MECHANISM AND TIMING EFFECTS ON THE KINEMATICS AND KINETICS OF THE RUNNING AND CUTTING MOTION

by
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ABSTRACT

JENNIFER J. PRESTON: Mechanism and Timing Effects on the Kinematics and Kinetics of the Running and Cutting Motion
(Under the direction of Dr. William Garrett and Dr. Henry Hsiao)

This study examines the lower extremity biomechanics, kinematics and kinetics during cutting maneuvers performed by recreational athletes by comparing the effects of anticipation, gender and training on the biomechanics of the cutting maneuver. Ankle, knee and hip injuries are thought to most likely to occur when performing such cutting maneuver. Understanding the dynamics of motions during cutting is the first step to prevent such injuries. Previous studies have compared the cutting maneuver to a straight-ahead run, however a more typical situation is an abrupt unanticipated change of direction. The hypothesis of this study is that decreasing the time between when an athlete is given a signal to the direction of a cutting maneuver and the performance of that cutting maneuver changes the motion dynamic which would lead to the increased risk of injury, specifically at the knee. Thirty-three recreational athletes (16 women and 17 men) participated in this study. Each of the subjects performed the three timing conditions (preplanned, planned and unplanned) for cutting in both the left and right directions and the straight-ahead run. A total of 46 dependent variables were examined for this study including: peak moments and angles at the ankle, knee and hip joints along with GRF, and trunk movement. There were significant difference found between the cutting maneuver compared to the straight-ahead run at the ankle, knee and hip joints. For the timing condition only the trunk rotation was found to be significantly different between unplanned and preplanned timing conditions for both the left and right cutting maneuvers ($p<.005$). Leg dominance significantly effected moments at the ankle and knee joints. The non-dominant leg was found to be potentially more susceptible to injury than the dominant leg. A significant difference in hip movement between men and women was identified with women showing more hip adduction than men ($p<.039$). Experience or training was found to have a significant effect on maximum dorsiflexion angle with the less experienced subjects having larger dorsiflexion angles.

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LIST OF ABBREVIATIONS

ACL	Anterior Cruciate Ligament
ASIS	Anterosuperioilliac Spine
CNS	Central Nervous System
COM	Center of Mass
EEG	Electroencephalogram
EMG	Electromyography
ERG	Electroretinogram
ERP	Early Reaction Potential
GRF	Ground Reaction Force
ICC	Intraclass Correlation Coefficient
LCL	Lateral Collateral Ligament
MCL	Medial Collateral Ligament
PCL	Posterior Cruciate Ligament
ROM	Range of Motion
SEM	Standard Error of Measurement
VER	Visual Evoked Response

1. INTRODUCTION

Sudden movements in an unexpected direction are common in athletic activities. As a defender steps between a soccer player and the goal, or a screen is set by an opposing player blocking the intended path to the basket, or a tree branch has fallen into the path of a runner, a quick adjustment needs to be made by the athlete to avoid a collision. These adjustments often require a cutting movement, i.e., a sudden change of direction along with either a deceleration or acceleration.[11,12,13,15,71,116]

Cutting movements have been linked to serious knee injuries including ACL (anterior-cruciate ligament) injuries. Performing cutting movements, especially unexpected cutting movements, may place high strains on the ACL because of the sudden deceleration, lower extremity flexion-extension, valgus-varus and internal-external rotation movements involved.[11,13,71] While athletes may be able to control their body positions, creating conditions that cause minimum mechanical loading on their bodies when performing an anticipated movement, more often the movement is an unanticipated response to external stimulus (an obstacle, another player or a reaction to change in direction of the movement of the ball).[11] Errors in control of the body's position and loading in unanticipated cutting movement may cause excessive loading to certain joint structures, such as the ACL, which can cause injuries.

This study examines lower extremity biomechanics, kinematics and kinetics, during cutting maneuvers performed by recreational athletes. The study will compare the effects of anticipation, gender and training on the biomechanics of the cutting maneuver. The effects of anticipation will compare the extent to which various signal times (preplanned, planned and unplanned) affect the cutting maneuver and to what degree kinematics and kinetics of the ankle, knee and hip joints, and the trunk are affected by the different signal times. The study will also examine if gender plays a significant role in the biomechanics of the cutting maneuver in reaction to different signal times. In addition, the study will explore the impact that prior training may have on the biomechanics among athletes performing cutting maneuvers in reaction to various signal times. Understanding the lower extremity biomechanics for these variables of the cutting maneuver could enhance the understanding of non-contact knee injuries such as ACL injuries, and therefore, may assist in developing intervention strategies to reduce the risk for non-contact ACL injuries.

An ACL tear is a common type of knee injury resulting from participation in athletic activities. The incidence of ACL ruptures has been estimated to be 1 in every 3,000 people within the general population in the United States per year. Over 70% of all ACL injuries occurred in recreational and competitive athletic activities.[30,56,100] The estimated incidence of ACL injuries is greater than 3 per 100 athletes over the course of a season.[71] Recent studies indicate that approximately 175,000 primary ACL reconstruction surgeries are performed annually in the United States, with an estimated annual cost of more than $2 billion.[36]

Participation in recreational athletic activities can be both beneficial and hazardous to one's health. In 2002 there were approximately 20.3 million injuries due to participation in recreational and organized athletic activities. Basketball and soccer accounted for 4.4 million of the total number of injuries.[69] One of the more common and serious injuries that occurs in basketball and soccer is an injury to the knee, specifically an ACL injury.[23,44,50]

An ACL rupture is a devastating knee injury that can significantly affect patients' activity levels and qualities of life. A complete ACL tear can induce many chronic knee disorders including knee instability, mensical and chondral surface damage, and osteoarthritis. Damages to joint structures significantly affect knee functions and often force patients to decrease their activity levels and change their life styles.[44] After an acute ACL rupture, 31% of the patients reported a subjective moderate to severe overall disability in walking activities alone, 44% of the patients reported a moderate to severe overall disability for routine activities of daily living, and 77% of the patients reported a moderate to severe overall disability for sports activities.[36,92]

Women have a higher incidence of ACL injuries than men. Studies have shown that the risk of ACL injuries for female collegiate soccer and basketball players is 3 to 10 times higher than the risk of their male counterparts.[4,46,85,97,119] There is no one specific factor that provides an explanation for the increased rate of ACL tears in women. Some of the factors that are thought to increase risk of injury for women are intrinsic, including the Q-angle, pelvic dimensions, and hormones; others are extrinsic, including muscle strength and activation of hamstrings.

Quadriceps muscles have been thought to be a contributor to ACL injuries. The role of the quadriceps muscles is to pull the tibia anteriorly, which places high stresses on the ACL at low flexion angles.[23] Hamstrings pull contrary to the quadriceps by resisting mediolateral and anterior tibial translation forces. These two forces combined provide dynamic stability to the knee joint.

1.1 Background of Injury Mechanism

Most of the cutting maneuvers performed by defenders in basketball and soccer games are unexpected quick changes in running directions.[106] To change direction one must steer the body towards a new direction which means reorientation of the entire body toward the new direction of travel.[95] The control of body positions and loading, however, may have increased errors if the movement is not well preprogrammed.[84] The amount of time an obstacle appears prior to the necessary movement also effects the way a person moves. The center of mass (COM) follows the visual system and the whole body follows the COM.[84] Therefore, the first part of the body that needs to change direction is the eyes. Research has shown that a preplanned movement starts at least one step prior to turning.[85] Motor tasks, including reflex responses, muscle activity and postural adjustments, are controlled by the central nervous system (CNS).[10] Postural adjustments are considered to be a feed-forward neural mechanism when they are anticipated. When preplanned, the movement starts with foot placement and the body follows the foot placement.[85] If the object or visual cue appears less than one step prior to the turn, the trunk will move first. The trunk will roll in the direction of the turn, followed by the head, rotating in the direction of the turn and the rest of the body will follow the trunk.[85]

1.2 Statement of Problem

Forces acting on the knee are increased with a cutting maneuver compared to a straight-ahead run.[6,13,96] The more typical game or practice situation is an abrupt, unanticipated change of direction, known as the unplanned cutting movement. Studies on the lower extremity biomechanics in unplanned cutting maneuver are limited. The studies that have been done used elite (college) soccer players who were very familiar with the sidestep cutting maneuver. Recreational athletes will have less training for sudden changes in direction associated with the sidestep cutting maneuver than elite soccer players. The lack of understanding of the lower extremity biomechanics in unplanned cutting movement prevents us from a complete understanding of the mechanism of non-contact ACL injuries in athletic activities.

1.3 Research Questions

1) Is there a significant increase in the forces and moments about the knee joint for an unplanned cutting motion versus a preplanned cutting maneuver? *Hypothesis*: There will be a significant increased in forces and moments about the knee joint for an unplanned cutting maneuver compared to a preplanned cutting maneuver.

2) Is there a significant difference between the muscle activation of the hamstrings and quadriceps for an unplanned cutting motion versus a preplanned cutting maneuver? *Hypothesis*: There will be a significant increase in the muscle activation of both the quadriceps and hamstrings during the unplanned cutting maneuver compared to the preplanned cutting maneuver.

3) Is there a significant difference in the forces and moments about the knee joint between male and female recreational athletes for the unplanned and preplanned cutting maneuver? *Hypothesis*: There will be a significant increase in the forces and moments about the knee joint for the female recreational athletes as compared to their male counterparts during both the unplanned and preplanned cutting maneuvers.

4) Is there a significant difference in the muscle activation of the quadriceps and hamstrings between male and female recreation athletes during the unplanned and preplanned cutting maneuver? *Hypothesis*: There will be significantly greater muscle activation for the quadriceps and significantly lesser muscle activation for the hamstrings for the female recreational athletes as compared to the male recreational athletes during both the unplanned and preplanned cutting maneuver.

Separating specific components tested within the four research questions, additional questions regarding those components were posed:

(1) What is the effect of different signal times (preplanned, planned and unplanned) on peak ground reaction force during the stance phase? *Hypothesis: A decrease in the reaction time is likely to cause an increase in the peak ground reaction force.*

(2) What is the effect of different signal times on peak moment requirement of the knee joint? *Hypothesis: A decrease in the reaction time is likely to cause an increase in the peak moment requirement.*

(3) What is the effect of different signal times on duration of the stance phase? *Hypothesis: A decrease in the reaction time is likely to cause an increase in the duration of the stance phase.*

(4) What is the effect of different signal times on the sagittal plane joint position of the ankle during the stance phase of the cutting motion? *Hypothesis: A decrease in the reaction time is likely to cause a decrease in the ankle flexion.*

(5) What is the effect of different signal times on the sagittal plane joint position of the knee during the stance phase of the cutting motion? *Hypothesis: A decrease in the reaction time is likely to cause a decrease in knee flexion angle.*

(6) What is the effect of different signal times on the sagittal plane position of the hips during the stance phase of the cutting motion? *Hypothesis: A decrease in the reaction time is likely to cause a decrease in hip flexion angle.*

(7) What is the effect of different signal times on the transverse plane position of the trunk during the stance phase of the cutting motion? *Hypothesis: A decrease in the reaction time is likely to cause an increase in the trunk motion.*

(8) What is the effect of different signal times on peak amplitude of the EMG of the hamstrings during the stance phase of the cutting motion? *Hypothesis: A decrease in the reaction time is likely to cause an increase of the muscle activation of the hamstrings during the stance phase of the cutting motion.*

(9) What is the effect of different signal times on peak amplitude of the EMG of the quadriceps during the stance phase of the cutting motion? *Hypothesis: A decrease in the reaction time is likely to cause an increase in muscle activation of the quadriceps during the stance phase of the cutting motion.*

1.4 Operational Definitions

Recreational athlete: one who participates in some athletic task for a minimum of three hours per week;

Dominant leg: the leg that the subject stand on when kicking a soccer ball;

Cutting movement: a deceleration followed by a sudden change in direction;

Cutting maneuver: running or jogging forward followed by a cutting movement;

Timing conditions: three conditions in each of the two turning directions: 1) an early timing signal approximately three seconds before the subject reaches the force plates, considered a preplanned condition; 2) a middle timing signal approximately two seconds before the subject reaches the force plates, also considered a planned condition; and 3) a late signal approximately one second before the subject reaches the force plates, considered an unplanned condition;

Timing device: a device with one motion sensor nine meters from the force plates that once activated randomly selects the timing condition. The timing device includes a white signal board with a light next to either a right or left arrow at the end of the laboratory toward which the subjects run;

Preplanned cutting maneuver: advanced knowledge, at least four steps prior to the movement, as to the direction that one will cut when reaching the force plates and the cutting maneuver that follows that knowledge;

Planned cutting maneuver: short-term knowledge, at least two steps prior to the movement, as to the direction that one will cut when reaching the force plates and the cutting maneuver that follows that knowledge; and

Unplanned cutting maneuver: very short-term knowledge, about one step prior to the movement, as to the direction that one will cut when reaching the force plates and the cutting maneuver that follows that knowledge.

1.5 Assumptions, Limitations and Delimitations

Assumptions:

- The data from previous studies involving the study of knee kinematics and/or kinetics for a cutting maneuver were reliable;

- Subjects gave 100% effort to perform the cutting maneuver correctly during each trial;
- All of the subjects were recreational athletes exercising a minimum of three times each week; and
- The Peak Analysis System synchronized the cameras and force plate correctly.

Limitations:

- Age of subjects (the age range was 18-33 years old);
- Models for MS3D65;
- The timing device randomized the time the signal was given and direction displayed; and
- Noise data existed.

Delimitations:

- The direction signals and times were randomly selected by a computer as to eliminate the anticipation factor;
- Both male and female subjects were included;
- Noisy data was reduced using Butterworth filter; and
- Body weight was correlated with the force plate data results to provide units of force allowing comparison between subjects.

1.6 Significance of the Study

The number of injuries occurring in recreational and competitive athletes is approximately 20 million each year.[69] The purpose of this study is to examine the anticipation factor with regard to the cutting maneuver; specifically, how does the length of time the subject has to make the decision as to which direction to cut affect the movement and the forces acting on the knee? The goal of this study is to determine the extent to which different signal times (preplanned, planned and unplanned) affect the cutting motion and to what degree the knee, ankle, hip and trunk are affected by the different signal times. The results of this study will further explain the extent to which sudden changes in direction increase forces at the knee. It may be possible to increase muscle control, by practicing high risk maneuvers, and educate trainers to train athletes to respond faster in reactive cutting movements, thus reducing the number of non-contact injuries that occur among recreational and competitive athletes.

2. LITERATURE REVIEW

The human body moves through space in three dimensions. In order to understand the body movement, the planes of the body first need to be understood. While standing, the frontal plane divides the body vertically into the front and back or anterior and posterior. Motion in this plane is know as flexion/extension or for the foot plantar/dorsiflexion. The mid sagittal plane separates the body vertically into left and right sides; the terms for this plane are medial and lateral with medial being the direction towards the center of the body. The motion in this plane is known as adduction/abduction. The third plane is the horizontal plane, which separates the body into top and bottom or superior and inferior. Superior means closer to the head and inferior is closer to the feet. Motion in this plane is known as internal/external or, for the foot, inversion/eversion.

All human movement is performed in three-dimensional space. This is described using a coordinate system with axes x, y, and z. In these axes, the body moves to the left and right, forward and backward, and up and down. Studying the movement of the body in the three-dimensional planes in relation to the planes of the body requires complex motion analysis technology.

The anatomy and biomechanics of the body, and those joints involved in the movement, need to be understood before the biomechanics of a movement and risk of injury from that movement can be understood. Once the anatomy and biomechanics of the body are known, the mechanics of the movement can be studied. Once the biomechanics of a movement is established, the next focus becomes the point at which, during that movement, the highest risk for injury occurs and in which plane.

The purpose of a literature review is to narrow the focus of what is a very large broad topic to parts relevant to a specific project or study. The lower extremity is a common area of study in the field of biomechanics. The ankle, knee and hip joints create movement in the lower extremities. An understanding of the anatomy of the ankle, knee and hip joints and their interaction with the trunk is important to the understanding of how the biomechanics of specific cutting motions affect the individual joints. This literature review will present research leading to an understanding of the anatomy and biomechanics, which explains how the cutting maneuver may be linked to many athletic related injuries. The focus of this study and paper involves subjects' reaction time to a signal displayed while running forward followed by a cutting maneuver. To understand how a subject will react to this signal, a review of the literature discussing reaction times is presented. Following the review of reaction times, this literature review will examine, various biomechanical methods available for measuring the variables, including running speed, EMG, videographic data and analog data.

2.1 Lower Extremity and Trunk Anatomy[40]

Biomechanics is musculoskeletal resistance either against gravity causing the body to remain stable or to move the body in a desired direction. Lower extremities carry the weight of the entire body and propel the body in the desired direction of travel, relying on a complex set of joints and muscles. The COM is located in the trunk, which can dominate body reorientation.[85] This section concentrates on the lower extremity and trunk bones, muscles, and the manner in which the individual joints (hip, knee and ankle) and trunk can articulate. Understanding how the lower extremity joints move will make it easier to understand what kinematics and kinetics are required to perform a specific maneuver. A complex structure of muscles and tendons counteracting each other are involved just to stand at rest.

2.1.1 Ankle Anatomy

The ankle joint consists of several bones and muscles that work together to balance and support the human body. The ankle joint is a hinge-joint between the foot and the lower leg or calf. The boniest part of the ankle joint is the foot.

The ankle joint, a hinge-joint, is comprised of four smaller joints: the talocural, talocacaneonavicular, transverse tarsal and subtalar joints. The talocural joint, comprised of the tibia, fibula and talus, is commonly referred to as the ankle joint in lay terms. The main motion of the talocural joint is plantar-dorsiflexion, but it also allows adduction/abduction, and inversion/eversion. The talocacaneonavicular, transverse tarsal and subtalar joints create foot pronation (dorsiflexion, eversion and abduction) and supination (plantarflexion, inversion and adduction). Working together, these four smaller joints allow six degrees of freedom of the ankle, movement of the ankle in each of the planes of the body in three translations and three rotations.

The ankle joint connects bones in the foot and calf. The foot has three regions the: tarsus, metatarsals and phalanges. The tarsus consists of the calcaneum (calcaneus), astragalus (talus), cuboid, navicular, and cuneiform bones (Figure 2.1). The calcaneum, commonly referred to as the heel, is the strongest and largest of the tarsus bones. Proximal to the calcaneum is the astragalus, the second largest of tarsus bones, which supports the tibia. The cuboid is on the lateral side of the foot in front of the calcaneum and behind the fourth and fifth metatarsals. On the medial side of the foot is the navicular. It sits between the astragalus and the cuneiform bones. The three cuneiform bones are: the internal, located between the navicular and base of the fifth metatarsal; the middle, the smallest of the three and located like a wedge between the other two navicular bones; and the external, also situated like a wedge, with the medial side in the middle cuneiform bone, on the lateral side of the cuboid, proximally to the navicular and distally on the third metatarsal. The metatarsal bones are five long bones that comprise what is known as the arch of the foot. These bones are numbered one to five with number one being the most medial of the five. At the end of the foot are the phalanges, also known as the toes. There are two phalanges in the big toe, and each of the other toes has three phalanges.

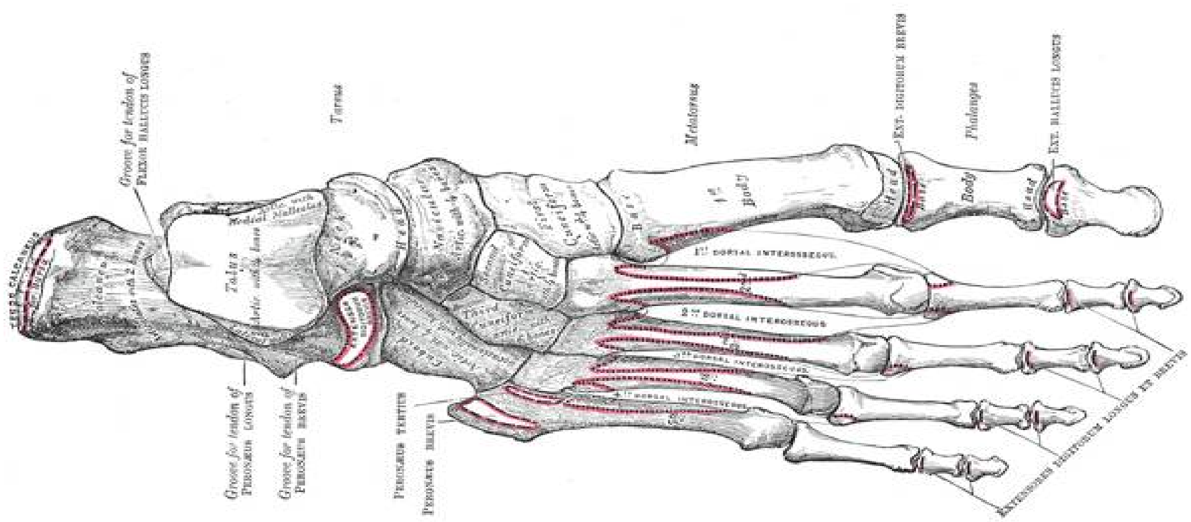

Figure 2.1 – Bone Anatomy of the Foot[40]

There are seven ligaments at the ankle joint. These ligaments cross the ankle joint, moving the foot in relation to the calf. The ligaments are divided into medial and lateral groups. The medial group consists of: the tabionavicular ligament connecting medial malleolus to the navicular preventing abduction; the calcaneotibial ligament, connecting the medial malleolus and calcaneus, also preventing abduction; and the anterior and posterior talotibial ligaments connecting the medial malleolus and talus, limiting plantar/dorsiflecion. The lateral ligament group consists of: the anterior talofibular ligament connecting the lateral malleolus to the talus limiting plantar flexion; the calcaneofibular ligament connecting the lateral malleolus to the calcaneus, also resisting adduction; the anterior talocalcaneal ligament which runs along the base of the calcaneus resisting adduction; and the posterior talofibular and posterior talocalcaneal ligaments connecting the lateral malleolus to the talus and limiting dorsiflexion.

The calf sits between the ankle joint and the knee joint, on the other side of the ankle joint from the foot. The calf is of much less complex bony composition than the foot, consisting of only two bones, the fibula and the tibia. The fibula is on the lateral side of the leg and is the smallest of the calf bones. The fibula is a very long slender bone that sits just distal to the head of the tibia. The distal end of the fibula, called the lateral malleolus, is located on the medial side of the astragalus. The tibia is located on the anterior, medial side of the calf. It is second in size only to the femur. The head of the tibia comprises the distal part of the knee joint and the distal part, the medial malleolus, is located on the lateral side of the astragalus.

