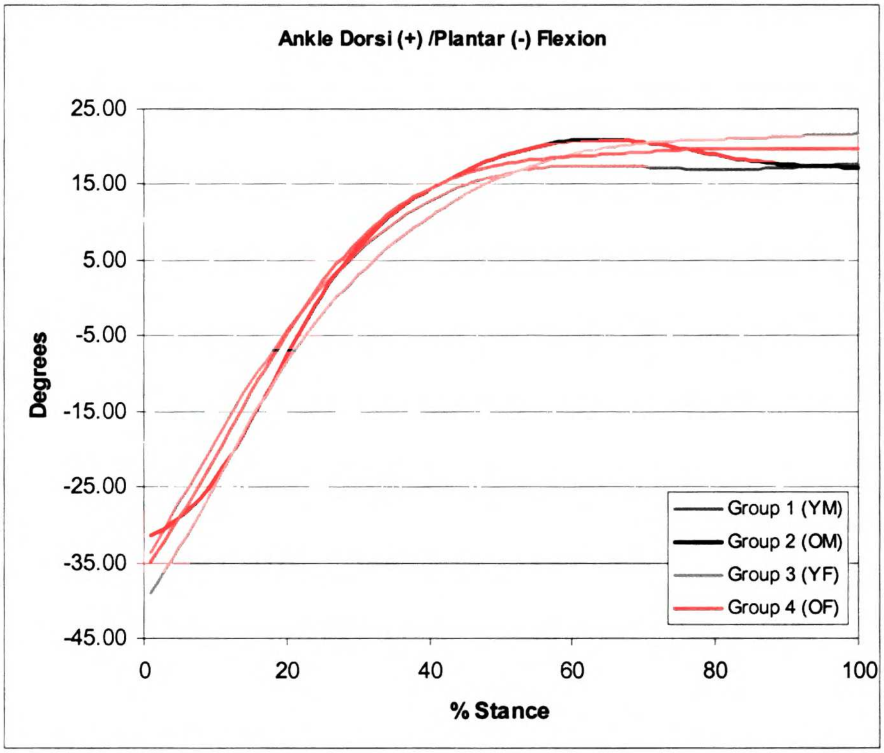

Figure 27: Soccer Heading Sagittal Plane Group Ankle Joint Angles

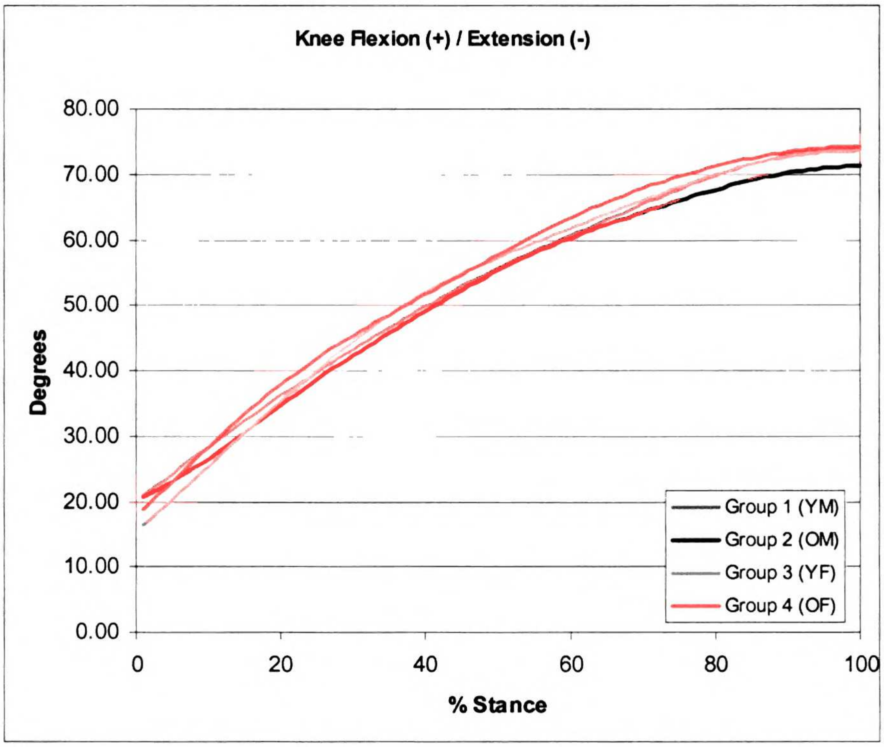

Figure 28: Soccer Heading Sagittal Plane Group Knee Joint Angles

Soccer Heading Joint Angle Kinematics Figures (*cont.*)