The calf is comprised of thirteen muscles. The muscles in the tibial region of the calf can be divided into three groups: anterior, posterior and outer. The anterior group is often called the anterior compartment. It consists of the tibialis anticus, externsor proprius halluscis, extensor digitorum longus and the peroneus tertius. These muscles work together to plantar/dorsiflex the foot, or to invert/evert the foot. The posterior group of muscles has two layers, superficial and deep. The gastrocnemius, often referred to as the calf muscle, soleus and the pantaris are found in the superficial layer. These muscles are very powerful and are constantly being used as they raise the heel and, thus, the entire body. The deep layer of posterior calf muscles consists of the popliteus, flexor hallucis longus, flexor digitorum longus and the tibialis posticus. The popliteus bends the calf toward the thigh, the tibialis inverts and extends the foot and the flexors plantar and dorsiflex the foot. The fibular region of the calf consists of the peroneus longus, which everts, dorsiflexes the foot and basically keeps the calf perpendicular, and peroneus brevis, which assists in the dorsiflex of the foot.

Muscle skeletal resistance starts at the ankle, as it is the joint closest to the ground[1]. The forces from the ground must first go through the ankle to reach other joints. As a person runs or walks forward the normal stance phase of the gait is a heel-to-toe motion. At the beginning of the stance phase, the calcaneus bears the majority of the body weight and the foot is flexed using the anterior compartment muscles. As the foot moves through the stance phase, first the arch and then the toes begins to absorb some of the weight. Near the end of the stance phase, from midstance to toe-off, the metatarsals or toes bear the majority of the body's weight and the heel rises off the ground, putting into use the superficial layer of the calf muscles.[41]

2.1.2 Knee Anatomy

The knee is the largest and one of the most complex joints in the human body.[34] It sits between the two longest lever arms in the body, bears most of the body weight and requires strong muscle groups to activate motion.[34] This makes it especially vulnerable to overuse and trauma. On average, the knee joint is used over a million times a year.[78]

There are three bony structures in the knee joint (Figure 2.2). The first bony structure is formed by the femur, in the thigh. The femur is the longest largest and strongest bone in the body and the only bone in the thigh. The upper part of the femur consists of the head and

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[1] Ankle stability is very important for the overall stability of the body.[41,74] The most influential ligaments in the lateral direction are the anterior talofibular ligament (ATFL) and the calcaneofibular ligament (CFL).[62]

neck, which are considered part of the hip joint. The greater and lesser trochanters are prominent parts of the femur, which provide leverage for the muscles that rotate the thigh. The shaft of the femur is almost perfectly cylindrical. The lower part of the femur is divided into knuckles, called condyles. As noted above, there are two bones in the calf, the tibia and fibula. These two bones form the second bony structure of the knee joint. The tibia is the larger bone and is a very important part of the structure of the knee. The fibula is much smaller than the tibia, is below the level of the knee joint and is only considered part of the knee joint because of the insertion point of the lateral collateral ligament. The third element to the bony structure of the knee is the patella. The patella plays an important part in connecting the two long lever arms. Protection of the knee joint is provided by the patella, which is connected to both the femur and the tibia via the patella tendon. Some consider the patella a bone in its own right; others consider it a sesamoid bone living in a long tendon.

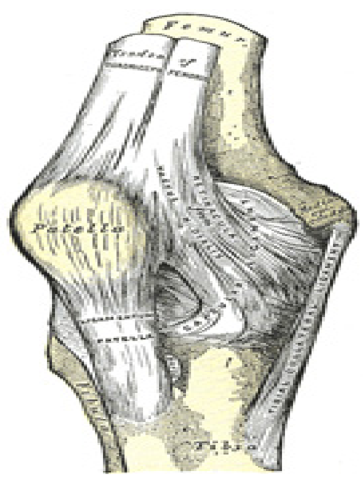


Figure 2.2 Knee Joint Anatomy[40]

The thigh has four regions of muscles, the anterior femoral, internal femoral, gluteal region and posterior femoral. The anterior femoral and posterior femoral regions, of the thigh are most often discussed as influencing the movement of the knee joint. The anterior femoral region of the thigh consists of what are the quadriceps (the rectus, vastus lateralis, vastus medialis, and vastus intermedius and crureus), the sartorius, the tensor fasciae femoris, and the articularis genu muscles. The posterior region of the thigh, the hamstring muscles, consists of the biceps, semitendinosus, and semimembranosus muscles. The patella allows the forces from the quadriceps to be translated to the tibia during knee flexion. The forces from the quadriceps provide an opposing moment to the moment produced by the ground reaction forces.[78]

The ligaments of the knee are the structures that stabilize the knee. Unlike other joints, the knee does not have much bony stability and for the most part relies on the ligaments for stabilization. This requires the ligaments to tolerate high rates of cyclic loading in order to keep the knee joint stable over time. Ligaments of the knee include two on the interior of the knee and two on the exterior. The interior ligaments are the posterior cruciate ligament (PCL) and the ACL. These two cruciate ligaments cross each other at the interior of the knee. They serve to prevent the knee from sliding excessively anteriorly or posteriorly; making sure that the tibia does not slide forward or backwards on the femur. On the exterior sides of the knee are the medial collateral ligament (MCL) and lateral collateral ligament (LCL). The MCL and LCL provide side-to-side stability, for example, during a cutting motion. The MCL and ACL account for the changing of the rolling versus gliding rotation during flexion.[42] The ACL also reduces the amount of internal and external rotation that occurs at the knee. A small amount of axial rotation is normal and the degree of rotation is dependent on the amount of flexion of the knee.[44] The ACL is one of the most commonly injured parts of the knee. It stretches from the medial surface of the lateral femoral condyle to the anterior tibial spine. The main function of the ACL is as a stabilizer of the knee for anterior tibial translation especially when landing from a jump or turning. When creating a model of the knee, the distance between the insertion points of the MCL and ACL must be considered.

Over the past decades the biomechanics of knee injuries have been studied by various researchers.[72,73,79,99,120] The knee has a total of six degrees of freedom, three in translational planes and three in rotational planes. Most of the motion occurs in the sagittal plane.[44] The pathway of motion for normal knees is a semicircular arc on the femoral condyles. Knee motion is a combination of rolling and gliding along the pathway.[110] Rolling motion initiates flexion and the gliding occurs near the maximum flexion. The instantaneous center is displaced from normal position, defined as a semi-circular pathway on the femoral condyle.[44]

Other properties that affect the mechanics of the knee joint are the surface area geometry, viscoelastic properties of the cartilage and menisci and the load at the joint surface.[44] The geometry of the surface area affects the amount of pain and wear that occurs. A rough surface area will cause more wear on the bone itself and the surrounding tissues causing swelling and excessive pain. A smooth surface area will allow for easy gliding of the joint. The viscoelastic properties of the cartilage and menisci affect the mechanics much in the same way that the surface area geometry does. The more elastic those tissues, the greater the ease of motion of the joint, although there is a balance that needs to be met as the cartilage or menisci can not be totally elastic or it would cause the knee to spring when moving. Controlling movement of the knee joint is the rotation of the hip joint.

2.1.3 Hip Anatomy

The hips are the bony area of the body that distinguishes gender. The female's hip bones need to be able to carry and deliver a child and, therefore, are shaped differently than the male hip bones, having a wider pelvic cavity, larger pelvic outlet and oval rather than heart shaped inlet. Although the hips in males and females are shaped differently, there are more commonalities than differences and the biomechanics of the hip in males and females are the same, as are their functions. The hip joint is a ball and socket joint, one of two in the body; the shoulders being the other ball and socket joint. This type of joint offers the largest possible range of motion. For the hips, it is formed by the head of the femur into the cup cavity of the acetabulum.

The hip joint consists of the coxal bone and the femur (Figure 2.3). The ilium, ischium, pubis and acetabulum make up the coxal bone. When people think of hip bones, most are actually thinking of the ilium, which is the superior, expansive portion of the coxal bone that creates the prominence of the hip. The bones that you sit on are the ischial tuberosities of your hips, and are the most inferior and strongest part of the hip bones. The pubis forms the front of the pelvis. The coxal bone has the sacrum on the medial inferior side and the femur on the superior side. Another important part of the hip joint is the acetabulum, which forms a cup-shaped, deep impression medially by the pubis, distally by the ilium and posteriorly by the ischium.

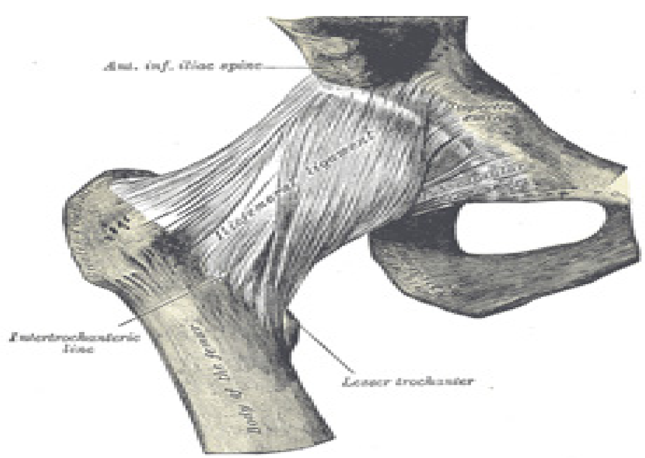


Figure 2.3 – Hip Joint Anatomy[40]

The hip joint has extensive movement. Flexion, extension, adduction and abduction are the normal functions of the hip joint, however, the hip joint also allows circumduction and rotation. Since the head of the femur fits closely into the socket of the acetabulum, it can extend more than 180 degrees. The head of the femur is held in place by the cotyloid ligament. The type of motion for the hip joint is rolling, like the knee.

The iliac region muscles and ligaments of the hips also assist in moving the hip joint. The iliac region consists of three muscles, the psoas magnum and parvus and the illiacus. These muscles flex the thigh upon the pelvis and assist in raising the trunk. Keeping the body upright without muscle fatigue is the job of the hip's ilio-femoral ligament. The ilio-femoral ligament is the strongest ligament in the body. It works with the muscles of the hip to balance the center of mass of the body over the lower extremities to stabilize the body.

The muscles of the thigh, simplified into the quadriceps and hamstring muscles, assist in movement of the hip joint. The muscles in the thigh and gluteus create flexion of the hip. The smaller gluteus muscles and quadriceps mainly perform flexion. The gluteus maximum and the hamstrings perform extension. The adductor muscles and the gluteus maximus adduct the thigh. The thigh is abducted by a combination of all three gluteus muscles. Rotating the thigh outwards requires the quadriceps, adductors, gluteus maximus and various other small muscles in the hip joint. Inward rotation is achieved by fewer muscles; just the two smaller gluteus muscles and tensor fasciae femoris are required.

Cartilage surrounds the hip joint providing a smooth surface for the joint to rotate. The synovial membrane is the cartilagonus surface at the head of the femur covering all portions of the head, which are contained in the hip joint. The femur must carry most of the body weight and while the strongest bone of the body, it can be weakened by osteoporosis, and when weakened the neck of the femur is more likely to break. The hips are part of the lower extremities and the trunk.

2.1.4 Trunk Anatomy

The main bony structures of the trunk are the spinal cord and rib cage. The definition of the trunk for this study is that part of the body from the hip joints to the shoulders. For this literature review it will be assumed that the trunk moves as one solid section not considered to bend to the side and not considered to curve at the spine.

Starting at the lowest part of what is considered the trunk, the hip region forms the base of the trunk (specifically the right and left anterosuperioilliac spines (ASIS) and the lumbar vertebrae, L4 and L5). The spinal cord has two sections lower than the lumbar vertebrae, which are the coccyx, more commonly know as the tailbone, and the sacrum, both of which are in the hip region, but not considered part of the hips. Moving upwards from the lumbar vertebrae are the thoracic vertebrae. The ribcage is attached to the thoracic or dorsal region of the spinal cord. The chest area of the body is often referred to medically as the thoracic region, with its bony anatomy consisting of the ribs and sternum. The cervical vertebrae make up the neck and shoulder region of the spine. The shoulders are the top part of the trunk, specifically the most lateral part of the clavicle and the scapulas, the bones on the upper back are often referred to as the shoulder bones. The acromioclavicular joints (AC joints) are the shoulder joints that define the upper part of the trunk.

Many muscles are necessary to move a large area of the body like the trunk. Some of the muscles used to flex or extend the trunk in relation to the leg are the hamstring and quadriceps muscles. Other muscles used to rotate and flex the trunk are found in the back and abdomen. The rotators spinae are found in the dorsal region of the spine, and multifidus spinae filling up the groves on either side of the spine. These two groups of abdomen muscles work together to rotate the spine, with the spine turning in the opposite direction of the active muscles. The abdominal muscles perform three functions. Two of those functions involve breathing. The third function, of interest for this literature review, involves the superficial abdominal muscles. These include the obliquus externus, obliquus internus, transversalis, and rectus, which act together to bring the pelvis upwards, when climbing stairs, and bending the trunk from side to side. The deep muscles of the abdomen, as discussed above in Section 2.1.3, are the psoas magnus, psoas parvus, iliacus and quadratus lumborum which, when acting together, flex the trunk.

The biomechanics of the trunk are very different from those of the lower extremity joints. The trunk can move relative to other parts of the body, but is not a joint itself. It is referred to as the core of the body, for it is where the COM is located.[85] The trunk movements of interest for this review are the movements from point at which the trunk starts to move toward the turning direction to the point at which the trunk is completely facing the turning direction. Only left and right rotation, will be reviewed in this study. The trunk controls the posture of the body. Strong trunk stabilization provides a solid base for other movements. When standing, the transverse abdominaus, multifidus internal and external oblique muscles are all active.[69] Weak core muscles can cause lower back pain and decrease stabilization of the trunk that can lead to injury. As a high percentage of the body mass is located in the upper body, movement of the trunk will dominate the body reorientation.[85]

2.2 Mechanics of the Cutting Maneuver

A quick change in running direction is important to the performance of some athletic activities.[92] The cutting maneuver is a specific movement often performed to quickly change the direction while running in an athletic activity or game. A cutting maneuver, described earlier, is defined as a sudden change of running direction along with deceleration of the body.[13,33,96] To change direction, one must steer the body towards the new direction, which means reorienting the entire body toward the new direction of travel.[92] However, the cutting maneuver may result in an increased number of errors in the control of body positions and loading of the joints if that movement is not well practiced.[23,33,46,79]

2.2.1 Types of the Cutting Maneuver

The two most common types of the cutting motion are the sidestep cut and the crossover cut.[23,92,96] The sidestep cut is an open maneuver in which a person plants the foot opposite from the direction he/she is turning.[49,92,96] In the crossover cutting maneuver a person plants the same foot as the direction to which he/she is turning.[92] For example, in the sidestep cut, the athlete would plant the left foot and turn to the right, in the crossover cutting maneuver, the athlete would plant the left foot, crossover and turn to the left. During the stance phase of both the sidestep cut and the crossover cut, the trunk completely turns toward the direction to which the person is turning,[92] for example, if the person is turning to the right, by the end of the stance phase the trunk would be turned completely to the right. Studies have compared these two cutting maneuvers.[13,23,49,50,73,92] It was found that the average values for the breaking and medio-lateral forces were greater in the sidestep cut than in the crossover cut.[92] The sidestep cut also showed higher vastus medialis activation than the crossover cut.[50] However, the crossover cut maneuver displayed significantly higher muscle activation for the hamstrings and gastrocnemius muscles as compared to both the sidestep cutting maneuver and straight-ahead run.[49]

Sidestep cutting maneuvers have been shown to be a mechanism that can cause non-contact ACL tears.[12,13,23,50,73,88,92,96,99] When beginning the sidestep cut, the first step, one step prior to turning, has been defined as that point at which the head changes direction during that step's stance phase.[92] A 90 degree sidestep cut has a very different momentum profile than the 45 degree sidestep cut or the straight-ahead run.[96] The sidestep cut values typically found in an athletic situation are cutting angles between 30 and 60 degrees from the straight-ahead run.[23,73] The goal of laboratory testing is reproduction of maneuvers found in games or practice. Although it is difficult to achieve exact reproduction of these maneuvers, using the angles these maneuvers are most often performed is as close a reproduction as is possible in a laboratory.

2.2.2 Joint Movement

During any type of movement the whole body follows the COM and the COM follows the visual system.[37] Research has shown that a preplanned motion starts at least one step prior to turning.[84] When preplanned, the movement starts with foot placement during the swing phase prior to the turning step, which will be slightly away from the direction of the turn, with the upper body turning after foot placement.[85] If the object or visual cue appears less than one step prior to the turn, the trunk will move first to face the new direction the body is turning and the foot placement will remain the same as if the body is continuing forward.[85] The trunk will roll in the direction of the turn followed by the head. The rest of the body will follow the trunk when a signal that is given is less than one step prior to the turn.[84]

As the foot touches the ground, the ankle is dorsiflexed allowing the heel to touch first as the touchdown part of the stance phase.[81] Peak dorsiflexion of the ankle is found near midstance of the sidestep cutting maneuver and peak plantar flexion occurs during toe-off of the sidestep cutting maneuver.[81] The most susceptible position for the ankle at the point of the heel-down is excessive supination, which can be caused by inversion/eversion imbalance leading to the possibility of an ankle sprain.[81]

The next joint, after the ankle joint, to be reviewed in relation to a sidestep cut is the knee joint. A sidestep cutting maneuver places greater forces on the medial side of the knee while reducing the forces on the lateral side.[96] For ligaments in the knee, dynamic situations are the most hazardous.[65,96] The muscles necessary to control the stability of the knee during a cutting movement can be studied using patients with an ACL deficiency (ACLD). In 1996, Beard et al.[6] found that ACLD patients had a greater flexion angle at mid-stance than the normal patients. From this it can be observed that by increasing flexion of the knee, the strain on the ACL is decreased.

Each lower extremity joint has a function to control movement and translate the body in the direction desired.[85] The hip joint can be the largest contributor to the horizontal velocity of the entire body when the trunk is upright.[120] The velocity of the hip joint affects the ground reaction forces at heel-down.[120] According to McLean et al. 2005,[72] in a sidestep cutting maneuver a correlation exists between the internal rotation position of the lower extremity and the degree of hip flexion. Due to this high initial internal rotation of the hips at initial contact, the medial muscles groups could be weakened leaving the knee susceptible to valgus load injuries.[72]

Unlike the lower extremity joint, the trunk is often ignored in cutting motion studies. It has been speculated that the torque generated by lower extremity, pelvis and torso is what actually changes the direction by applying a force to the ground.[96] The deceleration that occurs with a sidestep cutting maneuver has been suggested as necessary to aid in the change of direction of the trunk.[51]

2.2.3 Muscle Activation

Muscles control or resist the way a body movement occurs.[16,17,45] Different sets of muscles contract to produce different types of movements. The muscles associated with the sidestep cutting maneuver are those involved in moving the hip, knee and ankle joints. Of all the muscles in the lower extremity, the hamstrings and the quadriceps are most often discussed in relation to the sidestep cutting maneuver.

The purpose of the hamstring muscles is to extend the hip, flex the knee and restrict anterior tibial translation.[46,63,86,89] For the past decade, hamstrings strains have been one of the most common athletic injuries.[16] The anatomical properties of the hamstrings make them more susceptible to injury due to the large changes in length that occur.[16] During a cutting motion, hamstrings are most active when the knee is near extension, which is most often at the beginning of the stance phase.[63] The quadriceps muscles allow the hip joint to flex and extend the knee joint.[89] The quadriceps muscles are most active at touchdown of the stance phase in the cutting maneuver.[23] When the knee is flexed more than 70 degrees, the quadriceps muscles do not cause anterior tibial translation.[82,89] The purpose of the hip extenders, like the hamstring muscles, knee extenders, and quadriceps muscles, is to work together to stabilize the COM during deceleration of the sidestep cutting maneuver and propel the COM in the desired direction at toe-off of the stance phase.[81]

Stabilization of the hip and knee joints while completing a sidestep cutting maneuver is extremely important. Without stabilization at the hip and knee there is a lack of control of the body. Ironically, the muscular contractions that are attempting to stabilize the body during a sidestep cutting maneuver may actually be the cause of many knee injuries. Both the hamstring muscles and the gastrocnemius muscles assist in stabilization of the knee in the sagittal plane.[49] These two muscles can cause internal knee rotation to maintain the knee stabilization by activating at the same time.[49,89] Increasing hip flexion and rotation may reduce the ability of the medial muscle groups to resist valgus loads at the knee.[72] Activation of the gastrocnemius has been found to be significantly important for stability of the body, when gastrocnemius is more active in the beginning of the stance phase. At touchdown, the position of the COM of the body can shift from the back of the foot to the front of the foot, assisting with stabilization of the joints.[49,63]

A relationship has been shown to exist between the hamstring and quadriceps muscles at the knee joint. Hamstrings have been shown to have a much smaller maximum activation compared to the quadriceps, with the maximum torque of the hamstrings being approximately half the maximum torque of the quadriceps.[6,16] The small activation of the hamstrings coupled with the high activation of the quadriceps can produce significant anterior tibial displacement of the knee, which can increase the possibility of injury at the knee.[23]

2.2.4 Effect of Training

Studies have shown that those who participate in athletic activities requiring jumping, turning or twisting and which repetitively use the sidestep cutting maneuver are more controlled when performing the maneuver compared to those who participate in athletic activities that do not regularly use the cutting maneuver.[13,23,33,81,88,92,96,101] Experience or familiarity with the maneuver has been shown to have a strong correlation with the variability of the knee kinematics of the sidestep cutting maneuver; those with less experience have greater variability compared to the experienced athletes.[13,19,32,74,87,108]

After a knee injury, the rehabilitation techniques concentrate on the muscle activation patterns in landing and twisting that are believed to control the knee motion in cutting and pivoting maneuvers.[14,50] It is thought that if muscles used in the motions that are commonly believed to cause knee injuries are strengthened, these stronger muscles will reduce the chances of re-injury.[17,46] If the rehabilitation techniques of an injury are focused on the muscle activation patterns of the knee used to control motion during cutting maneuvers, then it would follow that training these muscles in a non-injured athlete would decrease the chance of an injury in the first place. In 1999 Hewett et al.[46] tested this idea and found that the untrained group had a 2.4 to 3.6 times greater rate of serious knee injury compared to the trained group (the difference in rate depended upon if the sport of volleyball was included or not). Using neuromuscular training, athletes can improve performance and reduce the risk of injury to the lower extremity, especially to the ACL in young female athletes.[23,33,46,47,72,73,79] With neuromuscular training of specific movements it is possible to more quickly change direction; again, possibly reducing the risk of injury.[19,73] Neuromuscular training can also influence the time it takes muscles to react to a signal.