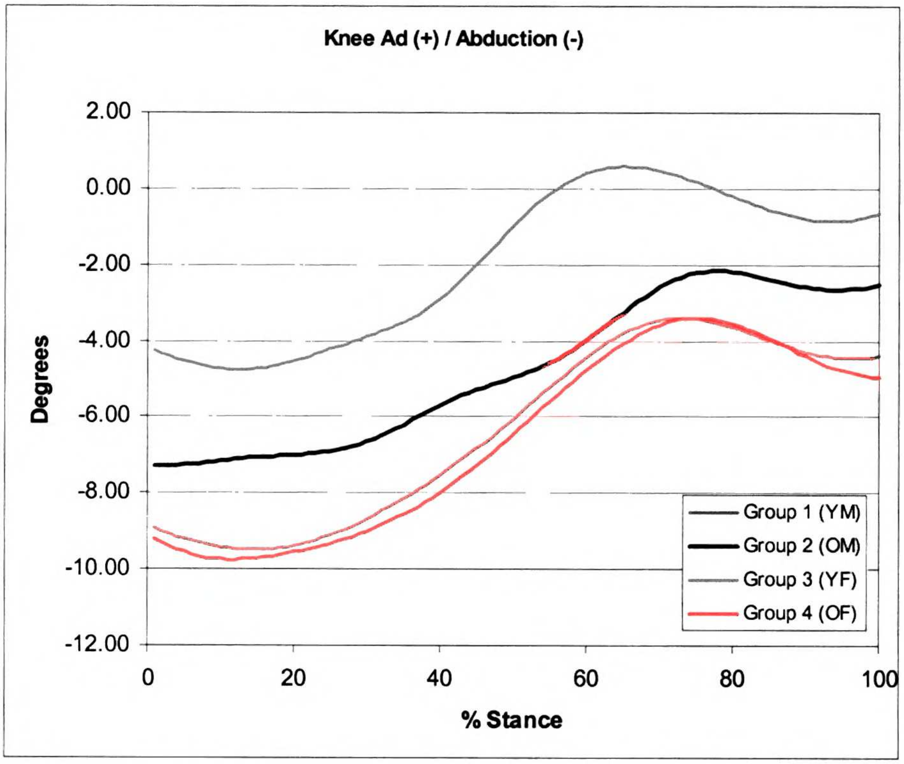

Figure 29: Soccer Heading Frontal Plane Group Knee Joint Angles

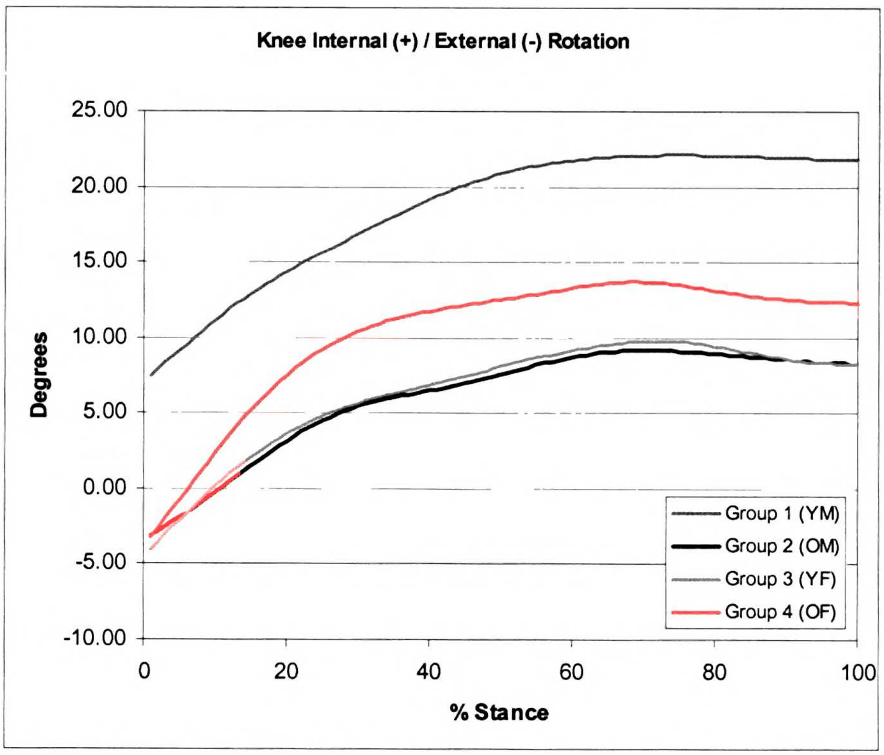

Figure 30: Soccer Heading Transverse Plane Group Knee Joint Angles

Soccer Heading Joint Angle Kinematics Figures (*cont.*)

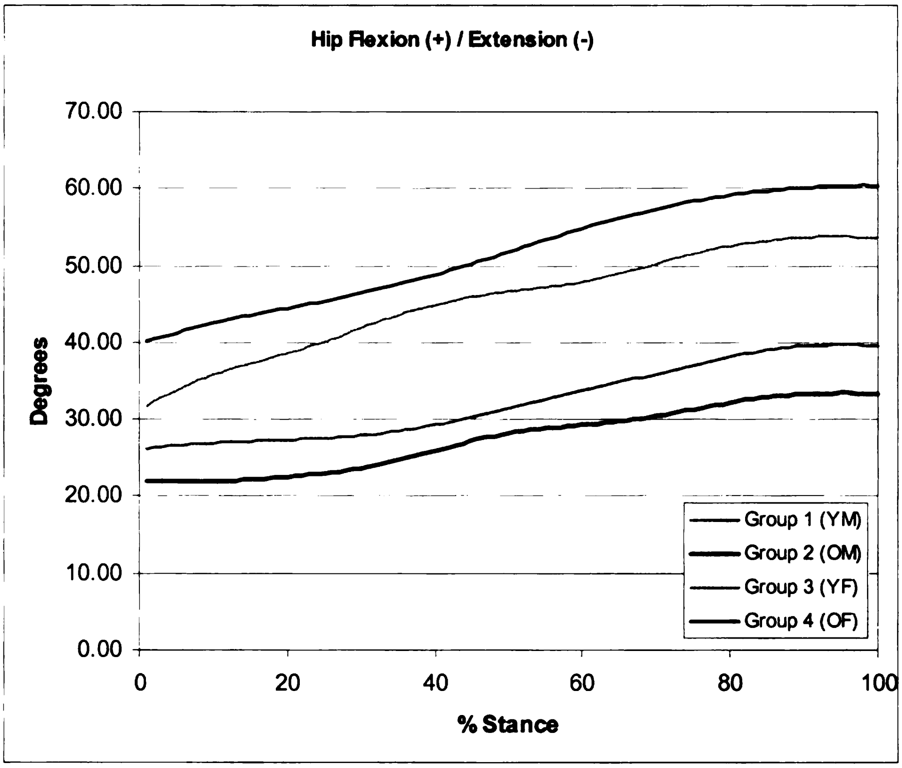

Figure 31: Soccer Heading Sagittal Plane Group Hip Joint Angles

Result Table Summary

Table 6: Result Summary of Statistically Significant Variables & Respective Task

Statistically Significant Variable	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons) YM	OM	YF	OF
DROP JUMP TASK							
ANKLE							
% Stance at Maximum Dorsi/Plantar Flexion	YM (*n*=7)	83.6 ± 11.1	0.028		0.124	0.834	0.986
	OM (*n*=7)	66.7 ± 20.1		0.124		**0.020**	0.181
	YF (*n*=7)	89.8 ± 7.8		0.834	**0.020**		0.609
	OF (*n*=9)	81.2 ± 13.2		0.986	0.181	0.609	
Maximum Ankle Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	1163.1 ± 214.1	0.010		0.912	**0.014**	0.091
	OM (*n*=7)	1234.4 ± 264.3		0.912		0.061	0.315
	YF (*n*=7)	1521.2 ± 125.1		**0.014**	0.061		0.722
	OF (*n*=9)	1414.0 ± 186.9		0.091	0.315	0.722	
KNEE							
HIP							
Touchdown Hip Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	24.9 ± 8.0	0.033		0.925	**0.043**	0.164
	OM (*n*=7)	28.1 ± 9.0		0.925		0.151	0.456
	YF (*n*=7)	39.1 ± 13.2		**0.043**	0.151		0.838
	OF (*n*=9)	35.1 ± 6.9		0.164	0.456	0.838	
STEP RIGHT, CUT LEFT TASK							
ANKLE							
Touchdown Dorsi (+) / Plantar (-) Flexion (*Deg*)	YM (*n*=7)	-25.6 ± 6.4	0.006		0.705	**0.004**	0.204
	OM (*n*=7)	-27.7 ± 4.4		0.705		0.063	0.867
	YF (*n*=7)	-37.7 ± 5.5		**0.004**	0.063		0.160
	OF (*n*=9)	-32.8 ± 5.8		0.204	0.867	0.160	
KNEE							
HIP							
SOCCER TURNING TASK							
ANKLE							
KNEE							
Maximum Knee Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	55.6 ± 6.2	0.062		0.317	0.997	0.742
	OM (*n*=7)	63.1 ± 3.1		0.317		0.231	0.039
	YF (*n*=7)	54.7 ± 5.0		0.997	0.231		0.858
	OF (*n*=9)	50.4 ± 10.9		0.742	**0.039**	0.858	