2.3 Reaction Time

The time it takes to begin to react to a cue or object in the way of a movement is known as reaction time, a combination of perception time, (the time it take the body to perceive the stimulus) and movement time, (the time it takes the body to move) represented by the formula (RT = PT + MT) where “RT” is the reaction time “PT” is perception time and “MT” is movement time.[61] In the case where a visual signal is given, a visual cue is the recognition of a need for a turn.

2.3.1 Signal Process Pattern

Once an object or visual cue, referred here to as a stimulus, is seen by the retina, the signal must be sent to the brain to be processed. A signal is processed by following a path through the brain. From the retina the signal is sent to the occipital lobe via the optic nerve and lateral geniculate. The occipital lobe then sends the signal to multiple areas of the brain, which identify the direction and indication and make the decision as to the best response to the stimulus. Once the brain makes a decision as to how to respond to the stimulus, the signal travels to the cerebellum, the part of the brain that controls coordination. Signals travel from the cerebellum to the motor neurons of the spinal cord and finally to the muscles that need to be activated in coordination to alter the direction in which the body is advancing.[112]

Knowing how the body will respond, instruments can be used to measure how quickly the different parts of an individual body will respond to the stimulus. The first substage of a response is the sensation stage.[112] An electroretinogram (ERG) looks at how the retina responds to a flash of light (visual cue). The electrodes used by an ERG are: an exploring electrode (usually a contact lens on the cornea containing an Ag/AgCl electrode) and an indifferent electrode placed on the temple, forehead or earlobe.[112] These electrodes measure the change in potential that occurs as a characteristic of a temporal sequence. The first response is an ERP (early receptor potential), which shows the changes in the photopigment molecules generated by initial light-induce changes. It takes approximately 30 milliseconds (ms) for the light to light up after which the average time for the eye to respond to a stimulus is approximately 30 ms.[68]

The next substages in a response to a stimulus are perception/recognition and response selection. The instrument used to help find how quickly a runner can avoid a collision is an electroencephalogram (EEG). An EEG records the fluctuating potentials produced by a variety of active neuronal current generators. The CNS is located in the spinal cord and brain. There are ascending (sensory) and descending (motor) nerve tracks in the spinal cord which can be represented to approximate the activation current orientated in the direction of propagation.[112] Because this study specifically examines both the time it takes the brain to receive the signal from the eye and the time it takes the brain to make the decision, the sensory and motor nerve tracks both will need to be analyzed. There are four wave groups in an EEG signal: alpha, beta, theta and delta.[112] The alpha wave (8 to13 Hz) is the wave to examine for the eye movements, because it occurs most intensely in the occipital region of the brain.[112] VER (visual evoked response) can affect potentials due to a flash of light (turn signal) and will allow a researcher to find the time of the eye-to-brain connection. Beta waves (14 to 30 Hz) are most intense during mental activity, therefore, this is the wave to examine to determine the time it takes the brain to make a decision, assuming making a decision requires significant mental activity.[112] It takes approximately 20-40 ms seconds for the brain to receive a signal from the eye[61] and 85 ms seconds for the brain to make a decision.[98] For women the decision time is a little longer than men by approximately 34 ms.[1]

These previous substages make up the perception time component of reaction time. With perception time considered, it is then appropriate to examine the movement time component, since the body part performing the movement affects the time it takes to start the movement. Once the brain makes a decision to move in response to a stimulus, the next step is to activate the muscles to complete the movement. An electromyograph (EMG) measures the changes in muscle activation. In the act of running, muscles are already being use to propel an individual forward, which means that those muscles are active prior to changing direction. An EMG provides a means to measure the difference in activation intensity of the muscles in question between running in a straight line and the cutting maneuver. An EMG measures the evoked action potential of a specific group of muscle fibers established by the placement of electrodes.[10,109,112] Surface electrode are used for an EMG of a moving person and are placed on the skin near the muscles being investigated. The time between the moment the brain makes a decision to change direction and the moment the muscles activate an initial movement toward the new direction is the response time of the muscles to a signal from the brain. Muscle activation takes approximately 0.31 seconds.[92]

2.3.2 What Can Affect Reaction Time?

An individual response to a visual stimulus is difficult to predict. The instruments discussed can help us understand how the average person responds to a situation in a laboratory setting, but the response to a situation may be much faster or slower due to a number of factors: the type of response required, difficulty of the response, skill of task, readiness to perform the task, gender, type of signal and body part required to respond.[11,12,13,73,103]

The three types of reaction time experiments are: simple, recognition and choice. Simple reaction time experiments have one stimulus and only one response, for example see a light, then press a key.[38,58,76] This type of reaction time experiment produces the most rapid response time. The second type of reaction time experiment is one that measures recognition. There are two types of stimuli for this type of reaction time experiment, one that requires a response and one that requires no response,[38,61,76] for example, see a red light press the breaks, or see a green light and do not press the brakes. The third type of reaction time experiment measures the least rapid response time.[38,61,76] The choice reaction time experiment has multiple signal options requiring a different response.[18,38] An example of the choice experiment is one in which a person sees a green light and has to turn left or sees a red light and has to turn right.

Previous studies have shown that the more challenging a task, the longer it takes a subject to respond.[25,108] The more complex the motor skills are to complete the task the more difficult the task. There are four types of motor skills: fine or gross, which depend on the muscles used; discrete, serial or continuous, which looks at the beginning and endings of a skill; closed or open-loop motor skills, which look at the sensory feedback, closed-loop motor skills return feedback, open-loop motor skills do not return feedback; and initiator or responder motor skills. An example of an initiator skill would be pitching; a responder motor skill would be batting.[68] More complex tasks would require input from the CNS, therefore, responder, closed-loop, serial, fine motor skill tasks would be the most complex tasks which would take the most time to achieve a correct response.[26]

Research has shown that the level of skill or attention needed to perform a task can effect the time it takes a person to respond to a cue.[60] The more familiar a person is with a complex skill or the more training person has had for the complex skill, for example the skilled lower-limb movements required in soccer, the faster that person will be able to complete the task and the less attention or thought that a skilled person will require to perform the complex task.[17,108] Therefore, the more attention required to perform a task, the slower the response time will occur. According to Green in 2000,[38] when studying braking times for drivers, if a task is expected, the person is aware something is going to happen can have a reaction time of 0.7 second to brake a car; if the task is unexpected but known as a possibility, the reaction time can increase to 1.25 second; and if the task is a surprise the reaction time increases to 1.5 seconds. This increase, with the surprise of the signal, falls under the concept that to perform at an optimal level, one should prepare as much in advance as possible.[55] With enough practice even the most complex tasks can be performed with little thought or effort. After practice of even a sensory cue, it becomes more of a habit and can be considered automatic.[3,87] In contrast, an individual not familiar with a task will require intense thought and effort.[87] For example, a study of a group of gymnasts found that they had significantly less dependence on attention with an increase in the difficultly of the task for a postural sway study as compared to a group which did not have gymnastic training.[108] This was thought to be the result of the gymnasts training to not move when landing from movements performed in gymnastic exercises.

Gender is another factor effecting reaction time. Males have faster reaction times than females with lag time of approximately a 34 ms difference between genders.[1] Once the muscles start to contract, the contraction times are the same for males and females.[61] This difference in reaction time is thought to be due to females taking a longer time to think.[22,33,46,71,72,79] Previous studies have shown that the reaction time for females is decreased in spatial choice tasks; thus supporting the idea that it is the thought process in reaction time, a spatial activity, that takes longer for females to complete than for males.[25,61]

It will take longer for a person to respond to seeing a stimulus or signal than hearing a stimulus or signal. Reaction times for visual signals are approximately 190 ms, and for auditory signals are approximately 150 ms.[61] For visual signals, when the signal is in the central visual field the reaction time is quicker than when the signal is in the peripheral vision.[2,63] Also, a longer visual signal can cause a quicker reaction time.[61] According to Stuss et al. 2005,[103] reaction times that were most rapid had a one second warning, in the middle were those that had a three second warning, and those with the longest reaction time had no warning.

There is a difference in reaction time between tasks that require movement of the arm versus movement of the leg, with an increase in reaction time for movements of the leg than the arm due to the distance necessary for the signal to travel from the brain. A minimum of 85 ms of CNS processing time is needed to complete a movement series between the hands and feet.[98] Requiring a choose between the left or right hand decreases the ability to prepare for the movement which increases the reaction time.[76] Also, reaction times are longer for the left hand than the right hand by approximately 25 ms.[118] The longer it takes to react to a signal the more awkward the movement that will occur and the great the chance of injury.

2.4 Injuries Related to the Cutting Motion

An ankle sprain is one of the most common injuries in athletic activities that involve turning, twisting and pivoting. Approximately 80% of sprains occur when the ankle inverts. This inversion sprain happens because the outer ankle is less stable than the inner ankle.[123] Achilles' tendon injuries are common in athletic activities that use the calf muscles extensively, for example, those with extensive jumping or running. Extensive pulling of the calf muscles can overstress the tendon. Following along the same lines of overuse, excessive training can cause stress fracture injuries. Ill-fitting shoes or uneven surfaces are often the cause of ankle injuries.[101,123] Ill-fitting shoes can also contribute to stress injuries and anterior compartment syndrome, also known as shin splints. Uneven surface often contribute to ankle sprains.[123]

Knee injuries can account for up to 50% of athletic activity related injuries and are especially common activities that repetitively use cutting maneuvers.[49] Thus, football, skiing, soccer and basketball are the highest risk sports for injuries, especially knee injuries.[22,51,122] In football, the injuries are often a result of contact between players.[27] In soccer or basketball, most of the injuries are non-contact in nature. Injuries seem to occur most often when an athlete is decelerating and changing direction, for example the sidestep cutting motion, as compared to a straight-ahead movement.[23,49] In general, the number of injuries that occur in female athletes, specifically ACL tears, is significantly higher than in their male counterparts.[46,52,74,88,121,123]

Strains of the muscles around the hip joint are found most often in athletic activities that require sudden changes in direction and sprinting. Common strains found in the hip are groin, hip flexor and quadriceps. Groin strains frequently result from participation in an activity with a sudden change of direction to the side. A groin strain most often involves the adductor longus. Hip flexor and quadriceps strains frequently result from activities that require a lot of kicking, sprinting and jumping, usually involving the rectus femoris muscle of the quadriceps.

Stress related or overuse injuries can cause the hip to be less stable and, therefore, more susceptible to dislocation. Inflammation of the hip is often a cause of overuse. There are many small muscles, tendons and ligaments at the hip. These smaller soft tissue muscles are more susceptible to overuse injury than the larger soft tissue muscles. Hip dysplasia, where the actabulum is too shallow and fails to completely cover the head of the femur, is an example of a condition that would make the hip more susceptible to dislocation.

2.4.1 Injury Mechanisms

What are the factors and reasons for so many injuries resulting from the cutting maneuver? Studies have focused on two factors; the postural adjustments and muscle activity. Postural control is extremely important when performing any type of movement. Without postural control, the movement becomes awkward, creating increased joint loads and increasing the chance of injury.[11] Postural control is dependent on the location of the body's COM and on the base of support. When performing a dynamic movement, adjustment must be made to balance the momentum and forces associated with the continuous muscle activity.[42]

One of the reasons that injuries occur during a sidestep cutting maneuver is the breaking force needed to change the direction of that movement.[15,49,88] These higher breaking forces are associated with an increase in quadriceps activation from the beginning of the stance phase.[49] Another reason for the injuries may be the planes in which the motion occurs. The movements in the frontal and transverse planes are unique to cutting maneuvers and are associated with increased rotational instability of the knee.[49,50]

The degree of knee joint flexion is also considered a factor for increased injuries during the cutting maneuver.[6,12,23,28,46,64,65,79,100] As knee flexion angles increase, the muscles around the knee joint must counter the flexion load by applying an equal extension moment on the knee joint.[15,31,66,82] As the knee flexion angle increases the quadriceps place an anterior shear force on the tibia, and the external valus/valgus and inversion/eversion moments are increased.[12,23,66] Increasing the knee flexion angle just ten degrees from thirty to forty caused the valgus and internal rotation moments to increase.[8,12]

The muscles surrounding the joints control the stability of the joints to perform various degrees of flexion/extension, inversion/eversion and internal/external rotation. For example, weak gluteus muscles can cause poor hip joint control. When the hip joint is loaded, weak gluteus muscles will cause the hip joint to adduct.[120] If the hip is adducted, it causes valgus at the knee joint by internally rotating the femur.[120] Knee joint resistance of both rotation and shear forces are increased with the contraction of the muscles across the knee joint.[116] A certain degree of rotational stiffness is required to prevent buckling of the knee joint. Contraction of the quadriceps prior to touchdown of the stance phase will assist in providing the necessary stiffness.[115] During standardized tests, co-contractions of the muscles across the knee have been shown to decrease displacements in both the anterior-posterior and rotational directions.[116] Voluntary muscle contractions that occur too slowly in response to an external force can fail to increase joint stiffness in time to prevent an injury.[115] Increases in activation of the muscles during the end of the stance phase of a sidestep cutting maneuver can be the result of increased off-path forces.[50] The increase in muscle activation is necessary to counterbalance the off-path forces keeping the joint stable[2].

2.4.2 ACL Tears

Approximately 70% of traumatic knee injuries are ACL tears, 80% of ACL injuries are non-contact.[46] The most common way for a non-contact ACL tear to occur is as a result of a

[2] Other factors which have been discussed as contributing to a knee injury are intrinsic, and extrinsic factors. Intrinsic factors include: joint laxity, notch size, ligament size, limb alignment and Q-angle.[4] Extrinsic factors that include: conditioning, muscle strength, age, cyclic loading, frictional resistance (for example shoe-surface interface), torque and fatigue.[31] Another extrinsic factor thought to affect performance of a movement is the time a person has to prepare for a task. This time to prepare is also thought to have an influence on joint load, increasing the loads across the joints as preparation time decreases.[11]

cutting maneuver.[51,73,74] This is thought to be caused by the positioning of the hip, knee and ankle joints.[51] When, due to the positions of the lower extremities, the loads at the knee joint are so high that the musculoskeletal structures can no longer resist those forces, the ligaments become excessively loaded, increasing the risk of injury to those ligaments.[60,73]

The load placed on the ACL not only depends on the flexion and rotation of the lower extremity joints, but also on the external load applied and the activation of the muscles surrounding the lower extremity joints.[12] When an ACL injury occurs at initial contact with the ground it is believed that the position of the lower extremity is a primary factor in the cause of the injury.[51] The excessive loading on the ACL is found specifically in the transverse and frontal planes.[5,51] In the frontal plane, an increased degree of valgus at the knee joint could cause up to six times the load on the ACL compared to a knee with no valgus, aligned in the frontal plane.[65] Studies have shown that increased valgus and extension at the knee joint along with internal rotation of the hip and knee joints potential create higher forces at the ACL, putting it at a greater risk for injury.[13,51,58,60,66,73,74] Internal tibial torque plus valgus torque can cause significant anterior tibial translation at the knee joint, placing high forces on the ACL.[28,58] The closer the knee joint is to full extension, the greater the torque the ACL must restrict due to the internal rotational and valgus angles.

As the joints rotate internally and increase in extension, the muscle must contract to resist the large external loads on the joints. Disproportional loading of the quadriceps and hamstring muscles have shown to increase the risk of an ACL tear.[23,51,64,66] Co-contractions of the hamstring and quadriceps muscles are necessary to reduce the stress on the ACL and lessen the anterior shear force at the knee.[66] Quadriceps acting alone will increase anterior tibial translation causing strain on the ACL.[23,51,64] The degree of knee joint flexion has been shown to affect the anterior shear and rotation forces at the knee joint and the stress on the ACL.[28] The more knee joint flexion, the more active the role hamstrings can play in stabilizing the knee, and the less quadriceps activation that is needed to reduce the anterior tibial load.[13,28,29,50,67] The degree of knee flexion to avoid the high risk load on the ACL varies between 0 and 40 degrees depending on the study conducted.[13,50,64,67,88]

2.4.3 Gender Differences

Since the adoption of Title IX over 30 years ago, the number of women participating in athletic activities has more than quadrupled.[125] The number of injuries in female athletes has also significantly increased. Athletic activities injuries seem to be concentrated in the knee joint for women. Injuries from athletic activities tend to be more evenly spread throughout the body for men.[27] The difference in the rate of occurrence of injuries among men and women varies among activities. For turning, jumping and twisting activities that occur in basketball and soccer, females are between two and ten times more likely to injure their knee, specifically non-contact ACL injuries, than their male counterparts.[4,28,46,51,52,66,74,88,97,116,121]

There remain differences of opinion as to the reasons for the discrepancies between the ACL injury rates for females and males.[46,88,121] Some researchers believe that physiological or anatomical differences, i.e., intrinsic factors, between the genders account for the discrepancy in injury rates.[33,46,66] Others believe that extrinsic factors such as conditioning, skill or experience level account for the difference in injury rates.[74,121] Extrinsic factors, such as conditioning or age are less gender specific and are easier to control than intrinsic factors.[66,121] Studies have shown that the baseline level of conditioning is significantly higher for men than women.[24,122] Like the general injury mechanism of the ACL, it is most likely a combination of the intrinsic and extrinsic factors that increase the risk of ACL injuries for female athletes.[121]

One physiological difference that is believed to have an effect on the stability of the ligaments in females is the cyclic changes in hormones.[33,46] Anatomical differences include the structure of the pelvis, and lower extremity alignment, specifically the Q-angle of the hip joints, and the intercodyle notch at the knee joint.[33,46,73,74,115] Women have wider hips which can cause higher compressive strain on the medial side of the knee.[33,46,66,74,115,116,121,122] This compressive strain is due in part to the angle of the femur from the hip to the knee. The Q-angle, which is formed by the intersection of a line from the center of the patella to the tibial tuberical and a line to the anterior superior iliac spine from the center of the patella, is a way to measure the angle of the femur from the hip to the knee.[77] A normal range of a Q-angle for women is 14 to 20 degrees, and for men a normal Q-angle range is 11 to 17 degrees. A higher Q-angle can cause knee subluxation, increase valgus and abduction especially during a sidestep cutting maneuver.[73,74,115]

Women also have a narrower intercondylar notches than their male counterparts.[46,73,74,115,121] The intercondylar notch lies between the two condyles of the femur. A narrower notch means more limited space for the movement of the ACL, which can cause pinching or stretching as the knee bends. This, in turn, increases the risk of injury due to wear.

Significant gender kinematic and kinetic differences have been found at the hip, knee and ankle joints for a sidestep cutting maneuver.[88] When performing a sidestep cutting maneuver, females use the GRFs to control the direction of the movement rather than being prepared to perform the movement and using the muscles to control the direction of movement.[33,51] This lack of neuromuscular control, due to weak muscles, causes a high amount of force to be placed on the knee ligaments by being unable to keep the leg from rotating internally.[33,51,98] Compared to their male counterparts, females have been shown to have increased hip joint flexion and adduction, greater valgus and internal rotation and/or decreased flexion at the knee joint and at the ankle joint.[66,70,72,73,121] Women have been found to have increased dorsiflexion and rear foot pronation compared to men.[50,68,73,74,88,121]

Studies have found that peak knee flexion is less for females than males during sidestep cutting maneuver.[60] Peak flexion that does occur in females during a sidestep cutting maneuver is much later in the stance phase than for males, increasing the possible risk of ACL tears in females.[28,46,50,66,74] Females have also been shown to have more quadriceps muscle activation along with generally decreased muscle activation than their male counterparts.[46,50,51,66] The greater muscle activation for men, especially a more even activation of the quadriceps and hamstring muscles, confirms the theory that men use the muscles surrounding the knee joint to better protect the ligaments than women do.[115,116,121]

Combining all the factors, intrinsic and extrinsic, there seems to be more than one factor that increases the risk of a knee injury for both genders, with some of those same factors increasing the specific risk of an ACL injury and increasing the risk of injury even more for women compared to men, for example, a discrepancy between quadriceps and hamstring muscle activation or degree of knee flexion. Having discussed the factors for injury mechanism of the sidestep cutting maneuver, the methods need to be established to find where these mechanisms occur during the cutting maneuver.

2.5 Analysis Methods of Biomechanics

2.5.1 Running Speed

The issue of standardized running speed exists due to the conditioning of subjects. For one subject a jog may be 3m/s for another subject it may be 5m/s. The amount of energy expended becomes a factor; the more work that is being done to complete the maneuver the more difficult the task is considered for that individual. The controversy of standardized running speed is unsettled in the literature. The positions seem to be evenly divided between those that believe that speed should be standardized for all subjects,[75,90,101] and those that believe that running speed should not be standardized between subjects.[90,101] Most researchers are in agreement that running speed should be standardized for an individual subject, although even that standardization has its opponents.[90,111]

For treadmill running speed, standardization is very simple, the belt is set to a specific speed and the subject must run at the set speed. Treadmill running studies most often use speeds between 2.5 m/s and 3.8 m/s,[75] although one study used speeds of 4 m/s and 6 m/s.[111]

Photocells placed a specific known distance apart have been used to calculate the running speed for over-ground running standardization.[33,66,74,88] When using photocells, subjects are usually required to maintain a consistent speed between five and eight percent of a predetermined speed or in ±5% of a self-selected pace.[88,90] With photocells, running speeds have been standardized between 1.5 m/s and 6 m/s with an average of 4 m/s.[102,111] Standardizing of running speed is useful when comparing kinematics and kinetics between and within subjects. Using the same speed for all subjects allows for a comparison between the subjects that is not affected by the running speed. Running speed has been shown to change the kinematics and kinetic of the lower extremities with an increase in speed, thus, the standardization will eliminate one variable.[23,57,66,88,90,121] Among subjects, standardization of running speed allow for comparison of conditions, without the kinematics or kinetics changing due to running speed.

2.5.2 Marker Placement

Marker placement is extremely important to identify joint angles. Various studies have different motions being investigated. The marker placement configuration depends on those motions that are being investigated. Two well-known marker sets are the Helen-Hayes, and the Cleveland Clinic. The Helen-Hayes marker set uses wands for the markers on the thigh and calf. The Cleveland Clinic marker set uses markers set in triads, which are often identified by motion analysis systems as one single marker.

Cutting motion studies, with the exception of Zeller et al.,[121] in 2003 and Ford in 2005,[33] have focused only on the lower extremities. Marker sets for studies looking at the sidestep cutting maneuver have placed the highest marker on the ASIS.[12,13,74,88,96,101,115] Foot, ankle, knee and hip marker placement is usually done using the Helen-Hayes or Cleveland Clinic methods, using only one fifth metatarsal marker on the foot.

Studies have been done to examine the accuracy of skin-base markers.[9,104,109] A criticism of the skin-based markers is that the movement of the skin over the joint alters the position of the joint. Unfortunately, the only other option for evaluating joint movement is rigidly attached bone-pin markers fixed to the bone.

2.5.3 EMG

Electromyography, EMG, is used to measure muscle activation during a movement task. The activation of one muscle is often compared to the activation of another muscle, or muscles, throughout a maneuver. An EMG, uses surface electrodes, designed to measure the activation of superficial muscles. Although most studies use surface electrodes, surface electrodes are controversial, being difficult to use to isolate one muscle.[10,57,109] The skin is a conductive tissue, and when surface electrodes are placed on the skin, the actual output at a specific electrode is likely to include activity from surrounding muscles. The position of a surface electrode moves when the subject's muscles being measured contract, as the subject moves though tasks. Surface electrodes should be placed on the belly of the designated muscle, recording along the length of the muscle to obtain the most accurate measurements.[69,99,120]

The quadriceps (vastus lateralis, rectus femoris) and hamstring (biceps femrois and senimembranosus) muscles are the muscles most frequently evaluated when examining sidestep cutting maneuvers,.[12,23,89,99] Placement of the surface electrodes on these muscles is not specified in the studies, which only state the surface electrodes are placed on the belly of the muscle of interest. For these studies, all of the factors that affect surface electrodes, equally affect both the hamstring and quadriceps muscle activation measurement.

2.5.4 Force Plate and Video Data

Force plate and video data are the tools used to collect data to measure the kinematics and kinetics of a motion. Infrared video cameras are placed in a specified space. The cameras, in combination with the reflective markers discussed earlier, are used to capture a 2D image showing the marker movement throughout a designed area of space. The number of cameras for a video system varies between four and twelve depending on the study.[33,51,66,72,74,88,99,109,121] The more cameras that are used, the more views that can be recorded. With six cameras all medial/lateral and posterior/anterior views can be seen.[72,99,121]

Sampling rate for the video data systems varies as much as the number of cameras used, ranging from 100Hz to 240Hz.[73,79,99,120]

Force plates are used to measure the GRF. For sidestep cutting maneuvers, force plates measure the GRFs of the leg that lands on the force plate. The GRFs of the leg are measured during the stance phase of a motion. Sampling rates of force plates have a greater variation than do video data systems, ranging between 200Hz and 2000Hz for force plates.[73,79,99,120]

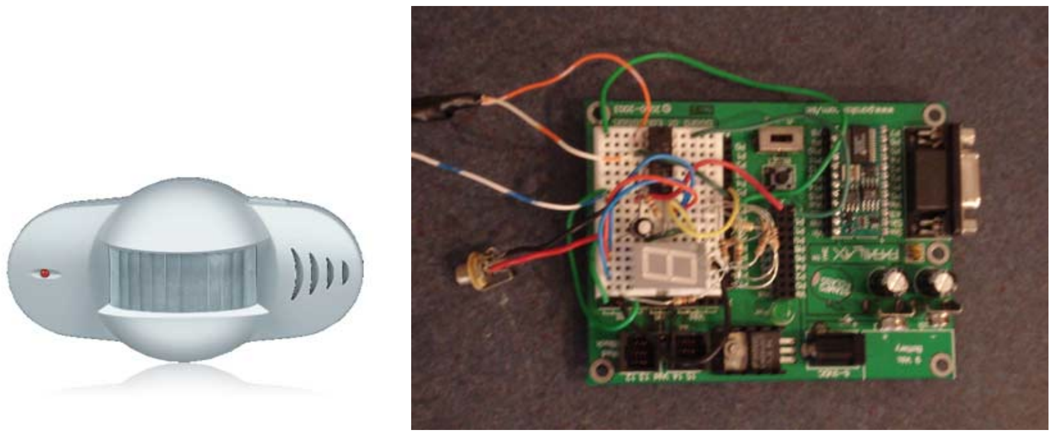
3. MATERIALS AND METHODS

3.1 Subjects

The Institutional Review Board at the University of North Carolina at Chapel Hill approved the use of human subjects for this study. The number of subjects for this study was chosen using the results of a power analysis done by previous studies examining similar dependent variables which needed only twelve subjects in each group for a power of 80%.[13,66,74,88] Recreational athletes ranging in age from 18-35 who participated in competitive or organized sporting activities three or fewer times a week and exercised at least three hours a week were recruited using email. Those subjects with previous lower extremity injuries that required missing practice or games for more than three weeks or had any current lower extremity injuries were excluded.

3.2 Equipment

The equipment used included: a timing device (Figure 3.1), a timer/counter, an EMG system, electrodes, twenty-four reflective markers, eight video infrared cameras, and two force plates. The timing device was designed and built by the author specifically for this study. It consisted of a motion sensor, a BASIC stamp (BS2) chip, two white LEDs, and an eight-digit display. Once the motion sensor was triggered, the BS2 program randomized the condition which defined the time and direction that was indicated by the light instructing the subjects to cut. The timer/counter used two infrared sensors that were set two meters apart to compute running speed. The EMG system was a T42L-8TO eight-channel receiver demodulator and pre-amplifier encoder. Electrodes for the EMG system were Ag/AgCl surface pre-gelled electrodes by Neorprine. The eight infrared video cameras recorded data at a rate of 120 frames per second. To collect the ground reaction force and moment data, two Bertec 4060A force plates (Bertec, Worthington, OH) were used, sampling at a rate of 1200 samples per second. The software used was the Peak Motus video analysis system (Peak Performance, Englewood, Colorado), MS3D65 and MSGraphics65 (version 6.5 Chapel Hill, North Carolina), MSDR60 (version 6.0 Chapel Hill, North Carolina) and SPSS statistical analysis (SPSS Inc., Chicago, IL).



(A) (B)

Figure 3.1 – Timing Device: (A) Motion Sensor (B) Basic Stamp Circuit

3.3 Experimental Procedure

The subjects were tested individually at scheduled times. Subjects were excluded if they were pregnant; had current or serious previous injuries to the ankle, knee, or hip; had any cardiovascular or respiratory disease; or had other musculoskeletal injuries. A signed written consent form (Appendix A) was obtained upon arrival in the laboratory. After signing a consent form, each subject's height and weight was recorded. To determine the dominant leg each subject was asked, "If a soccer ball were to be rolled to you, which leg you would use to kick the soccer ball?" The dominant leg was defined as the leg on which the subject would stand when kicking a soccer ball.

The attire for the subjects included spandex shorts, shoes and socks (provided by each subject) and a sports bra for the female subjects. Prior to testing, twenty-four reflective markers were placed on each subject. The markers were placed on the right and left first and fifth metatarsals, right and left heels, right and left medial and lateral malleoli, right and left lateral tibia, right and left lateral and medial femoral condyles, right and left greater trochanters, anterosuperioilliac spines, acromioclavicular joints, the L4-L5 spinous process and one on the front of the right thigh to signify the right leg during data analysis (See Figure 3.2). EMG surface electrodes were placed on the right and left hamstrings (biceps femoris) and right and left quadriceps (vastus medialis).

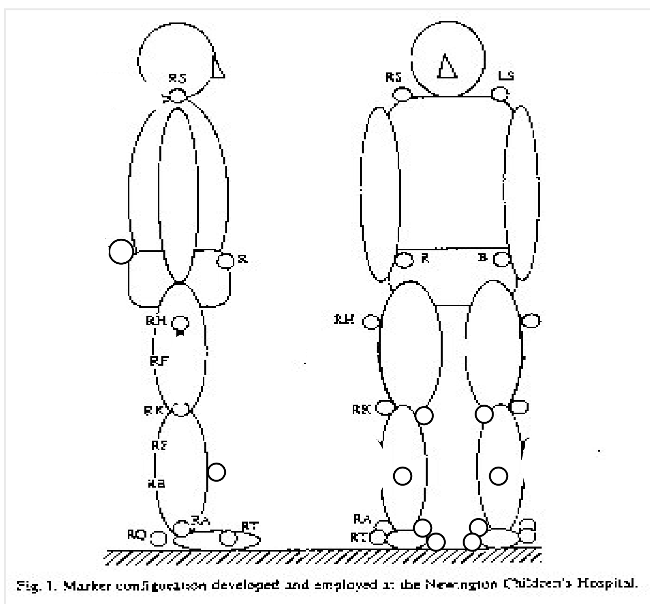


Figure 3.2: Marker placement for Standing Static Trial Calibration.

The standing trial data was collected first. Subjects were instructed to stand with one foot on each force plate, feet facing forward, shoulder width apart, with their arms crossed. This position was held for approximately two seconds and during this time, standing trial data was collected. Following the collection of data for the standing trial, the reflective markers on the right and left medial femoral condyle and malleoli were removed. The remaining markers and EMG electrodes were either pre-wrapped or taped down using either athletic tape or duct tape to ensure that they reminded in place for the entire data collection process.

The study was then explained to each subject. They were told that they would be running toward the white signal board of the timing device that had two black arrows on it with white LEDs next to each of the arrows (Figure 3.3). They were instructed to respond to the lights on the signal board as follows: if the lights remained off the subjects were to continue to run forward a few steps past the force plates, making sure that one foot landed entirely in the area of the two forces plates; if the left light appeared the subjects were to plant their right foot entirely in the area of the two force plates and, to the best of their ability, turn along the black lines on the floor at a 45 degree angle to the left, or if the right light appeared the subjects were to plant their left foot entirely in the area of the two force plates and, to the best of their ability, turn along the black lines on the floor, at a 45 degree angle to the right. This was demonstrated to the subjects so they could visualize the three movements of the study, straight, left turn or right turn. The subjects were told that the light would appear at irregular times, and that they were to make those adjustments necessary to be sure the correct foot landed entirely on the force plates and they turned in the correct direction. The subjects were told that with each trial, they would need to jog at a consistent pace, as if they were running about three miles, which would be monitored by the timers. They were told that they would be informed if they were outside their self-selected running speed range and the trial would be repeated. They were shown the location at which they would need to start each trial and were instructed that between each trial there would be at least a minute break. When it was time for the next trial, they would be told to “go when ready.” After the task was completely described, the subjects ran straight forward several times to establish a comfortable speed which they could maintain throughout the data collection. With their running speed practice, the subjects also practiced the cutting motion in each direction, without responding to the signal lights.

Figure 3.3: Turn Signal Board

3.4 Data Collection

Each subject’s performance of each condition was recorded using eight infrared video cameras with a frame rate of 120 frames per second. The calibration area for the cameras was 1.4 meters deep by 2.0 meters wide by 2.6 meters high. The cutting maneuver was performed in this area. Synchronized with the eight infrared video cameras were two Bertec 4060A force plates (Bertec, Worthington, OH). The force plates measured ground reaction forces and moment data with a sampling rate of 1200 Hz. A Peak Motus video analysis system (Peak Performance, Englewood, CO) was used to synchronize the infrared cameras and force plate system; with the synchronization occurring when the subject first landed on the force plates. The Peak Motus system also synchronized the telemetry EMG system to the ground reaction forces and the video data.

Seven successful trials for each of the seven timing conditions were collected per subject. The seven timing conditions included each of the three timing condition in each of the two directions and one straight ahead run. A successful trial for data collection was defined as one during which the subject's planted foot was completely on the two force plates and the subject turned the correct direction with the correct leg planted. Since the conditions were randomized by a computer program in the Basic Stamp chip, the number of trials was more than seven for some conditions in order to collect seven successful trials for each condition.

3.5 Data Reduction

The Peak Motus video analysis system software was used to digitize the trajectories of the reflective markers. A successful trial for data digitization was defined as a trial where all the points were visible prior to the subject landing on the force plates and remained visible for the entire time the subject was on the force plates. Digitization began in the first frame in which all the points were visible and continued until the subject was completely off the force plates. A low-pass Butterworth digital filter with an optimum cutoff frequency was used on the raw three-dimensional coordinates.[119] Using the MS3D65 program, virtual landmarks were created using the standing trial and the timing trials which defined the center of the hip, knee, and ankle joints. MS3D65 Force Plate Model (version 6.5) software was used to find the ground-reaction forces, free moments and center of pressure location.

An inverse dynamic process was used to find the joint resultant forces and moments at the knee joint for each successful digitized trial.[39] These estimates of the joint resultants and moments were made using MS3D65 MotionSoft Kinetic system software version 6.5. Euler parameters were used with the inverse dynamic procedure to estimate the segment angular velocities and accelerations.[20,43] Resultant forces and moment vectors of the hip, knee and ankle joints were converted to the tibial reference frame. The estimated forces and moments of the hip, knee and ankle were then further analyzed into the kinematic motions for this study: flexion-extension, valgus-varus and internal-external moments, anterior-posterior and medial-lateral shear, and axial force components.

The estimated joint resultant forces of the hip, knee and ankle joints were normalized to the subject's body weight to allow for comparison among subjects. Joint resultant moments were normalized to both the subject's body weight and height. The stance phase was defined as the period from the point the subject's foot landed on the force plate until the foot completely left the force plates. The stance phase was then divided into 100 time intervals. This division allowed normalization of 1% for each time interval of the stance phase. Data analysis is clearer when every trial is split into the same intervals.

3.6 Data Analysis

The data for each of the timing conditions was analyzed using the leg planted on the force plates during a sidestep cutting maneuver, producing joint kinematic, kinetic and EMG results. For statistical significance, a 0.05 level of Type I error was chosen. The overall Type I error rate was adjusted with the Bonferroni procedure. Three mixed model repeated measure design analyses of variance were conducted for each dependent variable: hip flexion angle, hip rotation, knee flexion-extension at landing, maximum knee flexion angle, knee flexion range of motion (ROM), ankle flexion, maximum ankle flexion, peak anterior-posterior ground reaction force (GRF), peak hamstring activation, peak quadriceps activation and peak vertical ground reaction force. The mixed model repeated measures designs were used to compare the left and right preplanned cutting maneuvers and the straight-ahead run, and both of the right and left timing conditions. The independent variables in each analysis were gender, type of sport played and timing condition (preplanned, planned and unplanned timing signals), with timing condition used as a repeated measure. Three two-way mixed model ANOVAs were conducted for each of the dependent variables to compared leg dominance. Each of the ANOVAs compared the right and left cutting maneuver for one of the timing conditions.

4. RESULTS

4.1 Subjects

Subjects were tested individually during the period June 2005 to January 2006 at the Center for Human Movement Science on the campus of the University of North Carolina. The mean age for the male subjects was 21.5 ± 4.08 yrs, the mean weight was 71.53 ± 11.14 kilograms, and the mean height was 1.77 ± 0.08 meters. For the female subjects the mean age was 19.4 ± 1.79 yrs, the mean weight was 61.01 ± 10.23 kilograms and the mean height was 1.65 ± 0.07 meters. Average running speed was 3.642 m/s for the men and 3.428 m/s for the women.

4.2 Reliability

The motion capture system at the Center for Human Movement was found to be reliable by Chappell et al. 2002, [22] the only changes since 2002 have been the addition of two infrared video cameras and a software upgrade. The coefficient of variance (CV) was found for the knee flexion angle at landing (Appendix C Table 1). A knee flexion at landing dependent variable was chosen because the data was collected at one specific point, the initial touchdown, during the stance phase not over the entire phase. The straight-ahead run had a lower average CV than any of the other timing conditions and the women were found to have lower CVs for each timing condition compared to the men. The intraclass correlation coefficient (ICC) was found for eight of the 46 dependent variables. Each ICC calculated was considered to be sufficiently reliable as all were greater than 0.7 (Appendix C Table 2).

4.3 Stance Phase

A significant interaction effect was found for the stance phase duration between condition and gender when analyzing the straight-ahead run and preplanned timing conditions ($p=.028$). (Appendix C Table 3) For the right cutting maneuver timing condition there was a significant interaction effect between condition and type of sport played ($p=.002$). (Appendix C Table 4) A non-significant interaction effect was found for the left cutting maneuver timing conditions between condition and gender, and for the right cutting maneuver timing conditions between condition, gender and sport played. Analyzing the dominant and non-dominant legs there was a significant interaction effect found between condition and gender for both the preplanned ($p=.013$) and planned ($p=.038$) timing conditions. (Appendix C Table 6) For the preplanned timing condition there was also an interaction effect, although not significant, found between condition and type of sport played ($p=.076$) when comparing dominant and non-dominant legs. A difference was found between the dominant and non-dominant legs for the unplanned timing condition ($p=.055$) and between the right cutting maneuver timing condition ($p=.144$), but neither was considered significant.

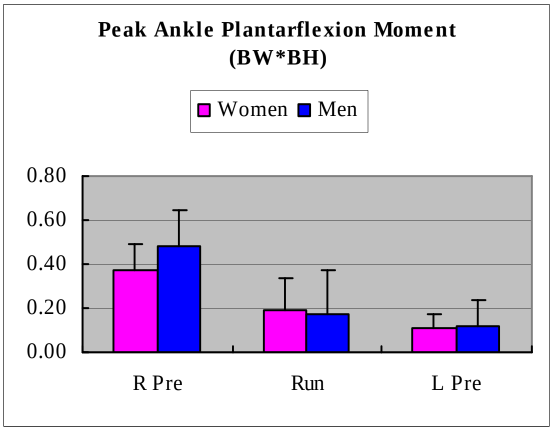
4.4 Ankle Joint Motion

4.4.1 Ankle Flexion/Extension

A significant interaction effect for the peak ankle joint plantarflexion moment was found between condition and gender for the preplanned condition when analyzing the dominant and non-dominant legs ($p=.020$) (Appendix C Table 6) and between condition and type of sport played for the left cutting maneuver timing conditions (p=.029). (Appendix C Table 5) Also found to have a significant interaction effect between condition and sport was the maximum dorsiflexion angle when analyzing the straight-ahead run and preplanned cutting maneuvers (p=.016) and the ROM of the ankle plantar/dorsiflexion angle when analyzing the straight-ahead run and the preplanned cutting maneuvers (p=.019), (Appendix C Table 3) and the dominant and non-dominant legs for the preplanned cutting maneuvers (p=.008) and the planned cutting maneuvers (p=.005). (Appendix C Table 6)

A significant main effect was found between subjects who played ball sports and subjects who did not play ball sports for the maximum ankle plantarflexion angle, and maximum ankle dorsiflexion angle. Those that did not play ball sports showing a greater ankle plantarflexion angle when analyzing the straight-ahead run compared to the cutting maneuver (p=.040) and when analyzing the right cutting maneuver timing conditions (p=.028). (Appendix C Table 9) A greater ankle dorsiflexion angle was found for those that did not play ball sports compared to those that played ball sports when analyzing the left cutting maneuver timing conditions (p=.009), the right cutting maneuver timing conditions (p=.009) and the non-dominant and dominant legs for each of the preplanned (p=.010), planned (p=.008) and unplanned cutting maneuvers (p<.005). (Appendix C Table 10)

The peak ankle plantarflexion moment was found to have a significant gender main effect, with men having an increased peak ankle plantarflexion moment compared to the women when anlayzing the dominant and non-dominant legs for the planned cutting maneuver (p=.047). Studying the main effect for conditions, significance was found between the dominant and non-dominant legs with the non-dominant leg having a greater peak ankle plantarflexion moment for all the timing conditions (p<.005). The straight-ahead run was also found to have a significantly greater peak ankle plantarflexion moment compared to the preplanned cutting maneuvers (p<.005). (Appendix C Table 8)



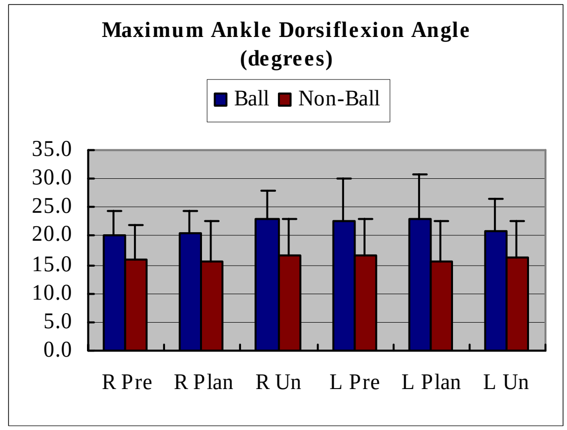


Figure 4.1 - Ankle Flexion/Extension[1]

4.4.2 Ankle Eversion/Inversion

A significant interaction effect was found for condition and sports for the peak ankle eversion moment when analyzing the right cutting maneuver timing conditions (p=.022). (Appendix C Table 4) The peak ankle eversion moment was found to also have a main effect for both gender and condition. The main effect for gender found men to have an increased peak ankle eversion moment compared to their female counterparts when analyzing the right cutting maneuver timing conditions (p=.041) (Appendix C Table 4) and the non-dominant and dominant legs for the unplanned cutting maneuver (p=.048). (Appendix C Table 6)

A main effect for condition was found for the peak ankle eversion moment, the maximum ankle eversion angle, the maximum ankle inversion angle and the ankle eversion/inversion ROM. The peak ankle eversion moment found that the right and left cutting maneuvers had greater ankle eversion moments compared to the straight-ahead run (p<.005) and that the

[1] For all graphs the x-axis displays timing conditions: right preplanned cutting maneuver (R Pre), right planned cutting maneuver (R Plan), right unplanned cutting maneuver (R Un), left preplanned cutting maneuver (L Pre), left planned cutting maneuver (L Plan), left unplanned cutting maneuver (L Un) and the straight-ahead run (Run).

dominant leg cutting maneuvers had greater eversion moments when compared to the non-dominant leg cutting maneuvers for all the timing conditions (preplanned, planned and unplanned) ($p<.005$). (Appendix C Table 12) The maximum ankle eversion angle (Appendix C Table 13) and maximum ankle inversion angle (Appendix C Table 14) were found to be significantly greater for both the left and right cutting maneuvers compared to the straight-ahead run ($p<.005$). The ankle eversion/inversion ROM was found to be greater for the right cutting maneuver compared to the straight-ahead run ($p<.005$). (Appendix C Table 15)