Statistically Significant Variable (*cont.*)	Group & Gender (*n*)	Mean ± SD	*P*	Adjusted *P* (Pairwise Comparisons) YM	OM	YF	OF
Touchdown Knee Internal (+) / External (-) Rotation (*Deg*)	YM (*n*=7)	13.1 ± 16.2	0.021		0.016	0.463	0.813
	OM (*n*=7)	-3.5 ± 9.4		0.016		0.280	0.059
	YF (*n*=7)	4.9 ± 8.6		0.463	0.280		0.887
	OF (*n*=9)	8.4 ± 7.6		0.813	0.059	0.887	
Maximum Knee Internal (+) / External (-) Rotation (*Deg*)	YM (*n*=7)	25.8 ± 1.6	0.014		0.012	0.086	0.369
	OM (*n*=7)	10.8 ± 6.1		0.012		0.749	0.187
	YF (*n*=7)	14.2 ± 9.3		0.086	0.749		0.726
	OF (*n*=9)	18.6 ± 8.2		0.369	0.187	0.726	
HIP							
<u>SOCCER HEADING TASK</u>							
ANKLE							
KNEE							
Maximum Knee Flexion/Extension Joint Angular Velocity (*Deg/s*)	YM (*n*=7)	674.0 ± 88.2	0.003		0.016	0.999	0.990
	OM (*n*=7)	532.4 ± 74.5		0.016		0.011	0.005
	YF (*n*=7)	680.3 ± 63.4		0.999	0.011		0.999
	OF (*n*=9)	686.7 ± 93.1		0.990	0.005	0.999	
HIP							
Touchdown Hip Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	26.2 ± 7.5	0.030		0.905	0.824	0.122
	OM (*n*=7)	21.9 ± 8.2		0.905		0.429	0.027
	YF (*n*=7)	31.7 ± 17.1		0.824	0.429		0.514
	OF (*n*=9)	40.2 ± 12.4		0.122	0.027	0.514	
Maximum Hip Flexion (+) / Extension (-) (*Deg*)	YM (*n*=7)	40.8 ± 11.9	0.018		0.913	0.398	0.109
	OM (*n*=7)	34.6 ± 6.8		0.913		0.136	0.025
	YF (*n*=7)	55.8 ± 28.7		0.398	0.136		0.907
	OF (*n*=9)	61.8 ± 15.9		0.109	0.025	0.907	

Task Comparison Joint Angle Kinematics Figures

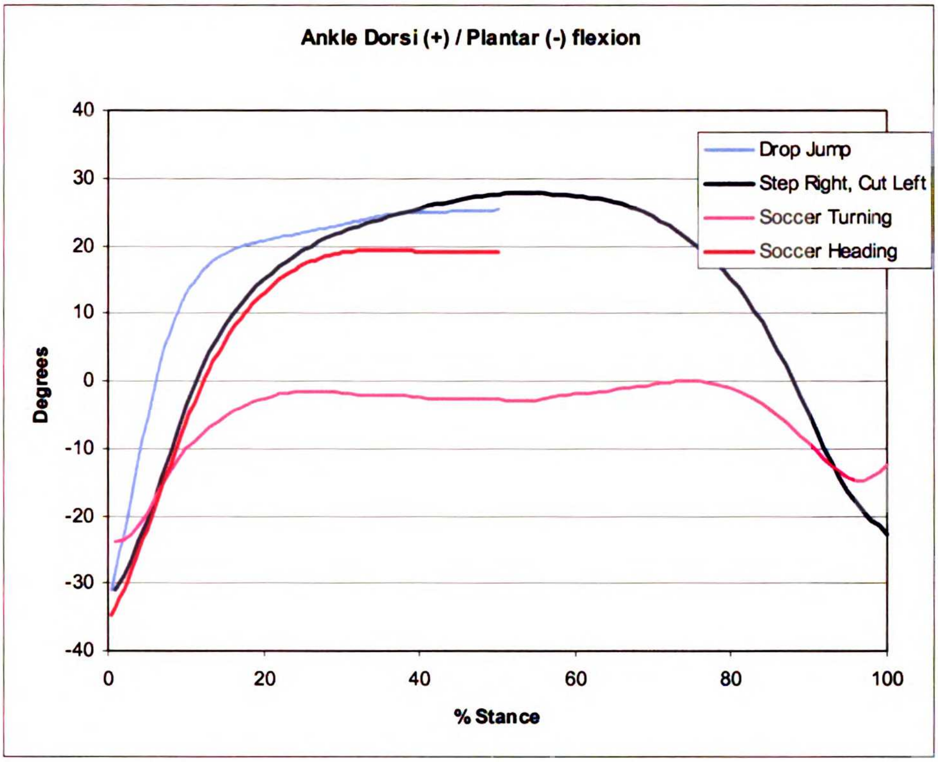

Figure 32: Sagittal Plane Task Ankle Joint Angles

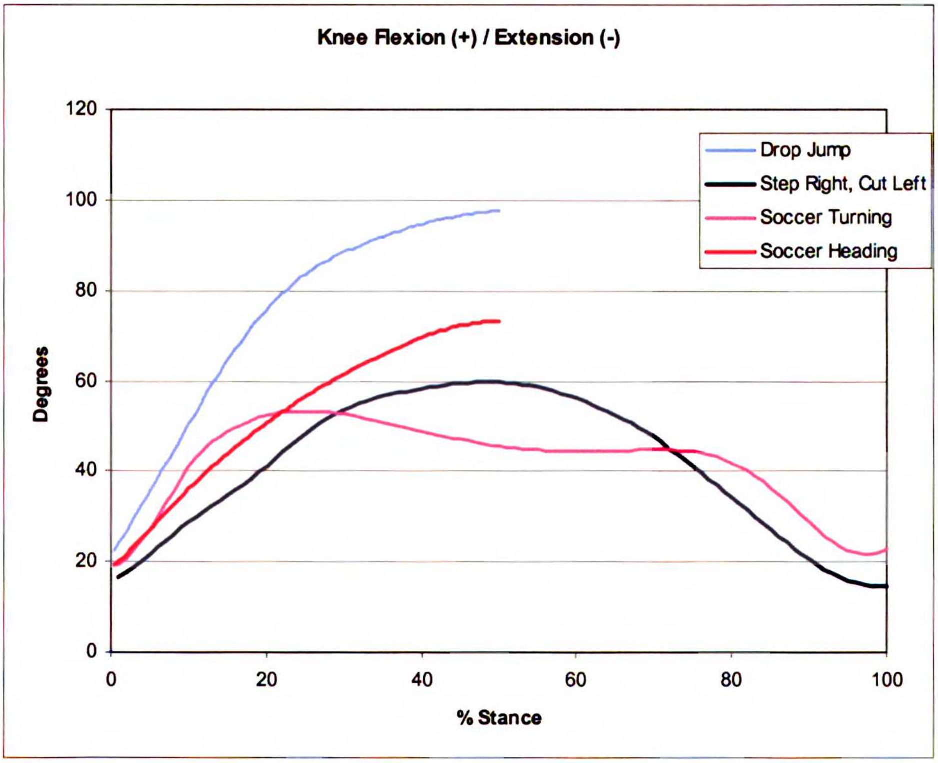

Figure 33: Sagittal Plane Task Knee Joint Angles

Task Comparison Joint Angle Kinematics Figures (*cont.*)