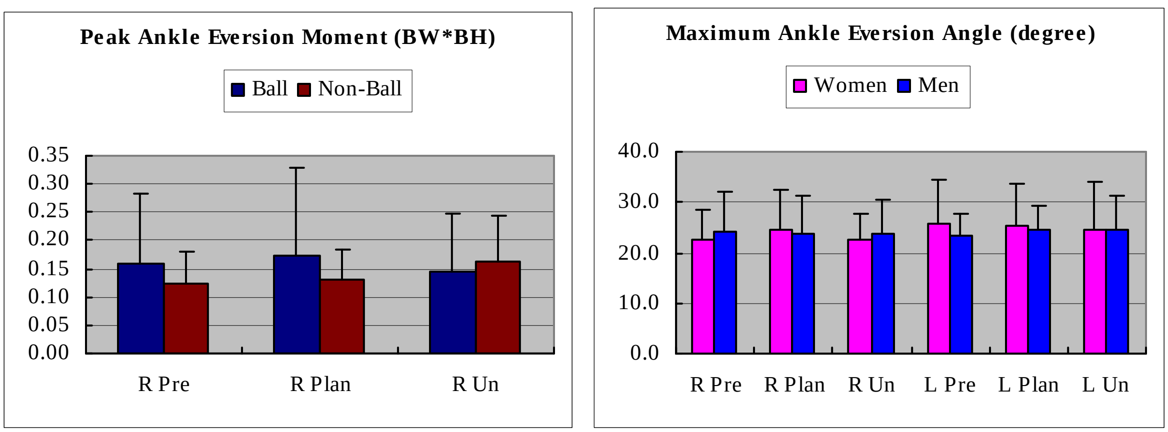


Figure 4.2 - Ankle Eversion/Inversion

4.4.3 Ankle Toe-out/Toe-in

There was no significant interaction effect for the ankle toe-out/toe-in dependent variables, peak moment or angles. A significant main effect for gender was found for the maximum toe-out angle with the women showing a significantly greater maximum toe-out angle compared to the men when analyzing the straight-ahead run to the preplanned cutting maneuvers ($p=.019$), (Appendix C Table 3) the dominant and non-dominant legs for the preplanned cutting maneuvers ($p=.021$). (Appendix C Table 6)

A significant main effect for timing condition was found for peak ankle toe-out moment, maximum toe-out angle and the ankle toe-out/toe-in ROM. The preplanned left cutting maneuvers were found to have a significantly greater peak ankle toe-out moment compared to the straight-ahead run (p=.009) and significantly less peak ankle toe-out moment compared to the unplanned left cutting maneuvers (p=.005). (Appendix C Table 16) The maximum toe-out angle was found to be significantly greater for the right preplanned cutting maneuver compared to the right planned cutting maneuver (p=.026) and significantly less for the right planned cutting maneuver compared to the right unplanned cutting maneuver (p<.005). (Appendix C Table 17) Ankle toe-out/toe-in ROM was also found to be significantly more for the right unplanned cutting maneuver compared to the right planned cutting maneuver (p=.040). (Appendix C Table 19)

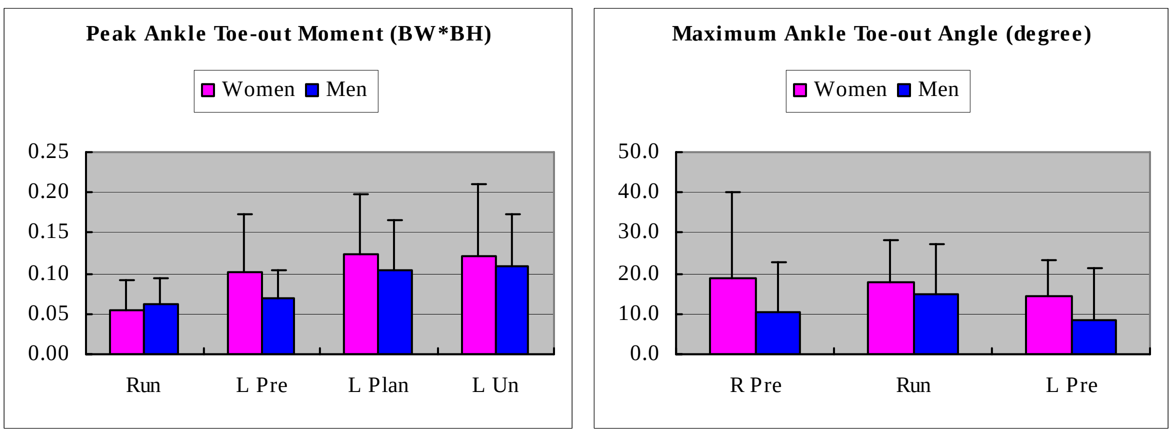


Figure 4.3 - Ankle Toe-out/Toe-in

4.5 Knee Joint Motion

4.5.1 Knee Flexion/Extension

Interaction effects were found for the peak knee flexion moment between timing condition, gender and sport when analyzing the straight-ahead run to the cutting maneuvers (p=.006) (Appendix C Table 3) and the dominant and non-dominant legs of the preplanned cutting maneuvers (p<.005). (Appendix C Table 6) No other interaction effects were found for the knee flexion extension dependent variables.

Main effects for condition were found for the peak knee flexion moment, maximum knee flexion angle, maximum knee extension angle and knee flexion angle at landing. The right cutting maneuver was found to have an increased peak knee flexion moment compared to the straight ahead run (p=.005). (Appendix C Table 20) The left and right cutting maneuvers were found to have greater knee flexion angles compared to the straight-ahead run (p<.005). (Appendix C Table 21) The maximum knee extension angle was found to be significantly greater for the left cutting maneuvers compared to the straight-ahead run (p=.027). (Appendix C Table 22) The right unplanned cutting maneuver was found to have more knee flexion at landing than the right preplanned cutting maneuver and the right planned cutting maneuver (p<.005). (Appendix C Table 24) There were no significant differences found between males and females or ball sports and non-ball sports for the knee flexion/extension dependent variables.

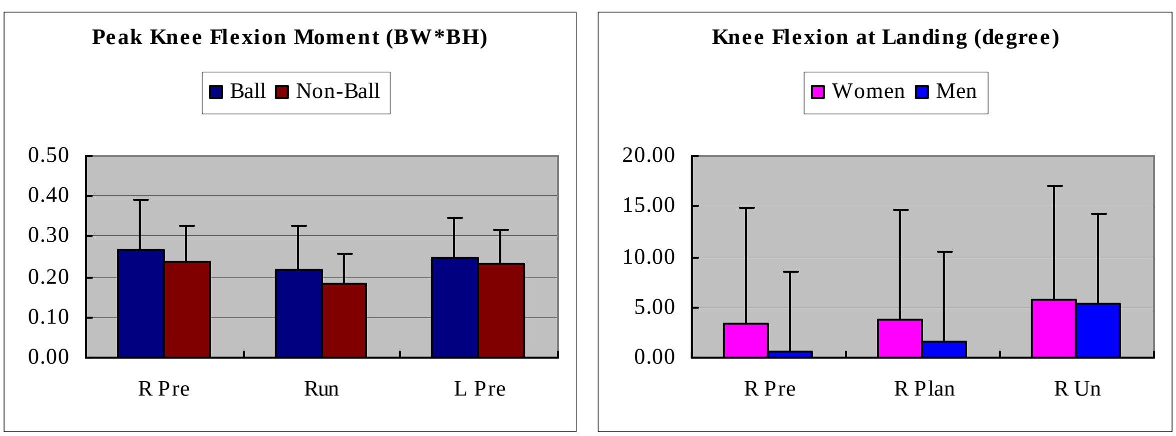


Figure 4.4 - Knee Flexion/Extension

4.5.2 Knee Varus/Valgus

One significant interaction effect was found for the knee varus/valgus variables. The interaction effect between condition and sport for the peak knee varus moment was found to be significant when analyzing the right cutting maneuver timing conditions ($p=.022$). (Appendix C Table 4) A main effect for sport was also found for the peak knee varus moment with the straight-ahead run compared to the cutting maneuvers show those that played ball sports had a significantly greater peak varus moment compared to those that did not play ball sports ($p=.029$). (Appendix C Table 3)

A main effect for condition was found for the peak knee varus moment and maximum knee valgus angle. For the peak knee varus moment, the non-dominant leg was found to have significantly greater peak knee varus moment compared to the dominant leg for all the timing conditions: preplanned ($p=.040$), planned ($p=.047$) and unplanned ($p=.011$). (Appendix C Table 25) The peak knee varus moment was also found to be significantly greater for the left and right cutting maneuvers compared to the straight-ahead run ($p<.005$). For the maximum knee valgus angle the straight-ahead run was found to be significantly greater than the left cutting maneuver ($p=.043$) and the right cutting maneuver ($p=.017$). (Appendix C Table 27)

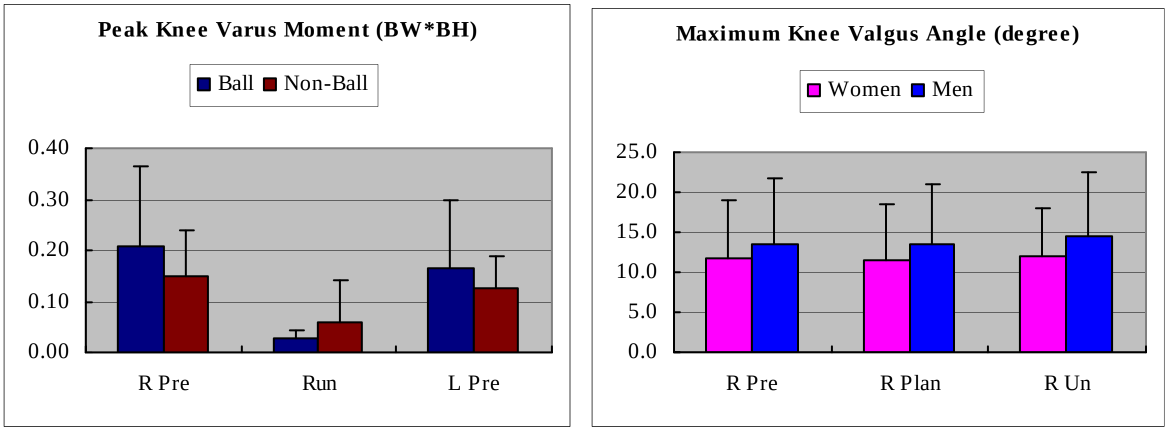


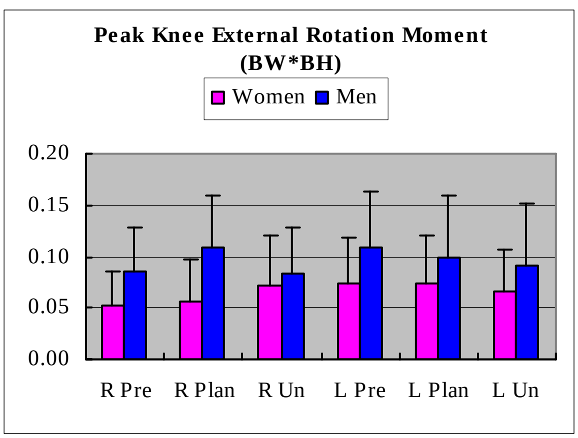
Figure 4.5 - Knee Varus/Valgus

4.5.3 Knee External/Internal Rotation

A significant interaction effect between condition and gender was found for the knee external/internal ROM for the preplanned cutting maneuver when analyzing the non-dominant and dominant legs ($p=.031$). (Appendix C Table 6) For the maximum knee internal rotation angle a significantly interaction effect was found between condition, gender and sport when analyzing the dominant and non-dominant legs for the planned cutting maneuver ($p=.042$) and the unplanned cutting maneuver ($p=.033$). (Appendix C Table 6)

A gender effect was found for the peak knee external rotation moment with male subjects having a significantly greater knee external rotation moment than female subjects when comparing the straight-ahead run to the preplanned cutting maneuvers ($p=.016$), (Appendix C Table 3) the left timing conditions ($p=.033$), (Appendix C Table 5) the right timing conditions ($p=.010$) (Appendix C Table 4) and the dominant and non-dominant legs for the preplanned cutting maneuver ($p=.013$) and the planned cutting maneuver ($p<.005$). (Appendix C Table 6) A gender effect was also found for the maximum knee internal rotation angle with the men having a greater maximum knee internal rotation angle compared to the women for the left cutting maneuver timing conditions ($p=.011$) (Appendix C Table 5) and the preplanned cutting maneuver dominant and non-dominant legs (p=.015). (Appendix C Table 6)

The maximum knee external rotation angle was found to have a main effect for sport when analyzing the dominant and non-dominant legs for the planned cutting maneuver with those that play ball sports showing larger maximum knee external rotation angles compared to those that do not play ball sports (p=.037). (Appendix C Table 6) The peak knee external rotation moment was the only knee rotation variable to show a main effect for condition. The left and right cutting maneuvers were found to have greater knee external rotation moments compared to the straight-ahead run (p<.005). (Appendix C Table 29) The dominant leg was found to have significantly greater knee external rotation moment compared to the non-dominant leg for the preplanned cutting maneuver (p=.027). (Appendix C Table 29)



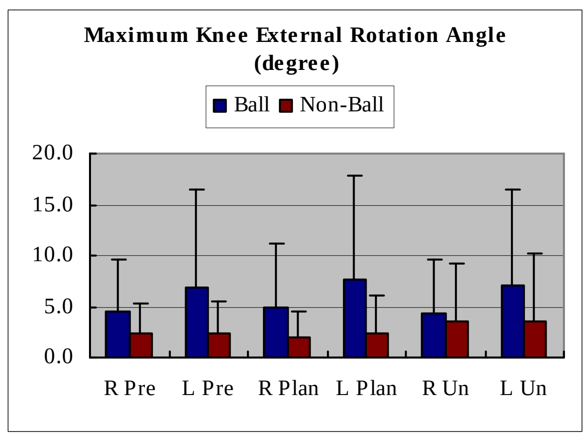


Figure 4.6 - Knee Internal/External Rotation

4.6 Hip Joint Motion

4.6.1 Hip Flexion/Extension

Significant interaction effects were found for the hip extension moment, the maximum hip extension angle and the hip extension/flexion ROM. For the peak hip extension moment a significant interaction effect was found between condition and gender for the preplanned cutting maneuver dominant and non-dominant legs (p=.047) (Appendix C Table 6) and between condition, gender and sport comparing the dominant and non-dominant legs for the preplanned cutting maneuver (p=.012) and unplanned cutting maneuver (p=.034), (Appendix C Table 6) and comparing the straight-ahead run to the preplanned cutting maneuver (p=.018). (Appendix C Table 3) The maximum hip extension angle had a significant interaction effect between condition, sport and gender is found when comparing the right cutting maneuver timing conditions (p=.023). (Appendix C Table 4) Also showing a significant interaction effect between condition, sport and gender was the hip extension/flexion ROM analyzing the straight-ahead run and the preplanned cutting maneuvers (p=.049). (Appendix C Table 3)

A main effect for sport was found only for the peak hip extension moment. The straight ahead-run compared to the preplanned cutting maneuvers found significantly greater peak hip extension moment for those that play ball sports than those that do not play ball sports (p=.006). (Appendix C Table 3)

A main effect for timing condition was found for each of the hip extension/flexion variables. For the peak hip extension moment there was a significantly greater peak hip extension moment found for the left preplanned cutting maneuver compared to the straight-ahead run (p=.006) and for the unplanned right cutting maneuver compared to the right planned cutting maneuver (p=.020). (Appendix C Table 33) There was significantly greater maximum hip extension angle for the straight-ahead run compared to the preplanned right cutting maneuver (p=.050). (Appendix C Table 34) The maximum hip flexion angle was found to be significantly greater for the straight-ahead run compared to both the preplanned left and right cutting maneuvers (p<.005) and for the right unplanned cutting maneuver compared to both the right preplanned cutting maneuver and the right planned cutting maneuver (p<.005). (Appendix C Table 35) The hip extension/flexion ROM was significantly larger for the non-dominant leg compared to the dominant leg for the unplanned cutting maneuver (p=.030) and for the preplanned left (p=.007) and right (p=.014) cutting maneuvers compared to the straight-ahead run. (Appendix C Table 36)

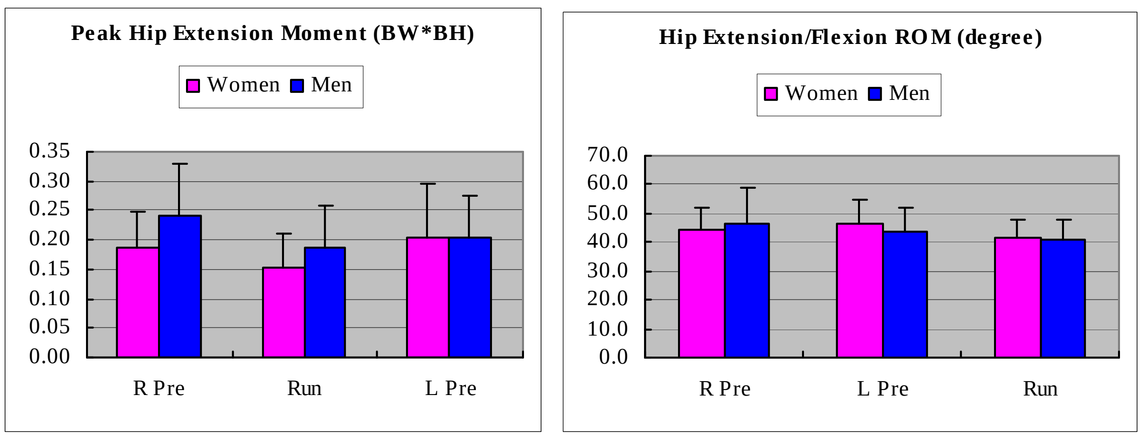


Figure 4.7 - Hip Flexion/Extension

4.6.2 Hip Adduction/Abduction

No significant interaction effects were found for any of the hip adduction/abduction variables. Significant gender effects were found for the maximum hip adduction angle and the maximum hip abduction angle. For the maximum hip adduction angle, women were found to have a greater hip adduction angle than men when analyzing the non-dominant and dominant legs for the three timing conditions: preplanned (p=.015), planned (p=.029) and unplanned (p=.016). (Appendix C Table 6) The maximum hip adduction angle was also found to be greater for women compared to men for the straight-ahead run compared to the preplanned cutting maneuver (p=.026), (Appendix C Table 3) for the left timing conditions (p=.013) (Appendix C Table 5) and for the right timing conditions (p=.038). (Appendix C Table 4) The gender effect for the maximum hip abduction angle was also greater for the women than the men comparing the straight-ahead run to the preplanned cutting maneuver (p=.047), (Appendix C Table 3) comparing the left cutting maneuver timing conditions (p=.020) (Appendix C Table 5) and comparing the dominant and non-dominant legs for the planned cutting maneuver (p=.020) and the unplanned cutting maneuver (p=.038). (Appendix C Table 6) A main effect for sport was found only for the peak hip adduction moment analyzing the non-dominant and dominant legs for the unplanned cutting maneuver with those that did not play ball sports showing an increased hip adduction moment compared to those that did play ball sports (p=.023). (Appendix C Table 6)

A main effect for condition was found for each of the hip adduction/abduction variables. For the peak hip adduction moment the left and right cutting maneuvers were found to have a significantly greater peak hip adduction moment compared to the straight-ahead run (p<.005). (Appendix C Table 37) The maximum hip adduction angle was found to be significantly larger for the straight-ahead run compared to both the left and right preplanned cutting maneuver (p<.005). (Appendix C Table 38) Analyzing the straight-ahead run against both the left and right preplanned cutting maneuver also showed a significant difference for the maximum hip abduction angle with the straight ahead run being significantly greater than the cutting maneuvers (p<.005). (Appendix C Table 39) The maximum hip abduction angle was also found to be significantly larger for the right preplanned cutting maneuver compared to the right unplanned cutting maneuver (p=.043). (Appendix C Table 39) The hip adduction/abduction ROM followed the trend of the each of the maximum angles showing the right and left preplanned cutting maneuvers to have a significantly larger ROM than the straight-ahead run (p<.007). (Appendix C Table 40)

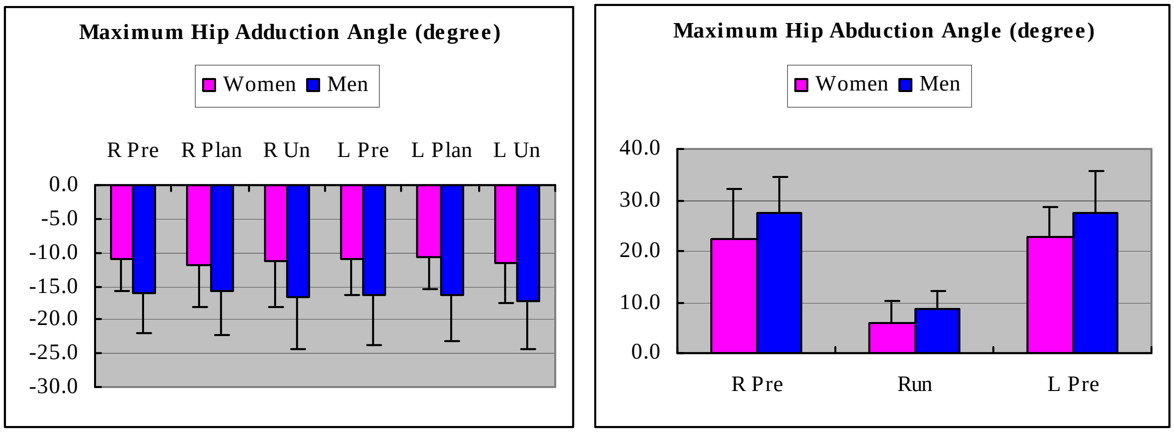


Figure 4.8 – Hip Adduction/Abduction

4.6.3 Hip External/Internal Rotation

The only significantly interaction effect found for the hip external/internal rotation variables was between condition and gender for the maximum hip internal rotation angle analyzing the dominant and non-dominant legs for the planned cutting maneuver (p=.039). (Appendix C Table 6) There were gender effects found for three of the four hip external/internal rotation variables. The men were found to have a significantly greater peak hip external rotation moment than the women when analyzing the straight ahead run against the preplanned cutting maneuvers (p=.043), (Appendix C Table 3) the right timing conditions (p=.017) (Appendix C Table 4) and the non-dominant and dominant legs for the preplanned cutting maneuver (p=.026) and the planned cutting maneuver (p=.008). (Appendix C Table 6) Men were also found to have a significantly larger maximum external rotation angle than the women when analyzing the straight-ahead run against the preplanned cutting maneuvers (p=.011), (Appendix C Table 3) comparing the right timing conditions (p=.032) (Appendix C Table 4) and comparing the dominant and non-dominant legs for the planned cutting maneuver (p=.029). (Appendix C Table 6) Since there is no gender significance found for the hip internal rotation angle it follows that the hip external/internal rotation ROM would be larger for men than women when analyzing the straight-ahead run against the preplanned cutting maneuvers (p=.007), (Appendix C Table 3) analyzing the right cutting maneuver timing conditions (p=.037) (Appendix C Table 4) and analyzing the dominant and non-dominant legs for the planned cutting maneuver (p=.025). (Appendix C Table 6)