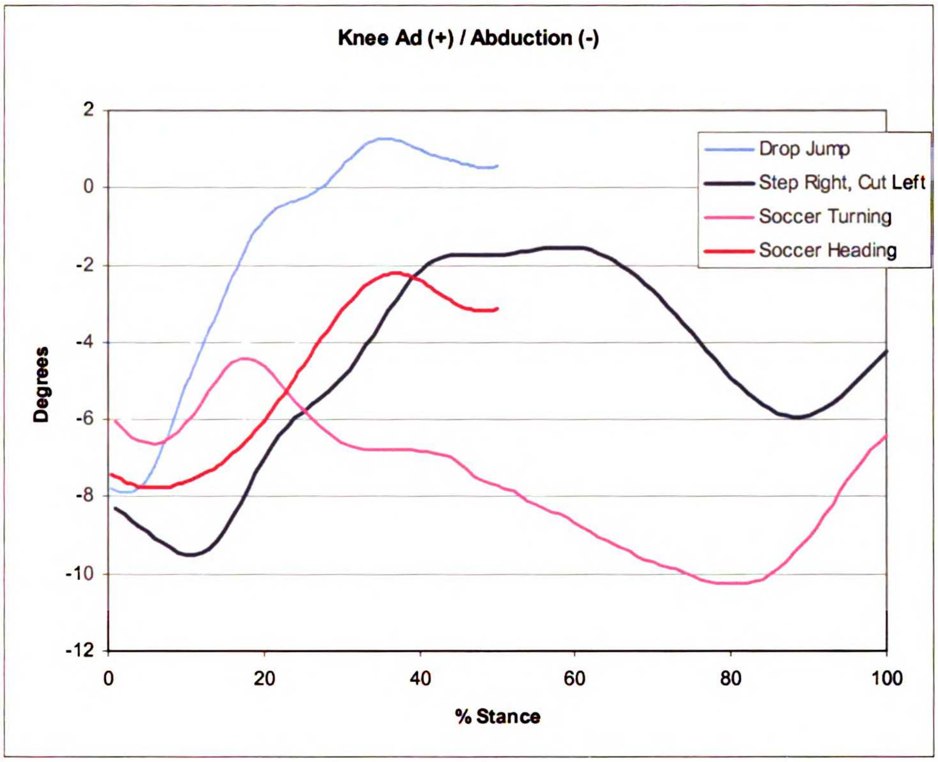

Figure 34: Frontal Plane Task Knee Joint Angles

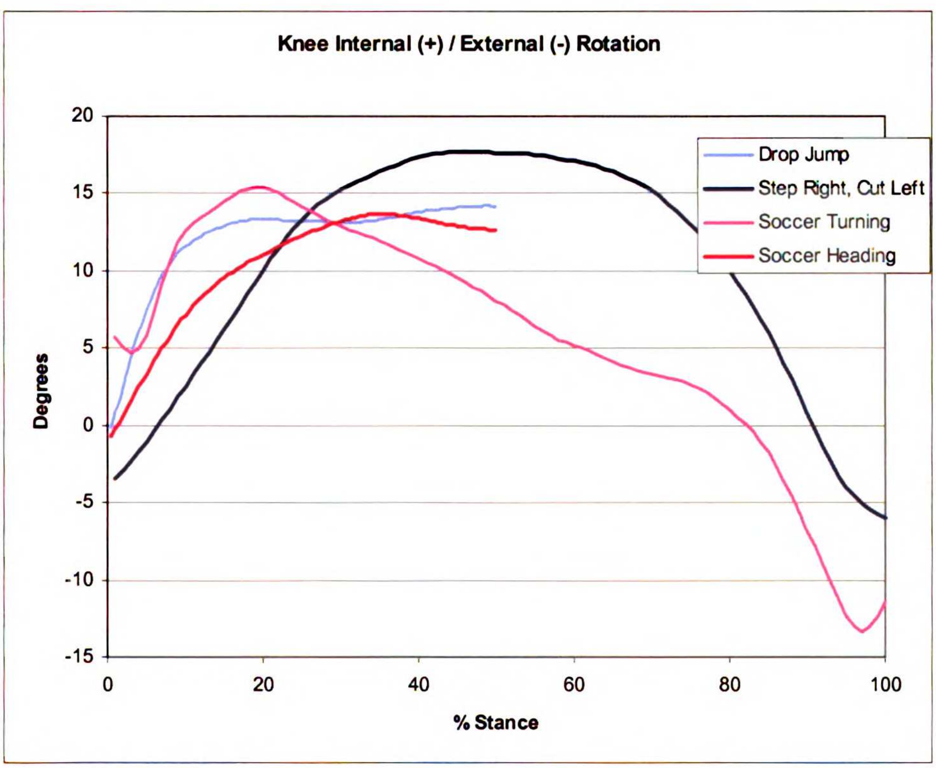

Figure 35: Transverse Plane Task Knee Joint Angles

Task Comparison Joint Angle Kinematics Figures (*cont.*)

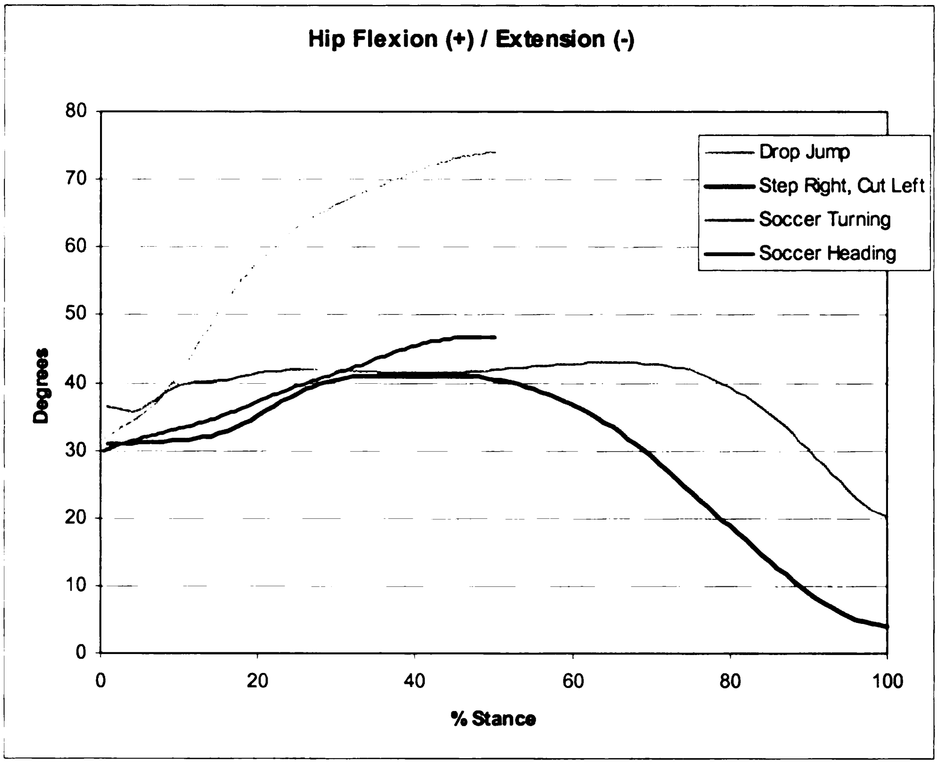

Figure 36: Sagittal Plane Task Hip Joint Angles

Discussion:

Drop jump and cutting tasks and their link to non-contact ACL injuries have been studied in research focusing primarily on knee joint loading, motion and muscle action during these movements.[4, 18, 19, 44, 46, 53] However, recent research suggests that the biomechanical interaction of the entire lower extremity (hip and ankle in addition to the knee) may be an important contributor to the overall risk of non-contact ACL injury.[14, 15] Additionally, it has been demonstrated that vision is important for accurate timing in landing kinematics.[54] A combined analysis of all lower limb joint motions during selected athletics tasks was therefore performed in drop jump, cutting and soccer ball focused tasks. Age and/or gender differences were found in all joints but not in all tasks.