A main effect for condition was found for the peak external rotation moment with the right preplanned cutting maneuver being significantly greater than the straight-ahead run (p=.001) and the left preplanned cutting maneuver (p=.025). (Appendix C Table 41) The maximum hip external rotation angle was found to be significantly greater for the left and right preplanned cutting maneuvers compared to the straight-ahead run (p<.005). (Appendix C Table 42) The hip external/internal rotation ROM was also found to be significantly greater for the left and right preplanned cutting maneuvers compared to the straight-ahead run (p<.005). (Appendix C Table 44)

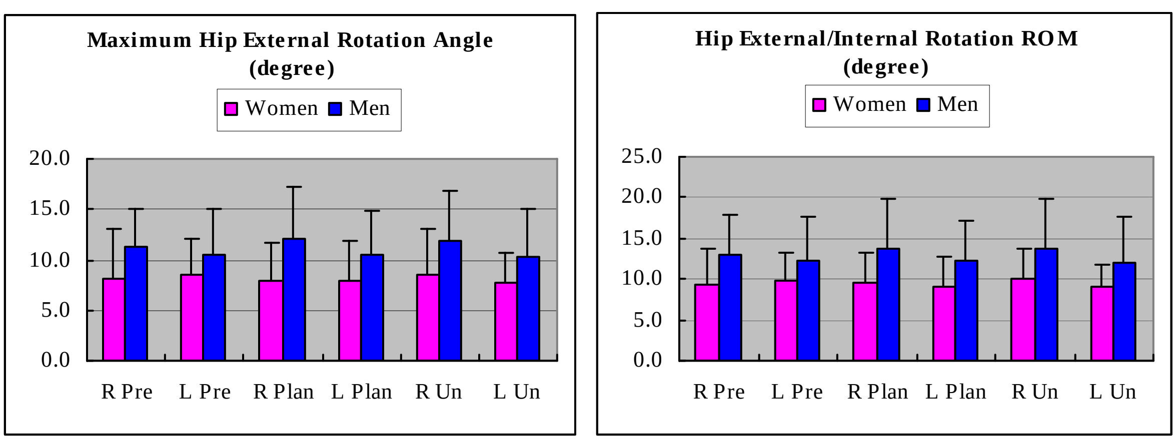


Figure 4.9 - Hip External/Internal Rotation

4.7 Trunk Motion

4.7.1 Trunk Rotation

An interaction effect was found between timing condition and sport analyzing the dominant and non-dominant legs for the maximum left trunk rotation angle for the preplanned cutting maneuvers (p=.030) and for the maximum right trunk rotation angle for the preplanned cutting maneuvers (p=.016) and planned cutting maneuvers (p=.050). (Appendix C Table 6) Main effects for condition were found for the maximum left trunk rotation angle with significantly greater maximum left trunk rotation angle found for the non-dominant leg having analyzed against the dominant leg for the preplanned cutting maneuver (p=.014), for the left preplanned cutting maneuver to the left planned cutting maneuver (p=.045), for the left unplanned cutting maneuver to the left planned cutting maneuver (p=.008), for the right unplanned cutting maneuver compared to the right preplanned cutting maneuver (p=.006) and for the right unplanned cutting maneuver compared to the right planned cutting maneuver (p=.042). (Appendix C Table 45) The maximum right trunk rotation angle was found to be significantly greater for the non-dominant leg compared to the dominant leg for the preplanned cutting maneuver (p=.019), for the left unplanned cutting maneuver compared to the left preplanned cutting maneuver (p=.025) and the left planned cutting maneuver (p<.005), and for the right preplanned cutting maneuver compared to the right planned cutting maneuver (p=.033) and unplanned cutting maneuver (p<.005). (Appendix C Table 46)

4.7.2 Trunk Rotation as % of Stance Phase

For the percent of the stance phase where the maximum left trunk rotation angle exists there was a significant interaction effect between condition and gender analyzing the right cutting maneuver timing conditions (p=.011) (Appendix C Table 4) and the dominant and non-dominant legs for the unplanned cutting maneuver (p<.005). (Appendix C Table 6) Also, there is a significant interaction effect found for the percentage of the stance phase where the maximum left trunk rotation angle exists, between condition and sport analyzing the left cutting maneuver timing conditions (p=.031) (Appendix C Table 5) and between condition, gender and sport analyzing the preplanned cutting maneuver to the straight-ahead run (p=.012). (Appendix C Table 3)

A main effect for condition was found for the percentage of the stance phase where the maximum left trunk rotation angle exist, with the dominant leg significantly later in the stance phase compared to the non-dominant leg for the cutting maneuver preplanned, planned and unplanned timing conditions (p<.005), for the straight-ahead run compared to the left preplanned cutting maneuver (p=.025) and for the right preplanned cutting maneuver compared to the straight-ahead run (p<.005). (Appendix C Table 47) The percentage of the stance phase where the maximum right trunk rotation angle is found was significantly later in the stance phase for the left preplanned cutting maneuver compared to the straight-ahead run (p<.005), for the straight-ahead run compared to the right preplanned cutting maneuver (p=.028), for the non-dominant leg compared to the dominant leg for each of the timing cutting maneuver conditions (p<.005). (Appendix C Table 48)

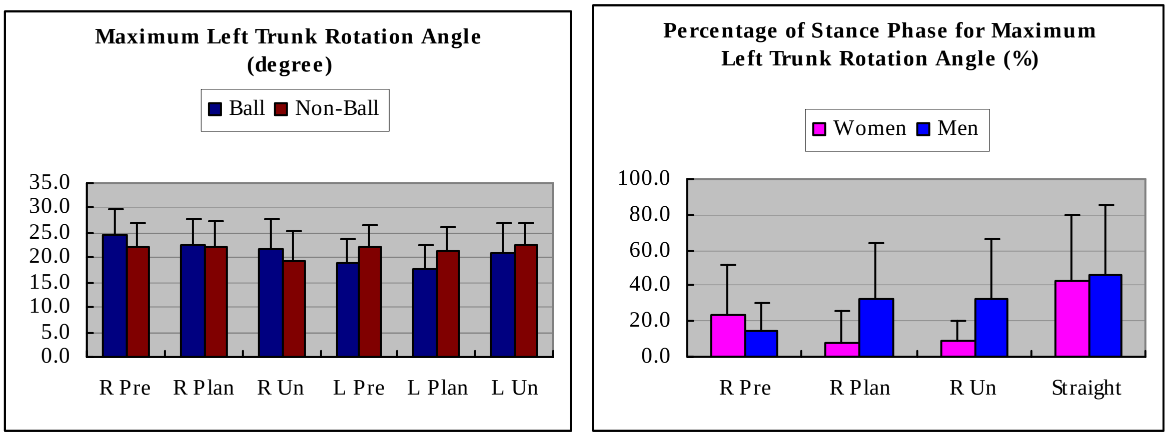


Figure 4.10 - Trunk Rotation

4.8 Ground Reaction Force

There was an interaction effect for the peak ground reaction force and peak ground reaction force as a percentage of body weight or the non-normalized peak ground reaction force between condition and type of sport played for the right cutting maneuver timing conditions (p=.029 and p=.025 respectively). (Appendix C Table 49) There was also an interaction effect found between condition, gender and sports for the peak ground reaction force, only when analyzing the dominant and non-dominant legs for preplanned cutting maneuvers (p=.029) (Appendix C Table 6) and analyzing the straight-ahead run to the preplanned cutting maneuvers (p=.038). (Appendix C Table 3)

A significant gender effect was found between men and women for the peak ground reaction force. Men were found to have a significantly greater peak ground reaction force than the women when analyzing the straight-ahead run to the preplanned cutting maneuver (p=.021), (Appendix C Table 3) the left cutting maneuver timing conditions (p=.012), (Appendix C Table 5) the right cutting maneuver timing conditions (p=.006), (Appendix C Table 4) and the dominant and non-dominant legs for all of the cutting maneuver timing conditions: preplanned (p=.011), planned (p=.009) and unplanned (p=.007). (Appendix C Table 6) When normalizing the peak ground reaction force to a percentage of body weight no difference was seen between the genders.

There was a significant main effect found for condition for the peak ground reaction force and the normalized peak ground reaction force between the cutting maneuvers and the straight ahead run. For the peak ground reaction force, the left preplanned cutting maneuver had a significantly increased peak ground reaction force compared to the straight-ahead run (p=.045) as did the right preplanned cutting maneuver compared to the straight-ahead run (p=.003). (Appendix C Table 49) For the normalized peak ground reaction force, it was found to be significantly greater for the right preplanned cutting maneuver compared to the straight-ahead run (p=.012), but not significantly different for the left preplanned cutting maneuver compared to the straight-ahead run (p=.097). (Appendix C Table 50)

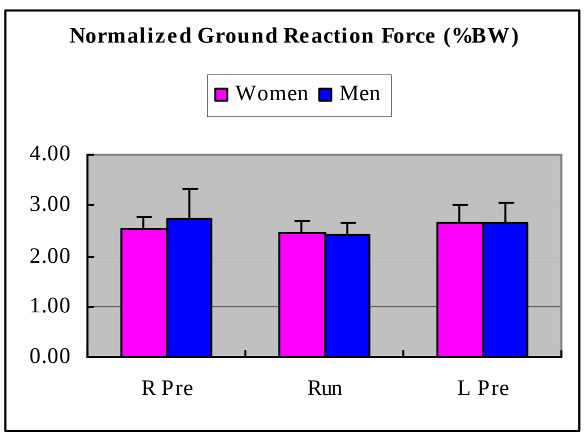


Figure 4.11 – Ground Reaction Force

4.9 EMG

A significant interaction effect was found for the hamstrings muscle activation when comparing the dominant and non-dominant legs in the planned cutting maneuver condition between condition and gender (p=.030) and between timing condition and sport (p=.014). (Appendix C Table 6) There was no interaction effect found for the quadriceps muscle activation. Only one significant main effect was found either of the two muscles measured. The left preplanned cutting maneuver both showed an increase in hamstring activation compared to right preplanned cutting maneuver (p=.037). (Appendix C Table 51)

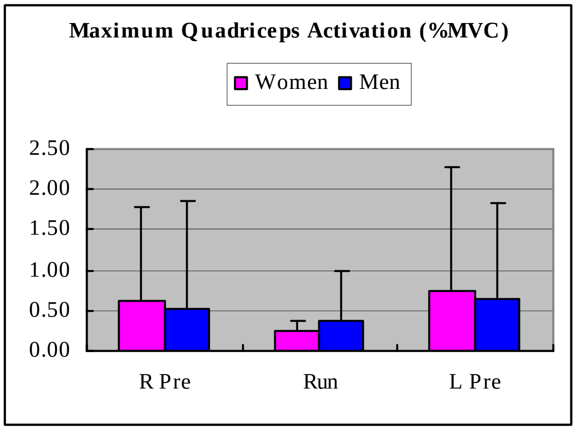


Figure 4.12 - EMG

4.10 Summary of Results

The preplanned cutting maneuver was found to have significantly different kinematics and kinetics compared to the straight-ahead run. For 27 of the 46 dependent variables, the right or left cutting maneuver or both were significantly different than the straight-ahead run. There were gender differences found for 11 of the dependent variables with five of the significant different variables located at the hip joint. Seven dependent variables had an interaction effect between condition and gender. A sport effect was found for six of the dependent variables evenly among the ankle, knee and hip joints. A total of 11 dependent variables displayed an interaction effect between condition and sport. An interaction effect between condition, gender and sport was found for seven of the dependent variables. The interaction was found for five of those dependent variables when comparing the straight-ahead run to the preplanned cutting maneuvers. For leg dominance, there were 10 dependent variables that were found to be significantly different between the dominant and non-dominant legs for at least one of the timing conditions. Half of those dependent variables were found to be significantly different between dominant and non-dominant legs for all three timing conditions. For the timing conditions, there were nine dependent variables that were found to have a significant effect for timing. Two of the dependent variables with timing condition significance were the maximum and minimum trunk rotation angles. The non-dominant leg cutting maneuver was more affected by timing conditions than the dominant leg cutting maneuver.

5. DISCUSSION

The purpose of this research was to study the lower extremity biomechanics, kinematics and kinetics during cutting maneuvers performed by recreational athletes; comparing the effects of anticipation, gender and training on the biomechanics of the cutting maneuver. Various signal times (preplanned, planned and unplanned) were compared to determine the effects of anticipation on the cutting maneuver and the degree kinematics and kinetics of the ankle, knee and hip joints, and the trunk are affected by the different signal times. In addition, this study explored the impact that prior training may have on the biomechanics among athletes performing cutting maneuvers in reaction to various signal times.

5.1 Subjects

Subjects ranged in age from 18 to 32 years old. On average the female subjects were about two years younger than the male subjects. All subjects were recreational athletes participating or performing an athletic activity a minimum of three times a week for at least an hour each time. Subjects were eliminated if they were part of a team that had someone supervising their workouts or had professional trainers. These subjects were considered to be competitive rather than recreational athletes. Approximately 50% of the subjects participated in ball sports: basketball, soccer, football, tennis or handball. The remaining 50% of the subjects were runners, who also lifted weights, swam, practiced yoga and/or participated in martial arts.

5.2 Reliability between Trials

The Intraclass Correlation Coefficients (ICC) were calculated for eight of the dependent variables: the stance duration, peak vertical ground reaction force, and two variables for each of the three joints; ankle, knee and hip. To find the ICC, three of the trials were selected out of the seven collected for each of the timing conditions. Dependent variables with ICC values of greater than 0.70 were considered to have high between trial reliability. Eight of the forty-six dependent variables were selected to examine between trial reliability. All variables selected were found to have an acceptable ICC (Appendix C Table 2). The dependent variables were discrete values found during the stance phase of the cutting maneuver or straight-ahead run.

Running speed was recorded for each of the timing condition trials collected, although it was not used as a variable for this study. Photocells placed two meters apart on the running path were used to measure the running speed.[13,33,66,74,87] Each subject was allowed to select his or her most comfortable speed within a specified range (3 to 4 m/s) and was to maintain the speed ±5% from the self-selected speed. If the subject was outside the ±5% ranges, the trial was not considered to be a good trial. The literature that exists on running speed is conflicting as to whether a self-selected running speed or a standardized running speed is more or less reliable.[75,90,101,111] Studies that examine only within subjects comparisons can use a more varied running speed as long as the running speed stays consistence within subjects, ±5%.[88,90] For this study, within and between subjects comparisons were made: this means that, to be dependent only on the condition studied, a specific range of running speed was used for all subjects for the between variables.

5.3 Answering Research Questions

There were four main research questions posed in Chapter One these are:

1) Is there a significant increase in the forces and moments about the knee joint for an unplanned cutting motion versus a preplanned cutting maneuver?

2) Is there a significant difference between the muscle activation of the hamstrings and quadriceps for an unplanned cutting motion versus a preplanned cutting maneuver?

3) Is there a significant difference in the forces and moments about the knee joint between male and female recreational athletes for the unplanned and preplanned cutting maneuver?

4) Is there a significant difference in the muscle activation of the quadriceps and hamstrings between male and female recreation athletes during the unplanned and preplanned cutting maneuver?

5.3.1. Answer to Research Question 1

The hypothesis of the first question was: *there would be a significant increased in forces and moments about the knee joint for an unplanned cutting maneuver compared to a preplanned cutting maneuver*. There was a significant difference between the unplanned maneuver and the preplanned maneuver of the non-dominant leg cutting maneuver for knee flexion at landing, the maximum hip flexion angle and the maximum hip abduction angle. However, the null hypothesis was accepted for the first research question, as the forces and moments about the knee joint were not significantly different between the timing conditions. Which means for this study the potential risk of knee injury did not increase for the unplanned cutting maneuvers compared to the preplanned cutting maneuvers as was seen in previous studies.[11,12,13]

5.3.2. Answer to Research Question 2

The hypothesis of the second research question was: *there would be a significant increase in the muscle activation of both the quadriceps and hamstrings during the unplanned cutting maneuver compared to the preplanned cutting maneuver*. The results of this study showed that the null hypothesis was accepted for the second question, as there was no difference found for either the quadriceps or the hamstring muscles when comparing the unplanned cutting maneuver to the preplanned cutting maneuver. This could be due in part to the inconsistency of the ground connection of the EMG system discussed further in the assumption and limitation section, section 5.7.

5.3.3. Answer to Research Question 3

The third research question hypothesized: *there would be a significant increase in the forces and moments about the knee joint for the female recreational athletes as compared to their male counterparts during both the unplanned and preplanned cutting maneuvers*. The null of this hypothesis was accepted. The two knee joint dependent variables were found to have a gender effect were the peak knee external rotation moment and the maximum knee internal rotation angle. The peak knee external rotation moment was the single variable found to have a significantly different result between the genders for all three of the timing conditions during both the left and right cutting maneuvers. The men were found to have a significantly larger peak knee external rotation moment compared to the women. The maximum knee internal rotation angle was found to have a significant difference between genders only when comparing the left cutting maneuver timing conditions and comparing the dominant and non-dominant legs for the preplanned condition. The study found the men to have a greater maximum knee external rotation angle than the women. This risk of knee injury for women was potentially increased by the lower peak external rotation moment and decreased by the lower maximum internal rotation angle compared to men.

5.3.4. Answer to Research Question 4

The fourth research question involved muscle reactions similar to the second research question. The hypothesis of the fourth research question was: *there would be significantly greater muscle activation for the quadriceps and significantly lesser muscle activation for the hamstrings for the female recreational athletes as compared to the male recreational athletes during both the unplanned and preplanned cutting maneuver*. The null hypothesis was accepted for the fourth research question, as there was neither significantly greater activation of the quadriceps nor significantly lesser muscle activation for the hamstrings among the female recreational athletes as compared to the male recreational athletes during any of the timing conditions. Muscle activation did not show any significance difference between gender, timing condition, sport, or leg dominance. This could also be due in part to the inconsistency of the ground connection of the EMG system.

5.3.5. Answers to Addition Questions Posed

Separating specific components tested within the four research questions, additional questions were posed:

(1) What is the effect of different signal times (preplanned, planned and unplanned) on peak ground reaction force during the stance phase? *Hypothesis: A decrease in the reaction time is likely to cause an increase in the peak ground reaction force.* The results of this study accepted the null hypothesis as the research found that as the reaction time decreased; neither the peak ground reaction force nor normalized ground reaction force increased.

(2) What is the effect of different signal times on peak moment requirement of the knee joint? *Hypothesis: A decrease in the reaction time is likely to cause an increase in the peak moment requirement.* The results of this study accepted the null hypothesis as the research found that the peak moments at the knee joint did not significantly increase as the reaction time decreased.

(3) What is the effect of different signal times on duration of the stance phase? *Hypothesis: A decrease in the reaction time is likely to cause an increase in the duration of the stance phase.* The results of this study accepted the null hypothesis as the research found there was no significant difference between the timing conditions during the duration of the stance phase.

(4) What is the effect of different signal times on the sagittal plane joint position of the ankle during the stance phase of the cutting motion? *Hypothesis: A decrease in the reaction time is likely to cause a decrease in the ankle flexion*. The results of this study accepted the null hypothesis as the research found there was no significant difference between the timing conditions for the ankle joint position in the sagittal plane.

(5) What is the effect of different signal times on the sagittal plane joint position of the knee during the stance phase of the cutting motion? *Hypothesis: A decrease in the reaction time is likely to cause a decrease in knee flexion angle.* The results of this study found the knee flexion angle at landing was the only sagittal plan motion to show a significant difference due to timing condition and only during the right cutting maneuver. There was a significant difference found between the timing conditions for the knee flexion at landing. The right unplanned timing condition was found to have significantly more knee flexion at

landing than either the right planned timing condition or right preplanned timing condition, rejecting the null hypothesis.

(6) What is the effect of different signal times on the sagittal plane position of the hips during the stance phase of the cutting motion? *Hypothesis: A decrease in the reaction time is likely to cause a decrease in hip flexion angle.* The results of this study accepted the null hypothesis as the research found there was no significant difference between the timing conditions for the position hip joint in the sagittal plane.

(7) What is the effect of different signal times on the transverse plane position of the trunk during the stance phase of the cutting motion? *Hypothesis: A decrease in the reaction time is likely to cause an increase in the trunk motion.* The results of this study accepted the null hypothesis. For the maximum left trunk rotation angle, there was a significant difference between the left preplanned timing condition and the left planned timing condition, between the left planned timing condition and the left unplanned timing condition and between the right unplanned timing condition and both the planned timing condition and preplanned timing condition. For the maximum right trunk rotation angle, the left unplanned timing condition was significantly increased compared to both the left planned timing condition and the left preplanned timing condition. The right preplanned timing condition had a significantly great maximum right trunk rotation angle when compared to the right planned timing condition and the right unplanned timing condition.

(8) What is the effect of different signal times on peak amplitude of the EMG of the hamstrings during the stance phase of the cutting motion? *Hypothesis: A decrease in the reaction time is likely to cause an increase of the muscle activation of the hamstrings during the stance phase of the cutting motion.* The results of this study accepted the null hypothesis

as the research found there was no significant difference for the hamstrings due to timing condition.

(9) What is the effect of different signal times on peak amplitude of the EMG of the quadriceps during the stance phase of the cutting motion? *Hypothesis: A decrease in the reaction time is likely to cause an increase in muscle activation of the quadriceps during the stance phase of the cutting motion.* The results of this study accepted the null hypothesis as the research found there was no significant difference for the quadriceps due to timing condition.