Drop Jump Task

The role of the ankle during drop jump landings (mean ankle joint plantarflexion /dorsiflexion) has only been reported in one previous study.[20] The subjects in Decker and Colleague's study performed drop jump landings off a 60cm platform as compared to the 62cm platform used in this study. Additionally, the subjects in the previous study were recreational volleyball and basketball players, unlike soccer players in this study. In contrast to the previous drop jump study involving twelve 28 year-old (average age) males, our participants landed in approximately 6° more plantarflexion at touchdown. Both female groups in our study reported more than 3 times the plantarflexion angles at touchdown compared to the previous study which included nine 26 year-old (average age) females. Decker and colleagues reported a statistically significant difference between females and males at touchdown ankle joint angles with females touching down in significantly more plantarflexion [20], however, in the current study post hoc group comparisons only showed a trend toward the older males having less plantarflexion than the young females at touchdown (Adjusted *P*=0.06). The difference in sports could possibly account for the differences observed at touchdown between the studies. Soccer players do not repeatedly perform as many vertical and rebound jumps during competition as volleyball and basketball players. Volleyball and basketball players may land in joint angles that enable them to quickly jump again, unlike soccer players which tend to land in joint angles that enable them to quickly sprint or kick. Additionally, soccer players use their ankles more in maneuvering and striking the soccer ball and may have greater ankle range of motion compared to volleyball and basketball players, which use their upper body to maneuver the ball. Peak ankle joint angles were calculated as range of motion in the previous study with the range of motion statistically greater for the females than the males. Similarly, that trend was observed in the present study with older and younger males having less range of motion (peak joint angle minus touchdown angle) than the females, yet no statistical differences were found between groups. Decker and colleague's reported values were similar for both the younger and older females in this study but the males had approximately 10° more range of motion than that reported by Decker. Ankle joint velocity significantly differed in Decker's study between genders with females having higher velocities. That was also seen in this study and a statistical difference was found between young females and young males in ankle joint angular velocity (Adjusted *P*=0.014). Young females and older males differed as well, yet not statistically significant at Adjusted *P*=0.06. Ankle joint velocities may indicate a lack of ankle control in the young females and may propagate throughout the kinematic chain, thereby placing the knee at risk for injury.

Previous studies involving knee kinematics during a drop jump have yielded conflicting results. Two studies have reported higher knee flexion angles at touchdown in males compared to females during a drop jump.[19, 20] Unlike Huston and colleagues, Decker and colleagues also found gender differences in knee flexion range of motion. In contrast to both of these studies, Fagenbaum found greater knee flexion angles and knee flexion accelerations in females than males, both groups consisting of division I basketball athletes.[47] In the drop jump task in this study, no differences between groups in any kinematic variables were found in all three planes examined at the knee. At touchdown, all the groups landed in approximately 22-23° of knee flexion. These touchdown knee flexion angles were similar to those observed by Decker in females, yet were 5 to 15° higher than observed in Huston's study. Additionally, maximum knee flexion angles in the current study were large for the both male groups and the young females (approx. 100°) with about 20° (or more) variability in each group. The older females had the least knee peak knee flexion (89.1°) and least variability (8.5°). The maximum knee flexion angles for the male groups and the young females in this study were similar to maximum knee flexion angles found in Huston's study which also found no statistical differences between groups. A maximum knee flexion angle greater than 90° has traditionally defined the landing technique as soft or stiff respectively.[55] According to this criterion, all groups in this study demonstrated soft landing technique with the lower extremities in slight flexion at initial ground contact followed by large joint range of motion. Although the older females had the least maximum knee flexion at

89°, no statistical differences were found between groups indicating that all the groups had similar landing technique. Knee flexion angular velocity was higher in this study compared to Decker's results.[20] The males in this study reached almost 200°/s higher velocities than Decker's males and the females were also higher by about 50°/s. The males in this study landed with very high knee flexion joint angular velocities which cannot be explained by the 2cm platform height difference between studies. Although maximum knee flexion can characterize the type of landing, the joint angular velocities demonstrate the subject's ability to dissipate the forces absorbed from the landing. Ankle angular joint velocities were significantly higher for the young females than the young males, yet there were no differences between groups for knee flexion joint angular velocities. Strength differences could play a role, possibly with the young females having less muscle strength in the ankle and knee to control the landing compared with young males. Reduced knee flexion observed in the older females may also be a consequence of lower muscle strength. Additionally, studies have demonstrated that hamstring and quadriceps strength could be a risk factor in ACL injuries, and future studies should include maximum strength measurements of the hip, knee and ankle.[2, 3]

The study by Decker and colleagues was also the only previous study to report hip kinematics during the drop jump.[20] Unlike Decker's results, both female subject groups in this study landed in greater hip flexion than both male groups. The younger females landed in statistically significant higher hip flexion at touchdown (39°) compared with young males (25°), (Adjusted P=0.043). The young females also had the highest maximum hip flexion and hip flexion angular velocity yet there were no statistical differences between groups due to high within group variability. No other group differences existed in hip kinematics during the drop jump. Decker's females also had higher hip joint angular velocities than the males but the females also had lower hip flexion angles at touchdown compared to the males. Again, with higher joint angle velocities at the ankle and the hip, female soccer players appear to absorb the landing at the ankle and the hip compared to males, which have higher knee flexion joint angular velocities. The ankle and hip touchdown values could possibly explain this difference with younger and older females having to move faster at the ankle and hip to control the landing from a 62cm drop jump.

Although previous studies such as Decker's and Huston's have shown females to land in a more erect position, this study's data suggests that female soccer players land in more flexion than males similar to the results of Fagenbaum and colleagues.[47] Trunk control and lower extremity strength may play a large role in landing position and future research should examine the characteristics between muscle strength, trunk and lower extremity kinematics during the drop jump. Future studies should also control for sport participation because soccer players may be different from other sports participants during drop landings. Basketball and volleyball players sustain more drop landings during sport than soccer players. Therefore the use of the drop jump experiment may not be appropriate for evaluating risk factors for ACL injury in soccer players. Verbal instruction may also play a role in subject behavior. Subjects were instructed to land naturally, yet if the subject was instructed to stick the landing and not move their feet afterwards, results may have slightly differed. Additionally, this data suggests that female athletes would be less likely to injure their ACL during jump landings because they move quicker in the ankle and hip flexion direction and achieve similar knee flexion angles compared with men. This contrasts with convincing epidemiologic research that has demonstrated that female athletes are more likely than male athletes to sustain ACL injury during non-contact situations such as jump landings.[45, 56]

Step Right, Cut Left Task

Unlike the drop jump, it is possible that the ACL injuries in women occur primarily during landing when the athlete intends to immediately change direction or jump again. The step right, cut left task and the soccer turning tasks were designed in this study to replicate these dynamic movements.

In this study's step right, cut left task, significant differences were found in only one variable: young females had significantly more plantarflexion at touchdown than the young males (Adjusted P=0.004). Older females also had larger plantarflexion angles compared with both male groups, although not statistically significant. Ankle plantarflexion angles at touchdown were almost identical to the plantarflexion angles at touchdown for the drop jump task. These results were obtained despite differences in platform height (62cm versus 30.5 cm) and takeoff approach between the two tasks (2 foot takeoff in the drop jump and right foot takeoff in the step right, cut left task). Ankle joint angular velocities were smaller for the step right, cut left task as expected since the subjects stepped off a smaller platform and did not have to dissipate as much force as the drop jump task. Both female groups demonstrated higher peak ankle joint angular velocities than the male groups as also seen in the drop jump task, yet not statistically significant.

Three previous studies have reported knee flexion angles for cutting tasks. In all of these studies, the females had less maximum knee flexion than the males. In Malinzak and colleague's study of 20 college age recreational athletes, knee flexion angles were found to be lower than the male subjects in side-cutting tasks although only statistically different when comparing the entire joint range of motion throughout stance cycle.[4] The subjects in the study by McLean and colleagues ran toward the force plate and then changed direction from their dominant leg to their non-dominant leg approximately 45° from the approach run direction.[43] Additionally, females had significantly lower peak knee flexion values than males.[46] In an earlier separate study of sidestep-cutting, McLean did not find any differences in maximum knee flexion values, however it was found that maximum knee flexion during cutting occurred significantly earlier in the stance phase for women than for men.[18] McLean explains that study results are sensitive to differences in movement task and subject population and that is why the different results for the two different studies. The literature is conflicted with respect to knee flexion angles during cutting tasks, as is especially evident in differing results between both of McLean's similar sidestep-cutting studies. However, all three studies did show that on average, females had lower knee flexion angles than males. Approach speed was controlled in both of McLean's studies and Malinzak did not find any differences in approach speeds. In this study, approach speed and stride length were controlled by using the 30.5cm platform for the step right, cut left task. Knee flexion at touchdown was not significantly different between groups, although the older females tended toward the least overall knee flexion at touchdown. Maximum knee flexion was also not significantly different between groups, thus contradicting previous study findings.

For the frontal plane, all three previously mentioned studies found statistical significance with regard to knee abduction angles during cutting, with females having significantly more valgus or abduction than males.[4, 18, 46] It seems logical that because of female's tendency to have higher Q angles than men [57] that they would have larger knee abduction values, however, this was not the case in this study with young females having higher knee adduction values. This study found the young female group to have the least valgus or knee abduction than any other group although not statistically different. Also, the young female group peaked in knee adduction and all other groups peaked in knee abduction (also not statistically different). Variability in the young female groups was very high in the knee ad/abduction joint angles examined in this study and could potentially explain why these results are not similar to previous studies. Additionally, skin marker artifact is also very large for small frontal plane movements and this will be discussed in more detail when the limitations of the methodology are addressed.

For the horizontal or transverse plane of the knee, both of McLean's studies found significant differences in knee internal/external rotation during the cutting task, with males having more internal rotation than females.[18, 46] Similarly in this study, young males had much larger knee internal rotation at touchdown and at maximum compared to all other groups. Unlike the younger males, the older males had the least internal rotation compared with all groups. This result and its connection to ACL injury appear counterintuitive, considering that females have an increased incidence of ACL injures and internal tibial rotation is known contributor to load the ACL. Again, small transverse plane movements are difficult to detect and this will be discussed in more detail when the limitations of the methodology are addressed.

During the step right, cut left task, the females tended to have more hip flexion at touchdown and at max hip flexion than both male groups. This was consistent in the drop jump task as well. In the only study to report hip flexion values during a dynamic task such as cutting, McLean reported that females had significantly less hip flexion than males during sidestep-cutting[46].

According to McLean, hip and knee flexion seem to be coupled in order to ensure that body center of mass remains above the foot during stance. Although results in this study differed from McLean's previous study, coupling was apparent with the females having more maximum knee flexion and more maximum hip flexion than males. In the current study, it seems the knee and hip flexion values for the females are in a safe range protecting the ACL. The large values of knee and hip flexion that the females exhibited may be due to lack of control and muscle strength. The females may be unable to resist the forward momentum of the tasks resulting in larger knee and hip flexion angles. This lack of control and strength although protecting the ACL, may predispose the females to other injuries from abnormal joint loadings that may result from fatigue or unexpected perturbation. Although differences were found in other cutting research, the cutting task in this study may have been too controlled with the use of the platform. Allowing the subjects to approach the force plate with a speed controlled approach may have allowed for more natural running and cutting patterns to appear between individuals, yet may lead to an increased within group variability for the task.

Soccer Turning Task

In order to combat the controlled, non-sport specific laboratory pattern of past kinematic research, soccer related tasks with a soccer ball were developed to simulate soccer based moves that may place the greatest load on the ACL. The soccer turning task was created to analyze the kinematics of the initial touchdown, knee rotation and quick change of direction often encountered in soccer participation. Additionally, a soccer ball was added to the task to truly simulate soccer based movement and encourage the focus of the task to be placed on the soccer ball and not on the movements of the task. Of all the tasks performed in this study, this task was hypothesized to have had the greatest risk for ACL injury. Internal rotation of the knee in addition to slight knee flexion are all viewed as likely contributors to increased risk of ACL injury.[3, 44, 58] Additionally, as the subjects approached the force plate to changed direction they had to decelerate. Kirkendall and Garrett reported that ACL injuries occurring in basketball and soccer were most often resulted from a deceleration type of movement.[59] Slight knee flexion, internal rotation of the tibia with respect to the knee and deceleration were all present in this task. Additionally, the soccer turning task was designed to be as repeatable as possible and did yield statistically significant differences in maximum knee flexion, touchdown knee internal rotation and maximum knee internal rotation joint angles.

Females had less knee flexion in this task at both touchdown and maximum knee flexion angles compared with both male groups. Older females had significantly less knee flexion than the older males (Adjusted $P = 0.039$). The young males and the older males differed significantly in internal rotation with the young males having significantly more knee internal rotation than the older males at both touchdown and peak internal rotation values, (Adjusted P_{TD} = 0.016, & Adjusted P_{Peak}=0.012). Unlike the drop jump and step right, cut left tasks, both female groups tended to have less maximum knee flexion in the soccer turning task than both male groups, although only significant for the older females versus the older males. Because older females tended to have less maximum angular displacement than the older males, it did not take as long to reach their maximum knee flexion angle resulting in a more abrupt absorption of the impact forces from landing and switching directions. These findings in the soccer turning task are consistent with results from other studies showing gender differences when doing athletic maneuvers. These studies showed that females tend to land with the knee in a more extended position[4, 44] and therefore subject themselves to higher forces per body weight during the impact of landing.[60] Also, more erect knee flexion positions in addition to knee torque as experienced during this soccer turning task could potentially elevate the risk for ACL injury.

In the transverse plane of the knee, the young males had significantly more internal rotation than the older males at peak internal rotation and at touchdown when performing the soccer turning task. Knee internal rotation has been linked to increase strain on the ACL. Additionally, knee internal rotation was greater in the young males than all groups during the soccer turning task. The young males had at least 10 more degrees of internal rotation than all groups. The young males may have had more internal rotation at the knee in order to prepare the rest of their body to follow during the task and to perform the soccer turning task as quickly as possible. Though subjects were told to perform the maneuvers "as quickly as possible" the speed of the task did vary with each subject. Inability to control internal rotation has been speculated as a possible cause for ACL rupture.[61] However, knee internal rotation joint angular velocities though higher for the older gender groups were not statistically different from the younger groups.

Since this soccer turning task was an exploratory experiment, there is no other research to directly compare results. However, lack of knee flexion at touchdown and large angles of knee internal rotation are known risk factors for ACL injury during dynamic sport maneuvers.[4, 44, 61] The older female's lack of knee flexion and the younger male's large knee internal rotation in the soccer turning task may predispose these groups to knee injury. The results indicate that older females and younger males may have the greatest risk of ACL injury during soccer turning compared with other laboratory tasks and further studies should be conducted.