5.4 Cutting Maneuver Compared to Straight-Ahead Run

A number of cutting maneuver studies have compared the straight-ahead run to the cutting maneuver.[13,23,72,73,74,88,95,98,109] Some of these studies focused on gender differences[73,88,99] and others on muscle activation.[12,23,49,81] This study used mixed model repeated measure statistical designs to examine the kinematic and kinetic effects of the cutting maneuver versus the straight-ahead run, the left and right cutting maneuver timing condition, and leg dominance. The effects of gender and sport were evaluated for each of the models. This study found an increase in peak moments for the ankle, knee and hip joints along with an increase in maximum ankle inversion and eversion angle, an increase maximum knee flexion angles and greater variability at the hip joint of the preplanned cutting maneuvers compared to the straight-ahead run. To explain the effects of the cutting maneuver, 46 dependent variables were used. Each subject ran at a self-selected pace between three and four meters per second. The straight-ahead run was used as a control maneuver for this study.

5.4.1. Main Effects of the Cutting Maneuver Compared to Straight-Ahead Run

From basic kinetics it is known that increased peak moments are the result of increased torque at the joint involved about the specified plane. This study found that all three of the peak ankle moments, all three of the peak knee moments, and all three of the peak hip moments increased for both directions of the preplanned cutting maneuver compared to the straight-ahead run. Since the peak moments increased for each of the lower extremity joint planes for the cutting maneuver compared to the straight-ahead run, the torque at these joint is significantly increased for the cutting maneuver. The maximum ankle eversion and inversion angles, the maximum knee flexion angle, the maximum hip flexion angle, the maximum hip adduction angle, the maximum hip abduction angle, the maximum hip external rotation angle, and the hip external/internal rotation ROM were found to increase for both directions of the preplanned cutting maneuver condition compared to the straight-ahead run. A greater degree of eversion in the cutting maneuver, compared to the straight-ahead run, had the ankle increasing the eversion angle toward the direction of turn. The straight-ahead run was found to have a larger maximum hip extension angle and larger maximum knee valgus angle. Greater moments at the joint, and specifically more variability at the hip joint coincide with previous research comparing the cutting maneuver to the straight-ahead run.[13,23,72,73,74,88,96,99,109]

5.4.2 Gender Effects of the Cutting Maneuver Compared to Straight-Ahead Run

The female hips are anatomically different than the male hips; with a different pelvic structure and lower extremity alignment.[40,53] Previous studies have suggested that a high degree of variability or lack of control at the hip joint can place the ACL at an increased risk for injury.[54,121] Examining the gender effect between the cutting maneuvers and the straight-ahead run in this study, five of the eight dependent variables were found to have a gender effect at the hip. Three of the five hip dependent variables measured hip external rotation kinetics: peak hip external rotation moment (men larger moment than women), maximum hip external rotation angle (men greater external rotation angle than women), and the hip external/internal rotation angle ROM (men greater ROM than women). The other two hip dependent variables found to have gender significance were the maximum hip adduction angle (women greater adduction than men) and the maximum hip abduction angle with (women greater abduction angle than men). These results suggest that women had more movement at the hip than men, are more adducted and were more internally rotated at the hip than men. According to previous studies, the lack of control at the hip causes adduction of the hip and internal rotation of the femur.[54,72,73,121]

The results of this study showed females to have turned their feet significantly more towards the turn direction than did their male counterparts. This was noted by the gender effect found for the maximum toe-out angle. These results indicate that women, more than men, use foot placement to control the COM of the body towards the new direction. When the knee joint flexion increases, the peak knee external rotation moment increases to counteract the increased flexion and keep the knee from increased anterior tibial rotation strain, creating greater risk of an ACL injury.[13] There was a lesser degree of external knee rotation found for the cutting maneuver among the women, than the men. With no difference in the maximum knee flexion angle between women and men, this could mean that men were protecting the knee better than women when performing the cutting maneuver.

The average weight for the male subjects was greater than the average weight of the female subject. When the peak GRF was not normalized to body weight, a significant difference was found between genders, with the men having a significantly greater peak GRF than the women (p=.021). When normalizing to body weight, the men continued to display a greater peak GRF than the women, but the difference was no longer significant. The GRF results are consistent with previous cutting maneuver studies that focused on gender differences.[33,66,73,88,97]

5.4.3 Sports Effect of the Cutting Maneuver Compared to Straight-Ahead Run

Previous research has shown that athletes who participate in sports that repetitively use the cutting maneuver are more controlled at performing the maneuver than those that do not often participate in sports involving the cutting maneuver.[23,33,81,88,92,101] The type of sport that the subjects regularly played was found to have a significant main effect on three of the dependent variables in this study; the maximum ankle plantarflexion angle, peak knee varus moment and peak hip external rotation moment. The maximum ankle dorsiflexion angle was found to increase significantly for subjects who did not play ball sports as compared to subjects who did play ball sports. The peak ankle dorsiflexion angle is usually found at the beginning of the stance phase, as the foot touches the ground.[117] By increasing the peak dorsiflexion angle, the anterior compartment of the ankle is more active. A lower maximum plantarflexion angle, usually found that the end of the stance phase, means that the anterior compartment is less active at toe-off. Previous studies have found that women have increased dorsiflexion angles compared to men, theorizing that the increased dorsiflexion angle is one of the factors that decrease the lack of postural control for women when performing the cutting maneuver.[66,73,113] Considering the increased dorsiflexion angle for those that do not play ball sports they would be more likely to have an injury occur when performing a cutting maneuver than those that regularly play ball sports, extending the theory that women are at an increased risk compared to men. However, this extension in theory is beyond the scope of this study.

Subjects who played ball sports were found to have a greater peak knee varus moment than subjects who did not play ball sports. The same was true for the peak hip external rotation moment, subjects who played ball sports had a significantly increased peak hip external rotation moment compared to subjects who run, practiced yoga or swam. Both greater peak knee varus moments and greater peak hip external rotation moments are considered to put the knee or hip joint at a lesser risk for injury, which could mean that those that play ball sports are at less risk of a groin strain or ACL tear than those that do not play ball sports.[12,13,54,72,121]

5.5 Timing Conditions

To establish the three different timing conditions three separate signals were given at three different times. The first signal, the preplanned condition signal, was given approximately 9 meters before the cutting maneuver was to be performed and, dependent on speed, between 3 and 3.5 seconds ahead of the set cutting maneuver. The second signal, the planned timing condition, was given either 900 or 1200 ms after the first signal would have been given; meaning it was giving approximately 6 meters before the cutting maneuver was to be performed or between 2 and 2.5 seconds before the subject arrived at the place to perform the cutting maneuver. The last signal, for unplanned timing condition, given 1.5 meters before the cutting maneuver was to be performed, varied among subjects, ranging between 400 and 750 ms after the second signal would have been given. The time set for this signal was chosen through a process ideally causing the unplanned signal to be the shortest time between when the signal was given and when the subject was required to perform the cutting maneuver. This process started with a time 550 ms after the second signal would be or would have been given. The time between signals was increased in increments of 50 or 100 ms until the subject failed to complete the cutting maneuver in the correct direction. That time was then used as the unplanned cutting maneuver signal. If the subject failed to complete the correct cutting maneuver at 550 ms, the time was reduced in increments of 50 ms until the subject successfully completed the correct cutting maneuver, and the time was held at that time for the data collection. Other studies have utilized similar methodologies to study anticipation. Besier et.al.[11] used a signal board with different LEDs appearing during the different maneuvers for the different conditions. The delay signal was triggered as the participants ran through the photocells or timing gates. The delay was set so each subject did not have enough time to react to the signal and was then reduced until the subject was able to successfully complete the maneuver. Pollard et.al.[83] also used a signal board with LEDs to show the task the subjects would be performing.

5.5.1 Interaction Effects for Timing Conditions

There were seven interaction effects found for timing condition. Six of the seven interaction effects existed for the right timing condition: two between condition and gender (peak ankle eversion moment and percent of stance phase where maximum left trunk angle found), three between condition and type of sport (peak ankle eversion moment, peak knee varus moment and normalized GRF) and one between condition, gender and sports (maximum hip extension angle). An interaction effect for the left timing condition was found between condition and sport for the percentage of stance phase where the maximum trunk rotation angle existed.

5.5.2 Main Effect for Timing Conditions

Nine dependent variables were found to have a significant difference between two or more of the timing conditions. These dependent variables included: peak ankle toe-out rotation moment, maximum ankle toe-out angle, ankle toe-out/toe-in ROM, knee flexion angle at landing, hip joint extension moment, maximum hip flexion angle, maximum hip adduction angle and maximum left trunk rotation angle and maximum right trunk rotation angle.

A study of the ankle, hip and trunk rotation for running and cutting motion with preplanned and unplanned timing conditions has not been found in a review of previous literature. In this study, the timing condition effect on ankle joint peak toe-out/toe-in rotation moment was found to be greater during the left unplanned cutting maneuver compared to the left preplanned cutting maneuver. The maximum ankle toe-out angle was found to be greater for the right preplanned cutting maneuver than the right planned cutting maneuver and for the right unplanned cutting maneuver than the right planned cutting maneuver. A larger maximum ankle toe-out angle would result in the foot being positioned more towards the new direction. Previous ankle research has shown that to turn towards the new direction, when given the signal a step before having to turn, the movement starts at foot placement.[84,85] The finding of this study are consistent with that research. The ankle toe-out/toe-in ROM was also affected for the right timing conditions, with the right unplanned cutting maneuver having a greater ROM than the right planned cutting maneuver. The more movement that occurs at a joint throughout the stance phase the less stable the joint is considered to be, increasing the possibility of an injury.[113,117]

Previous studies have had subjects performing movements in a way that is considered unplanned or unanticipated.[11,33,97] These studies have concentrated on the knee joint, finding that knee flexion at landing increases significantly for the unplanned condition compared to the preplanned condition. Showing consistent results with the previous studies, this study found knee flexion at landing to be greater during the right unplanned cutting maneuver as compared to the right preplanned and planned cutting maneuvers. Previous studies also found a combination of increased valgus moments and internal rotation moments during unplanned cutting maneuvers compared to preplanned cutting maneuvers that were not found in this study.[11,12]

The hip joint extension moment, maximum hip flexion angle, and maximum hip adduction angle were each found in this study to have significant effects for right cutting maneuver timing conditions. Both the peak hip extension moment and maximum hip flexion angle were found to increase for the right unplanned cutting maneuver compared to the right planned cutting maneuver. The maximum hip flexion angle also increased for the right unplanned cutting maneuver compared to the right preplanned cutting maneuver. The maximum hip adduction angle was found to be greater for the right preplanned condition than the right unplanned condition. Larger maximum hip adduction angles have been found by previous studies to be a potential sign of less control of the hip muscles which can cause the femur to internally rotate increasing the valgus at the knee joint, putting it at a greater potential risk for ACL injury.[54,72,74,114,121] The results of this study would then indicate that the right preplanned cutting maneuver was more susceptible to increase the risk for an ACL injury than the right unplanned or planned cutting maneuvers.

This study found the maximum left trunk rotation angle was less for the left planned cutting maneuver timing condition than for either the left unplanned cutting maneuver or the left preplanned cutting maneuver. For the left unplanned cutting maneuver timing condition, the study found the maximum right trunk rotation angle to be greater than either the left preplanned cutting maneuver or the left planned cutting maneuver. For the right cutting maneuvers, the preplanned timing condition was found to result in a greater maximum right trunk rotation angle than either the unplanned or planned timing conditions. According to previous studies, a later signal will cause the to trunk roll toward the new direction of travel later in the stance phase if the signal is given with enough time to place the foot.[85]

5.5.3 Non-significance for Timing Conditions

The lack of significant difference between timing conditions is relevant. Previous studies have shown a timing condition difference between the unplanned maneuver and the preplanned cutting maneuver.[11,12,13,88] The differences between this study's results and the previous studies could be due to the maneuvers performed by the subjects and/or the subject population. A similar study, done by Beiser et. al,[11,12,13] used only elite male soccer players as the subject population. Similar studies had a subject population of high school boys and girls basketball players.[33,88,97] Both of these studies compared athletes who were familiar with the cutting maneuver. The maneuver performed in all the anticipation studies reviewed was neither the cutting maneuver nor even a stop-jump. Some studies, for example Pollard et.al.,[88] had participants start from a flexed position and without running cut to the side, and other anticipation studies used a stop-jump task.[21,33,97]

5.6 Comparison between Dominant and Non-Dominant Legs

Few studies have examined the cutting maneuver performed in both the left and right directions.[88,109] Most cutting maneuver studies have the participants perform the cutting maneuver in the left direction. Some studies have found a significant strength difference between the dominant and non-dominant legs, which is thought to affect the lower extremity stability.[91,94] Other studies have found no significant differences between the dominant and non-dominant legs.[33,35,48,74]

5.6.1 Main Effects of Dominant and Non-Dominant Legs

As discussed in the literature review, there are two types of cutting maneuvers, the sidestep cut where the turn is perform on the leg opposite the direction of the turn and the crosscut which is performed on the same leg as the direction of the turn. For this study, only a side-step cutting maneuver was performed, so that the stance phase leg was different for the left and right directions. With one exception, all subjects for this study were considered left leg dominant. The data for that exception, the right leg dominant subject, was eliminated when running the statistics on leg dominance. A significant difference was found between the dominant and non-dominant legs for 11 of 46 dependent variables using the pairwise comparisons for one or more of the timing conditions. The peak ankle joint flexion/extension moment (dominant turn greater peak moment than non-dominant turn), peak ankle eversion/inversion moment (non-dominant turn greater peak moment than dominant turn), peak knee varus moment, and percentage of the stance phase where the maximum left trunk rotation angle and maximum right trunk rotation angle exists (non-dominant turn later stance phase than dominant turn for maximum and reverse for minimum), were dependent variables found to have dominant or non-dominant leg difference for each of the timing conditions.

As discussed earlier, a basic study of kinetics teaches us that increasing the moments about a joint increases the torque at that joint in the specified planes, requiring the application of greater resistance forces to stabilize the joint. Peak ankle plantarflexion moment and peak knee varus moment both increased significantly for the dominant leg compared to the non-dominant leg cutting maneuver for each of the three timing conditions. The peak ankle eversion moment, however, also increased significantly for the non-dominant leg compared to the dominant leg during cutting maneuvers in all three timing conditions. The moments about the ankle joint were counterbalanced as ankle plantarflexion moment increased for the dominant leg cutting maneuvers and the ankle eversion moment increased for the non-dominant leg cutting maneuvers. There are no previous studies on leg dominance to which the results of this study can be compared, however, reviewing studies involving ankle injuries, the ankle plantarflexion moment could put the ankle joint at a greater risk for sprains, as previous studies have found that decreased dorsiflexion is a potential predictor for ankle sprains.[113]

There was only one difference found at the hip joint between the dominant and non-dominant legs. The hip flexion/extension ROM was greater for the dominant leg for the unplanned cutting maneuvers. Greater hip extension/flexion ROM has been associated with increased hip adduction and increased knee valgus in previous studies.[72,121]

When examining leg dominance for this study, the intent is to find the difference in the biomechanics, between the right and left cutting maneuvers. For this study, the maximum left trunk rotation angle was considered the positive trunk rotation angle. The results show that the body turned completely towards the direction in which it was going to turn near the end of the stance phase, which is consistent with previous research.[84,85,92] Thus, it follows that the left cutting maneuvers would have a maximum left trunk rotation angle later in the stance phase than the right cutting maneuvers. The trunk will turn more towards the left later in stance phase since the entire body must turn 45 degrees to the left to complete the cutting maneuver. On the other hand, the right turn will have the maximum left turn angle at the beginning of the stance phase when the body is facing forward; as the body turns to the right direction the maximum left trunk angle will decrease. Patla et. al.,[85] studied steering and how it related to control of the body's COM. Their research found that either foot placement or trunk roll initiate the body towards the direction of travel. The complete trunk rotation towards the new direction of travel is the last stage of the turn near toe-off.[85]

A cutting maneuver increases the pressure on the medial side of the knee.[96] Peak knee varus moment and peak knee external rotation moment had a significant difference between non-dominant and dominant legs. For the peak knee varus, the dominant leg was significantly greater for all timing conditions when compared to the non-dominant leg. The opposite was true for the peak knee external rotation moment; it was significantly greater for the non-dominant leg than the dominant leg but only for the unplanned timing condition. Studies have shown that increasing the knee valgus moment put the ACL at a greater risk for injury and is often found with increased internal rotation.[70,72] Following the conclusions found by the research of the previous studies, greater knee varus moment and/or more knee external rotation would be advantageous to reduce the potential risk of an ACL injury.

5.6.2 Gender Effect of Dominant and Non-Dominant Legs

For all three timing conditions, this study found there was a significant gender effect only when comparing the non-dominant and dominant cutting maneuvers for the maximum hip adduction angle and the peak GRF. The gender significant gender difference found for the peak GRF did not exist when the subjects were normalized for body weight; which means that the gender difference noted in the peak GRF can be attributed to the difference in body weight between the male and female subjects. When examining leg dominance for all three timing conditions, women were found to have a significantly larger maximum hip adduction angles than men. This result is consistent with previous studies which found that women have a larger hip adduction angle than men and have suggested that the larger hip adduction angle can cause greater valgus and internal rotation at the knee, both movements theorized to increasing the risk of an ACL injury.[66,70,72,73,121]

Other dependent variables that were found to have an effect for gender for at least one of the timing conditions when comparing leg dominance were: the peak ankle plantarflexion moment (men greater than women for planned cutting maneuver only), the peak ankle eversion moment (men greater than women for the unplanned cutting maneuver only), the maximum toe-out angle (women greater than men for the preplanned cutting maneuver only), the peak knee external rotation moment (men greater than women for both the preplanned and planned cutting maneuvers), the maximum knee internal rotation angle (men greater than women for the preplanned cutting maneuver only), the maximum hip abduction angle (women greater than men for both the planned and unplanned cutting maneuvers), the peak hip external rotation moment (men greater than women for both the preplanned and planned cutting maneuvers), the maximum hip external rotation angle (men greater than women for the planned cutting maneuver only) and the hip external/internal rotation ROM (men greater than women for the planned cutting maneuver only). Greater maximum toe-out indicates the women were using foot placement to start the turn more than men for the preplanned condition; as the time decreased the maximum toe-out angle was decreased meaning the start of the turn was less dominated by foot placement. The greater ankle planter flexion and ankle eversion moments, both of which increased for men compared to women, are consistent with previous research indicating a greater potential for ankle sprains.[62,113,117,122]

The greater peak knee external rotation angle potentially balances out the increase maximum knee internal rotation angle, as both also increased for men in the preplanned timing condition. For the preplanned cutting maneuver, the knee external rotation moment has a positive effect; it counteracts knee internal rotation, which is a strong indicator, for higher strains placed on the ACL.[70] As stated above, less control of hip joint is associated with weaker muscles and potentially a risk for ACL injury.[54,72,74,121] For this study, larger maximum hip abduction angle was noted for women compared to men in both the planned and unplanned timing conditions. Men were found to have a greater external rotation moment, a larger hip external rotation angle and more hip internal/external ROM than women. Each of these results were found for the planned cutting maneuver condition, which, as internal rotation is the important variable, could actually indicate that women had more constant internal rotation than men, placing the women at a greater potential risk for groin injuries and ACL tears.

5.6.3 Sports Effect of Dominant and Non-Dominant Legs

Previous studies have shown a linear relationship between experience with the cutting maneuver and variability of the kinetic and kinematics.[74] In this study, for subjects that did not play ball sports, the maximum ankle dorsiflexion angle was significantly greater than for subjects that did regularly play ball sports, for both the dominant and non-dominant legs. The maximum ankle dorsiflexion angle and maximum knee external rotation angle were both found to have a sports effect when comparing the non-dominant and dominant leg cutting maneuvers for all three timing conditions. As seen previously, greater ankle dorsiflexion is thought to be a cause of ankle sprains, which would mean subjects who did not play ball sports were at a potentially greater risk of ankle sprain than subjects who repetitively performed cutting movements.[113] The opposite was true for the maximum knee external rotation angle; subjects who played ball sports had a greater maximum knee external rotation angle than subjects who did not play ball sports regularly. Since more knee internal rotation is a potential factor that is theorized to place greater strain on the ACL,[70,72] greater knee external rotation can reduce this potential strain by decreasing the potential injury risk for subjects who regularly play ball sports. When examining leg dominance, the peak hip adduction moment was the only other dependent variable to show a sports effect. This study found that, for the unplanned timing condition, subjects who did not play ball sports had an increase in the hip adduction moment compared to subjects who played soccer, basketball, tennis, volleyball or handball. Previous studies, discussed in the section on gender effects, have shown that increased hip adduction potentially increases the strain on the ACL placing it at a greater risk for injury.[66,70,72,73,121]

5.7 Assumptions and Limitations

This study assumed that the data from previous studies using similar equipment were accurate. In this study, some of the results agree with the results of previous research, for example, increased hip adduction for women than men and increased moments about the knee joint for the cutting maneuver compared to the straight-ahead run. Some of the results of this study contradict the results of previous research, for example, no varus/valgus or internal rotation at the knee increased for unplanned timing condition compared to the preplanned timing condition. For these results that differ from previous studies, further investigation may be necessary. The results may be different depending on the equipment or methods used.

A limitation in this study may be the sampling frequency of the infrared cameras. The force plates collected data at a rate of 1200 Hz, whereas the cameras collected data at a rate of only 120 Hz. When the data was integrated, the sampling frequency was reduced to 120 samples per second. This low sampling rate could have an effect on the peak joint-resultant forces and moments during the landing phase, possibly underestimating those joint-resultant forces and moments because of the high frequencies associated with the impact. The actual frequency of the GRF signals compared to the low sampling rate may result in a low estimate of joint-resultant forces and moments. Applying an estimation error across subjects in the joint-resultant forces, the difference between the actual frequency and sampling rate for the GRF signals should not have a significant effect on the results of the study, causing the results of this study to be considered to be the actual joint-resultant forces. This study compared the joint resultant force within and between subjects using all the same equipment. Therefore, if the estimate of the joint-resultant forces is low, it is still consistent across all subjects.