Soccer Heading Task

Similar to the soccer turning task, the soccer heading task was also designed to place the subject's visual and mental emphasis on heading a soccer ball. In a study by Santello and colleagues, vision was important for the accurate timing of muscle activity onset and the kinematics of landing movements in humans.[54] In a laboratory atmosphere, the subject's visual focus during controlled tasks such as the drop jump is on landing. Before the subject leaves the platform they are focused on landing. However, in the soccer heading task, the subject's focus was on heading the soccer ball and not on landing, thereby producing more natural landing kinematics that may be experienced during soccer competition.

As seen in the drop jump task, females continued to have higher plantarflexion angles at touchdown, though not significantly different. Also similar to the drop jump task, females had higher peak knee flexion values and knee flexion angular velocities than the males, though not statistically different. Most different from the drop jump task was that females tended to have less knee flexion at touchdown than the males, despite having larger peak knee flexion joint angles. This indicated that the joint range of motion for the females was larger than the joint range of motion for the males. Although not statistically different between genders, a more erect knee at touchdown may decrease the ability of the hamstring muscles to prevent anterior tibial translation, thereby increasing the risk of ACL injury.[47]

Significant differences were found between the older males with lower peak knee flexion angular velocity compared to all other groups (Adjusted P=0.016 {YM}, 0.011 {YF}, 0.005 {OM}). This demonstrated that the older males moved the slowest into knee flexion than all other groups. Physiological changes such as decrease in flexibility, joint laxity and joint range of motion may have played a role in the older males low knee flexion joint angular velocities. Although no studies have shown that low knee flexion velocities are a potential risk factor for knee injuries, low knee joint velocities may not allow the knee to quickly recover from an unexpected perturbation and could possibly result in injury. Also similar to all other tasks, the young males had greater internal rotation at the knee than all other groups and could potentially be due to the subject population studied.

Also similar to the drop jump task, females tended to have higher hip flexion angles at touch down and at peak hip flexion. Female's hip joint angular velocities were also higher than the males. Significant differences were found between the older females and older males in both hip flexion joint angle measurements, with older females having significantly more hip flexion than the older males (Adjusted P_{TD}=0.027, Adjusted P_{Peak}=0.025). Lack of strength and control during landing could possibly account for the older females large hip flexion angles. Also, female soccer players appear to absorb the heading landing at the knee and the hip compared to males, which have higher ankle flexion joint angular velocities. The knee and hip touchdown values could possibly explain this difference with younger and older females having to move faster at the knee and hip to control the landing after heading the soccer ball. This differs from the drop jump task, where females relied upon their ankles and hips to absorb the landing. Reasons for this difference could be in either the height from which the players are landing and/or the inclusion of a ball focused task.

Soccer heading task results are very similar to the drop jump results in this study. Females had higher plantarflexion angles at touchdown, higher peak knee flexion values, higher knee flexion angular velocities and higher hip flexion angles at touchdown than men, although not statistically significant. Similar to all other tasks was the fact that young males had greater internal rotation at the knee than all other groups. Most different from the drop jump task was that females tended to have less knee flexion at touchdown than the males, despite having larger peak knee flexion joint angles. Also, significant differences were found between the older males with lower peak knee flexion angular velocity compared to all other groups. Although no studies have shown that low knee flexion velocities are a potential risk factor for knee injuries, low knee joint velocities may not allow the knee to quickly recover from an unexpected perturbation and could possibly result in injury. The relationship between soccer heading landings and

ACL injury remains unclear and more subjects should be tested to determine if females differ significantly in knee flexion/extension at touchdown during soccer heading tasks.

Task Comparison

In order to determine which task would most likely injure the knee, comparisons of the results from all subjects were averaged for each task and then plotted for the five joint angles examined. By examining the joint kinematic figures and using the results from the individual tasks, the task that would place the knee in the most vulnerable position according to known risk factors from the literature is the soccer turning task. Dynamic knee injuries result from a combination of factors. From the literature, lack of knee flexion and large angles of knee internal rotation are considered risk factors for ACL injury.[4, 44, 61] These factors, combined with lack of flexion in the ankle and hip are hypothesized to contribute to the risk for knee injury because of the inability of the body to react and subsequently control perturbation that may lead to injury. The soccer turning task placed the subject's ankles in a neutral position throughout the majority of stance. This demonstrated that the majority of the body weight load was on the knee and not the ankle during the task. Additionally, the knee flexion was the least overall for soccer turning task compared to the other tasks. This lack of knee and ankle flexion, in addition to the most abduction (knee valgus) around 80% of stance and the twisting of the knee from 15 degrees of internal rotation to about 15 degrees of external rotation potentially places the subjects in the most injury prone position, especially toward the second half of the stance phase. The soccer turning task was also the only task that had significant differences in age and gender at the knee in more than one plane of motion. Maximum knee flexion differed between the older females and older males. Additionally, touchdown knee internal/external knee rotation and maximum knee internal/external rotation was significantly different between the older and younger males.

The step right, cut left task although showing very few significant differences between age and gender is the next task that could potentially lead to knee injury. The step right, cut left task had the greatest ankle dorsiflexion, moderate knee flexion, the largest degree of knee internal rotation and the least amount of hip flexion compared with all other tasks. From risk factors established in the literature, this combination of moderate knee flexion, large knee internal rotation and low hip flexion could potentially place the athlete in an injury susceptible position earlier in the stance phase than the soccer turning task.

The soccer heading task encouraged the athletes to place visual emphasis on a soccer ball hung 10 inches from the subject's height. The results from this task showed that although similar degrees of ankle dorsiflexion are achieved compared to the drop jump task, the knee is less flexed, in more abduction and the hip is in less flexion. This combination places the subjects in a more susceptible knee position than the drop jump.

One of the most interesting results from this study is that the drop jump placed the subjects into the least knee injury susceptible position of the four tasks studied. Although significant differences were found between age and gender for this task in the ankle and the hip, no differences were found in the knee; yet, the drop jump continues to be used to identify lower limb kinematic differences between genders.[62, 63] It may be more useful in detecting these differences in basketball and volleyball players; however, this study has demonstrated that there are no differences in drop jump landings at the knee in recreational soccer players. If research on the risk for ACL injury in soccer players is to continue, tasks such as the soccer turning and step right, cut left tasks appear to be more appropriate.

Methodology

As mentioned previously, methodology plays an important role in interpretation of the results. As is the case with all assessments of in vivo joint motion, the accuracy of the results is limited by the use of skin markers. The impact of skin marker movement error is unknown for movements other than walking or running but steps were taken in the current study to minimize this problem by using rigid marker clusters as proposed by Capozzo.[50] A residual analysis was performed on the collected data and a 17 Hz cut-off frequency was chosen to filter the data. It is possible that filtering the data at this frequency may have failed to remove some movement artifacts due to skin marker motion on impact. Additionally, it has been shown that in *in vivo* experiments only motion about the flexion/extension axis of the hip, knees and ankles can be determined reliably.[64] Motion about other axes at those joints such as ad/abduction and internal/external rotation should be regarded with much more caution as skin marker artifact produces effects with magnitudes comparable to the amount of motion actually occurring in those joints.[64] This is due to the fact that ad/abduction and internal/external rotation are small relative to flexion-extension motion, and are therefore easily influenced by minor variations in the definition of the joint coordinate system. Therefore, the reader should approach all studies reporting kinematic variables for these planes of rotation with caution.

Subject Population

The subject population was also of concern in this study. No group differences were found in average hours of soccer per week indicating that subjects had similar activity levels. Although activity levels were similar, soccer experience levels were significantly different between groups. The older males in particular, had been playing for approximately 11 years longer on average than the younger male group. However, the older females exhibited no soccer experience differences between the young gender groups suggesting that the older female group may have had a similar soccer skill level as the younger groups. Although no older subjects were beginning soccer players with less than 3 years of soccer playing experience, skill level differences may have played a role in neuromuscular control and ease of task when performing the selected soccer maneuvers. Additionally, no differences in any of the independent kinematic variables existed between the older females and the younger females. Experience levels may have been similar in these groups resulting in similar kinematics between groups. Additionally, very few differences were found overall and experience may have explained some of the variability obtained in the study. Mclean reports that experience level has an effect on resultant knee joint kinematic variability regardless of gender and that subjects with high levels of experience typically displayed decreased variability.[18] Matching men and women for experience needs to be considered in future studies. Additionally, variability in joint kinematics during complex movement tasks has similarly been linked to low levels of conditioning and experience.[14] Poor physical conditioning has also been viewed as a major reason for increased knee injury rates in women compared with men.[14, 65]

The small number of subjects in this study greatly affected the statistical power. Only 7 subjects were able to be tested in three groups: young males, older males and young females, and only 9 subjects were gathered for the older female group. Time constraints with studying a working population and subject availability made it very difficult to recruit subjects. In Decker's study of lower extremity kinematics during a drop jump, only 12 males and 9 females were used. [20] In Fagenbaum's study of drop landings, 6 males and 8 females were used. [47] In Huston's study of the drop jump, 10 males and 10 females were tested. [19] The number of subjects in each group of this study should have been slightly greater, however, increasing the number of subjects although increasing the power of the study, may still have not yielded statistically significant findings due to the large reported *P* values for the drop jump landing knee kinematics.

According to statistical power calculations for a One-Way ANOVA, 23 subjects would have been needed in each group to detect a 10 degree difference in joint angles and joint angular velocities (power=0.80). In order to detect a 15 degree difference, 11 subjects per group would have been needed (also power=0.80). Increasing the number of subjects might have decreased the high variability between subject groups, yet, a 10 degree difference in joint angles was not seen the majority of the variables in this study. However, the high variability between groups may have been attributed to experience levels and/or conditioning levels and future studies should take this into consideration.

The significance of these findings and their implications for age and sex differences in lower extremity injury rates still remains unclear. Further investigation of the soccer turning, soccer heading and cutting tasks with more subjects and slight task alterations could yield information that could help identify risk factors for lower extremity kinematics. In future studies, trunk motion and strength should also be included to help determine if landing characteristics are a result of lack of strength or altered neuromuscular landing patterns.

Conclusion:

This study attempted to find age and gender differences in landing kinematics between recreational soccer players. Studies have linked increased age with injury, however, specific studies linking other factors such as gender, generalized joint laxity and neuromuscular control to age are lacking. Gender-specific neuromuscular control strategies at the knee and hip have been demonstrated in young athletes, yet little information is available regarding strategies at other joints such as the ankle and how these may change with age. Studies of dynamic sport specific movements are also rare, yet they may be more valuable in examining movements that may lead to injury. This study attempted to explain the increasing number of lower extremity injuries seen in older athletes by examining landing kinematics during controlled and dynamic athletic tasks.

Although results varied with task, females in this study tended to land with more knee flexion than the males contradicting all but one previously reported study. Additionally, the females also tended to have greater hip flexion. The cause of both the increased knee and hip flexion in females is unknown and may possibly be due to sport participation, skill level, strength and neuromuscular control. Interestingly, the addition of dynamic tasks in this study such as soccer turning and soccer heading did yield interesting results. At touchdown during soccer heading, females tended to have less knee flexion, yet, in the drop jump they had similar knee flexion values compared with the males, although not statistically significant. The difference in controlled landings and sport specific landings needs to be further studied to identify potential risk factors for lower extremity injury. Additionally, the relationship between the hip, knee and ankle needs to be addressed during landing.

The results of this study, although inconclusive, yielded interesting findings with respect to age and gender differences in kinematics in adult recreational soccer players.

The drop jump task, although easy to execute and control, may not be appropriate for evaluating soccer player kinematics. Rarely are soccer players required to land from a height of 60cm. Additionally, soccer is not a vertical jumping and landing intensive sport. Even though knee flexion angles were similar between genders for the drop jump, the results from the drop jump task also indicate that female soccer players may have a different landing strategy than males, absorbing the impact from landing in the hip and ankle as opposed to the knee. The implication of this and its relation to ACL injury remains unclear in the recreational soccer population. When compared with other tasks in this study, the drop jump placed the knee in the least injury prone position of the four tasks examined in this study. Additionally, no significant differences were found at the knee in age or gender. Despite this, the drop jump continues to be studied in the literature; however, may not be appropriate for studying a recreational soccer population.

The step right, cut left task did not yield any significant kinematic findings and may have been too controlled with use of a small platform for takeoff. Although previous studies found differences between genders, differences between two similar studies were conflicting and evidence that kinematic gender differences exist during sidestep-cutting maneuvers remains inconclusive. Kinematic task comparison results demonstrate that the step right, cut left task does place the knee into an injury prone position and despite the lack of significant findings in this study could be a useful task to examine in future studies of soccer players.

The soccer turning task was designed and hypothesized to place the ACL into the most injury susceptible position as researched from the literature. The athlete decelerated the knee into flexion and then placed the knee into internal rotation. Both of these movements are known mechanisms for ACL injury. Also, this task was soccer ball focused and may have yielded more natural movements similar to those achieved in an actual soccer practice or match. The results from this task demonstrated that older females have significantly less maximum knee flexion than older males. Additionally, young males had significantly more knee internal rotation at touchdown and maximum values than the young females. Unlike other tasks performed in this study, the soccer turning task demonstrated that both female groups had less overall maximum knee flexion than the males, although not significant for the young females. The older females and younger males may be most susceptible to ACL injury during this task because of the lack of knee flexion in the older females and the increased internal rotation in the young males. The soccer turning task was also the only task that had significant differences in age and gender at the knee in more than one plane of motion. Task comparisons also demonstrate that this task placed the knee at the greatest risk for injury by combining the least amount of knee flexion on average with the greatest abduction and greatest range of knee external rotation during the second half of the stance phase.

The soccer heading task yielded similar results to the drop jump task, with one exception: females tended to have less knee flexion at touchdown than the males (although not statistically significant). For soccer players, the soccer heading task may be a better kinematic evaluator in terms of knee flexion as compared to the drop jump task. The inclusion of the soccer ball in this task may have yielded more natural and "realistic" landing patterns observed in soccer matches. The fact that females have less flexion during this task should be validated and more subjects should be tested to increase power and decrease variability. The results from the soccer heading task also seem to indicate that older males may be more susceptible to knee injury during this task because of their lack of knee flexion angular velocity. Although the literature does not state low knee angular velocity as an ACL risk factor, older athlete kinematics have not been evaluated. Physiological changes and associated kinematic differences have not been established and perhaps low knee angular velocity in older males may make them more susceptible to injury because they cannot absorb the landing at the knee as quickly as females and younger males. Further kinematic studies on older athletes should be evaluated.

Not all injuries are preventable, but finding risk factors that lessen the chance for injury are extremely important. Knee injuries in particular have long rehabilitation regimens and have been linked to osteoarthritis later in life. Preventing injuries by determining the risk factors and creating intervention programs to lower the risk for injury at all ages can lead to a healthier generations of athletic participants.

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