A limitation in this study may have been the models used to reduce the data (Appendix B). The markers chosen to define the base of the trunk and for the distal knee influence the angular results of the trunk, hip and knee joints. Specifically affected were the trunk rotation, the knee flexion and extension angles, and the hip internal and external rotation angles. These models are not incorrect as they do define the knee and hip joint in the correct way, but have a different zero axis as to what is considered flexion and extension or adduction and abduction than do some other models. For this study, the model used the shank marker to define the third and most distal point of the knee joint. Some models use lateral ankle marker to define the third and most distal point of the knee joint. With the marker placed on the front of the shin, extension is found at the knee. If the distal marker were on the lateral ankle no extension would be found at the knee joint. To define the hip joints in this study the opposite ASIS marker was used as the negative distal axis reference point rather than a medial knee used in some studies. The marker reference frame used in this study takes into account the entire motion of the hips rather than just the motion of the right or left femurs measured if the medial knee was used as the reference point. For trunk definition, in this study the L4-L5 marker was used to define the negative axes rather than the ASIS markers used in some studies. Examining the rotation of the trunk, this study's definition has one focal point around which the shoulders rotate, rather than using the hips which would result in two focal points, hip rotation along with the shoulders to measure the rotation of the trunk. Thus, the maximum knee flexion and extension angles and maximum hip internal and external rotation angles found in this study may vary from those angles reported in other studies even though the actual angles in both studies may be identical. As a result of the marker selection for the models, the maximum flexion may be less and the maximum extension may be greater in other studies than reported in this study. A limitation for this study was the EMG system. Throughout testing the system produced inconsistent results due to a loose ground connection to the battery. Although the EMG data was analyzed it will not be considered for publication.

5.8 Implications of the Results

A cutting maneuver is one of the most common movements performed in athletic activities such as soccer, basketball, tennis, handball and football.[23,27,50] The cutting maneuver has been shown to be one of the movements linked as most likely performed when an injury occurs, specifically an ankle sprain, ACL tear or groin pull.[46,51,74,88,115,116,121,124] Separating the components of the movement into the kinematics and kinematics of the lower extremity joints to study the biomechanics of the cutting maneuver, can establish the susceptible joint motions that increase the risk of injury.

The ankle joint positions that have been found to be at risk for an ankle sprain are higher maximum inversion angles, higher peak ankle inversion/eversion moments or increases in the ankle inversion/eversion ROM.[40,80] Women in this study were found to have greater maximum ankle toe-out angles than men, but men were found to have higher moments than women, both for ankle plantarflexion and ankle eversion. Greater variability in ankle movement was found for the cutting maneuvers compared to the straight-ahead run in this study. This would indicate that, consistent with previous research, the cutting movement would cause the ankle to be more susceptible to injury than the straight-ahead run. [40,80] Although few cutting maneuver studies concentrate on the ankle joint, the increases in the moment in the sagittal, frontal and transverse planes and the increases in both the maximum ankle inversion and eversion angles have all been shown to be factors that can potentially increase the risk of ankle injury.[62,113,124]

The combination of a decrease in knee flexion, an increase in valgus and an increase in internal rotation of the knee and hip make the knee more susceptible to an ACL tear.[6,12,23,27,46,64,65,67,79,99] Increased adduction of the thigh and higher peak adduction moments can lead to groin strains.[40] In this study, significant kinematic and kinetic gender differences were found at the hip joint for sidestep cutting maneuver compared to the straight-ahead run, which was consistent with previous research.[88,121] The cutting maneuvers in this study were found to have greater maximum hip extension moment, more hip adduction and abduction, and a larger hip external rotation angle compared to the straight-ahead run. The higher hip adduction moment increases the risk of a groin strain especially when combined with the larger peak hip adduction moment. The variation of movement found in the hip between the cutting maneuver and the straight-ahead run suggests that, not only was the hip joint less stable during the stance phase of the cutting maneuvers, but also, as the entire COM needed to change direction, which required rotating the entire body, resulting in more hip movement required by the cutting maneuvers than the straight-ahead run. An increased hip adduction moment not only increases the potential for a groin strain, but also increases the potential risk for an ACL injury.[54,72,73,114,121] In this study, increased hip adduction moment was found between the cutting maneuvers and straight-ahead run, between women compared to men and for the subjects who do not play ball sports when compared to subjects who play ball sports.

Lack of neuromuscular control, increasing the variability of the joint movement, has been shown to theoretically increase the risk of a lower extremity injury. This is especially true for those with less experience with a sidestep cutting maneuver.[13,32,74,87,108] Considering the recreational athletes that do not play ball sports as the non-trained group and recreational athletes who regularly play ball sports as the trained group, a training effect can be seen as the cutting maneuver is more awkward for non-trained athletes than for the trained athletes. The non-trained athletes are more susceptible to injury.[72,88]

A significant difference was found in this study between the dominant leg and non-dominant leg during the cutting maneuvers. By increasing the variability of the ankle eversion movement for the left cutting maneuver, these differences increased the factors suspected as increasing the risk of injury to the ankle joint for the non-dominant leg compared to the dominant leg. Another difference was found between the cutting maneuver directions, and thus, the non-dominant leg and dominant leg. In this study, an increase was found in the maximum knee external rotation angle for the left preplanned cutting maneuver compared to the right preplanned cutting maneuver. This decreased maximum valgus angle increased medial pressure on the knee for the non-dominant leg when compared to the dominant leg.

There have been no previous cutting maneuver studies that examined the dominant and non-dominant legs of healthy subjects. One study on leg dominance found that leg preference affected the strength of the lower extremity.[91] Other studies have reported no difference between dominant and non-dominant legs.[33,35,48,74]

5.9 Future Directions

The approach to the force plates, especially for the unplanned timing condition, was an observed difference, but not a studied difference, during testing in this study. The type of adjustments made to perform the cutting maneuver in the correct direction varied between subjects. Some subjects used a stutter step, some used a lunge, and some used a hop. The stutter step was more common for subjects who played soccer or football. As the stance phase was examined for this specific study, the approach types were observed only during data collection and were not recorded. Prior to data normalization, some of the approach adjustment can be seen in the 3D data causing one to speculate as to how that approach affected the landing for the cutting maneuver.

The training difference between recreational athletes and competitive soccer players would be another direction to examine in the future. Previous studies of competitive soccer players only have shown a timing condition effect for an unplanned cutting maneuver.[12,13,88] This study found a difference between subjects who played ball sports including soccer and subjects who were participants in non-ball sports.

Another possible future study could consider all the joint angles, moments and velocities at landing. ACL injuries are thought to occur at the initial landing portion of the stance phase.[51,75] By further analysis of the joints at the initial landing portion of the stance phase, the risk of an ACL tear could be better understood. Muscle activation is another risk factor for ACL tears. Testing more muscles within the thigh and muscles on the calf would aid in understanding how the different timing signals effect the position of the lower extremity when initiating a cutting maneuver.

6. CONCLUSION

Sudden movements in an unexpected direction are common in athletic activities. Quick postural adjustments often need to be made by the athlete to avoid a collision in sports such as soccer, basketball and even when running along a path. These adjustments often require a cutting movement, i.e. a sudden change of direction along with either a deceleration or acceleration.[11,12,13,15,71,116] These adjustments can lead to injury. This study focused on identifying the different lower extremity kinematics and kinetics resulting from postural adjustments made during the stance phase of the cutting maneuver.

- Preplanned cutting maneuvers for this study were found to display greater peak moments at the ankle, knee and hip joints, larger ankle eversion and inversion angles, greater maximum knee flexion angles and increased variability at the hip joint, which other studies have shown to potentially increase the risk of injury to the ankle, knee and hip joints compared to the straight-ahead run. These results are consistent with those found in previous research.[13,23,72,74,88,96,99,109]
- Between the unplanned and preplanned timing conditions, trunk rotation was found to be significant different for both the left and right cutting maneuvers. Other timing condition significance (peak toe-out moment, maximum toe-out angle, ankle toe-out/toe-in ROM, knee flexion at landing, peak hip extension moment, max hip flexion angle, and max hip adduction angle) were found, mostly between the right planned condition and either the unplanned and/or preplanned condition. The right unplanned cutting maneuver condition was found to be the most susceptible to injury compared

to the right planned and preplanned cutting maneuvers. Besier et.al.[11] found that an unplanned left cutting maneuver had a large increase in knee varus/valgus and internal/external rotation moments and greater maximum knee flexion angles compared with a preplanned left cutting maneuver.

- A significant difference was found between the dominant leg and non-dominant leg cutting maneuvers. The ankle peak plantarflexion moment and peak knee varus moment increased for the dominant leg compared to the non-dominant leg, whereas the peak eversion moment increased for the non-dominant leg compared to the dominant leg. The dependent variables with significance between dominant and non-dominant legs showed the non-dominant leg to have a greater potential risk for injury compared to the dominant leg. Previous studies have shown no difference between dominant and non-dominant legs when looking at cutting maneuvers.[33,74]
- Gender differences were found when comparing the preplanned cutting maneuvers to the straight-ahead run, comparing both the left and right the timing conditions and comparing leg dominance. The peak GRF was the only dependent variable that was found to be significantly different across all statistics computed; when normalized no gender significance existed for the peak GRF. For the timing conditions the peak knee external rotation moment had a gender effect for both the left and right cutting maneuvers, with men having more external rotation at the knee than women, and the maximum hip adduction angle with women showing a great hip adduction angle than men. The variables which were found to have significance in this study support the theory that women are at a greater potential risk for a knee injury compared to men when performing a cutting maneuver which agrees with previous research showing

women to be more potentially susceptible to ACL injuries than men.[33,54,66,70,72,74,88,97,121]

- Significance difference between the types of sports played was consistent across all statistical models for the maximum dorsiflexion angle. Subjects who did not regularly play ball sports showed an increased dorsiflexion angle compared to subjects who played ball sports.[66,73,113] This result shows a training effect with athletes who did not play ball sports at a greater risk of ankle sprain while performing the cutting movement under any condition than athletes who regularly participated in ball sports: basketball, soccer, volleyball, tennis or handball. Those that are familiar with a task have been shown in previous studies to be more controlled at performing the maneuver than those less familiar with the task.[23,32,33,74,81,87,88,92,101,108]

APPENDIX A

Subject Consent Form

University of North Carolina-Chapel Hill
Consent to Participate in a Research Study
Adult Subjects

IRB Study #___05-AHS-266_________________
Consent Form Version Date: __6-1-05____________

Title of Study: Mechanism and Timing Effects on the Kinematics and Kinetics of the Running and Cutting Motion

Principal Investigator: Jennifer J. Preston, MS
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Co-Investigators: William Garrett Jr. MD PhD, Henry Hsiao PhD, Carol Lucas, PhD

Faculty Advisor: Bing Yu, PhD
Funding Source:
Study Contact telephone number: 919.966.9797
Study Contact email: preston@email.unc.edu

What are some general things you should know about research studies?
You are being asked to take part in a research study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason.

Research studies are designed to obtain new knowledge that may help other people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Deciding not to be in the study or leaving the study before it is done will not affect your relationship with the researcher, your health care provider, or the University of North Carolina-Chapel Hill. If you are a patient with an illness, you do not have to be in the research study in order to receive health care.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?
The purpose of this research study is to determine how a signal given at different times will effect the way a person performs a cutting motion, specifically when the trunk moves and how hip, knee, and ankle joints flexes. The results of this study will help determine how preplanned motions, a signal given early differ from unplanned motions, late signal given.

Are there any reasons you should not be in this study?
You should not participate in this study if: (1) you have had a previous knee injury that required missing practice or games for more than 3 weeks, (2) you do not exercise at least 3 times a week or for at least 3 hours a week, (3) you are younger than 18 years of age or older than 35 years of age, (4) have a current lower extremity injury.

How many people will take part in this study?
If you decide to be in this study, you will be one of approximately 36 people in this research study.

How long will your part in this study last?
Your participation in this study will last for approximately 2 hours either in one day or two separate days without further follow-up.

What will happen if you take part in the study?
During the course of this study, the following will occur:
You will come to the Motion Analysis Laboratory in the Center for Human Movement Science. Your body mass and standing height will be measured. Cutting movement will be described to you. You will have 10 minutes to warm-up and practice the task.

You will be asked to run straight forward like you were running to the opposite side of a court or field, unless given a signal. If you are given a turn signal, you will be asked to cut in the direction of the signal on the force plates. If the signal is given to late, try to complete the cutting motion to the best you can.

Reflective markers will be placed on your body at several points on your foot, leg, shoulder and hips. Four surface electrodes will be placed on the surface of the outside of your upper leg, over the hamstring and quadriceps muscles, on both of your legs.

While you are running and cutting, eight infrared cameras, two force plates, electromyographic, and pressure data collection systems will collect your movement, force, muscle activity, and foot pressure data.

You will be asked to perform five successful trials of each of the timing conditions. You will be running forward more than performing any of the trials. You will be given a minute rest between trials. Your visit will be completed after completing five successful trials for each condition.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. You will not benefit personally from being in this research study.

What are the possible risks or discomforts involved with being in this study?
This study might involve the following risks and/or discomforts to you: you may experience the same kind of injuries during running or cutting, during the motion test as may occur in your daily sports activities. The risk for physical injuries in this study is minimal and will not be greater than that you encounter in your daily sports activities. We anticipate that any possible injury would be minor. Injuries that could occur in daily sports activities include: ankle or knee sprains, tearing of the anterior cruciate ligament (ACL) or medial collateral ligament (MCL)or hip injury.

What if we learn about new findings or information during the study?
You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

How will your privacy be protected?
No subjects will be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

What will happen if you are injured by this research?
All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

What if you want to stop before your part in the study is complete?
You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected reaction, or have failed to follow instructions, or because the entire study has been stopped.

Will you receive anything for being in this study?
You will be receiving $10 for taking part in this study upon completion.

Will it cost you anything to be in this study?

The cost of this research will be limited to any transportation costs needed for you to come to the University of North Carolina at Chapel Hill's campus.

What if you are a UNC student?
You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

What if you are a UNC employee?
Taking part in this research is not a part of your University duties, and refusing will not affect your job. You will not be offered or receive any special job-related consideration if you take part in this research.

Who is sponsoring this study?
This research project is not funded by any outside source.

What if you have questions about this study?
You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research subject?
All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the

Biomedical Institutional Review Board at 919-966-1344 or biomed_irb@unc.edu.

- -

Subject's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

______________________________________ ________________
Signature of Research Subject Date

____
Printed Name of Research Subject

______________________________________ ________________
Signature of Person Obtaining Consent Date

____
Printed Name of Person Obtaining Consent

APPENDIX B

Data Reduction Models

<u>Landmark Models:</u>

<u>Right Medial Ankle</u>

Origin: Right Lateral Ankle

Principle Axis (z):	Right Lateral Knee (+)	Right Lateral Ankle (-)
Intermediate Axis (y):	Right Shank (+)	Right Lateral Ankle (-)
Crossed Axis (x):	Principle X Intermediate	

<u>Right Medial Knee</u>

Origin: Right Lateral Knee

Principle Axis (z):	Right Lateral Knee (+)	Right Lateral Ankle (-)
Intermediate Axis (y):	Right Shank (+)	Right Lateral Ankle (-)
Crossed Axis (x):	Principle X Intermediate	

<u>Left Medial Ankle</u>

Origin: Left Lateral Ankle

Principle Axis (z):	Left Lateral Knee (+)	Left Lateral Ankle (-)
Intermediate Axis (y):	Left Shank (+)	Left Lateral Ankle (-)
Crossed Axis (x):	Intermediate X Principle	

<u>Left Medial Knee</u>

Origin: Left Lateral Knee

Principle Axis (z):	Left Lateral Knee (+)	Left Lateral Ankle (-)
Intermediate Axis (y):	Left Shank (+)	Left Lateral Ankle (-)
Crossed Axis (x):	Intermediate X Principle	

<u>Virtual Landmarks:</u>

<u>Right Hip Joint Center:</u>

Origin: Right ASIS

Principle Axis (y):	Left ASIS (+)	Right ASIS (-)
Intermediate Axis (x):	L4 - L5 (+)	Right ASIS (-)
Crossed Axis (z):	Principle X Intermediate	

Local 3-D Coordinates:

x = -22.0	Left ASIS	Right ASIS
y =14.0	Left ASIS	Right ASIS
z =-30.0	Left ASIS	Right ASIS

<u>Right Knee Joint Center:</u>

Origin: Right Lateral Knee

Principle Axis (y):	Right Medial Knee (+)	Right Lateral Knee (-)
Intermediate Axis (z):	Right Thigh (+)	Right Lateral Knee (-)
Crossed Axis (x):	Principle X Intermediate	

Local 3-D Coordinates:

x = 0.0	Right Medial Knee	Right Lateral Knee
y =50.0	Right Medial Knee	Right Lateral Knee
z = 0.0	Right Medial Knee	Right Lateral Knee

<u>Right Ankle Joint Center:</u>
Origin: Right Lateral Ankle

Principle Axis (y):	Right Medial Ankle (+)	Right Lateral Ankle (-)
Intermediate Axis (z):	Right Lateral Knee (+)	Right Lateral Ankle (-)
Crossed Axis (x):	Principle X Intermediate	

Local 3-D Coordinates:

x = 0.0	Right Medial Ankle	Right Lateral Ankle
y =50.0	Right Medial Ankle	Right Lateral Ankle
z = 0.0	Right Medial Ankle	Right Lateral Ankle

<u>Right Toe:</u>
Origin: Right 5th Metatarsal

Principle Axis (y):	Right 1st Metatarsal (+)	Right 5th Metatarsal (-)
Intermediate Axis (x):	Right Heel (+)	Right 5th Metatarsal (-)
Crossed Axis (z):	Principle X Intermediate	

Local 3-D Coordinates:

x = 0.0	Right 5th Metatarsal	Right 1st Metatarsal
y =50.0	Right 5th Metatarsal	Right 1st Metatarsal
z = 0.0	Right 5th Metatarsal	Right 1st Metatarsal

<u>Left Hip Joint Center:</u>
Origin: Left ASIS

Principle Axis (y):	Left ASIS (+)	Right ASIS (-)
Intermediate Axis (x):	Right ASIS (+)	L4 - L5 (-)
Crossed Axis (z):	Intermediate X Principle	

Local 3-D Coordinates:

x = -22.0	Left ASIS	Right ASIS
y =-14.0	Left ASIS	Right ASIS
z =-30.0	Left ASIS	Right ASIS

<u>Left Knee Joint Center:</u>
Origin: Left Lateral Knee

Principle Axis (y):	Left Lateral Knee (+)	Left Medial Knee (-)
Intermediate Axis (z):	Left Thigh (+)	Left Lateral Knee (-)
Crossed Axis (x):	Principle X Intermediate	

Local 3-D Coordinates:

x = 0.0	Left Medial Knee	Left Lateral Knee
y =-50.0	Left Medial Knee	Left Lateral Knee
z = 0.0	Left Medial Knee	Left Lateral Knee

Left Ankle Joint Center:
Origin: Left Lateral Ankle
Principle Axis (y): Left Lateral Ankle (+) Left Medial Ankle (-)
Intermediate Axis (z): Left Lateral Knee (+) Left Lateral Ankle (-)
Crossed Axis (x): Principle X Intermediate
Local 3-D Coordinates:
x = 0.0 Left Medial Ankle Left Lateral Ankle
y =50.0 Left Medial Ankle Left Lateral Ankle
z = 0.0 Left Medial Ankle Left Lateral Ankle

Left Toe:
Origin: Left 1st Metatarsal
Principle Axis (y): Left 5th Metatarsal (+) Left 1st Metatarsal (-)
Intermediate Axis (x): Left Heel (+) Left 1st Metatarsal (-)
Crossed Axis (z): Principle X Intermediate
Local 3-D Coordinates:
x = 0.0 Left 1st Metatarsal Left 5th Metatarsal
y =50.0 Left 1st Metatarsal Left 5th Metatarsal
z = 0.0 Left 1st Metatarsal Left 5th Metatarsal

Segment Linear Model:
Right Thigh
Segment Shape: Thigh
1st Proximal: Right Hip 1st Distal: Right Knee
2nd Proximal: Right Hip 2nd Distal: Right Knee

Right Shank
Segment Shape: Shank
1st Proximal: Right Knee 1st Distal: Right Ankle
2nd Proximal: Right Knee 2nd Distal: Right Ankle

Right Foot
Segment Shape: Foot
1st Proximal: Right Ankle 1st Distal: Right Toe
2nd Proximal: Right Heel 2nd Distal: Right Toe

Trunk
Segment Shape: Trunk
1st Proximal: Right Shoulder 1st Distal: Right Hip
2nd Proximal: Left Shoulder 2nd Distal: Left Hip

Left Thigh
Segment Shape: Thigh
1st Proximal: Left Hip 1st Distal: Left Knee
2nd Proximal: Left Hip 2nd Distal: Left Knee

Right Shank
Segment Shape: Shank
1st Proximal: Left Knee 1st Distal: Left Ankle
2nd Proximal: Left Knee 2nd Distal: Left Ankle

Right Foot
Segment Shape: Foot
1st Proximal: Left Ankle 1st Distal: Left Toe
2nd Proximal: Left Heel 2nd Distal: Left Toe

Segment Frame:
Right Thigh (Tri-Axis)
x-axis (Moment of Inertia 0.1052)
Translation: Anterior-Posterior Rotation: Adduction (+) / Abduction (-)
y-axis (Moment of Inertia 0.1052)
Translation: Medial-Lateral Rotation: Flexion (+) / Extension (-)
z-axis (Moment of Inertia 0.0000)
Translation: Superior-Inferior Rotation: External (+) / Internal (-)
Crossed-Axis (x): *Intermediate X Principle*
Principle Axis (z):
1st Positive: Right Hip Joint Center
2nd Positive: Right Hip Joint Center
1st Negative: Right Knee Joint Center
2nd Negative: Right Knee Joint Center

Intermediate Axis (y):
1st Positive: Right Medial Knee
2nd Positive: Right Medial Knee
1st Negative: Right Lateral Knee
2nd Negative: Right Lateral Knee

Right Shank (Tri-Axis)
x-axis (Moment of Inertia -0.0505)
Translation: Anterior-Posterior Rotation: Varus (+) / Valgus (-)
y-axis (Moment of Inertia 0.0505)
Translation: Medial-Lateral Rotation: Flexion (+) / Extension (-)
z-axis (Moment of Inertia 0.0000)
Translation: Superior-Inferior Rotation: External (+) / Internal (-)
Crossed-Axis(x): *Intermediate X Principle*
Principle Axis (z):
1st Positive: Right Knee Joint Center
2nd Positive: Right Knee Joint Center
1st Negative: Right Ankle Joint Center
2nd Negative: Right Ankle Joint Center

Intermediate Axis (y):
1st Positive: Right Medial Knee
2nd Positive: Right Medial Knee
1st Negative: Right Lateral Knee
2nd Negative: Right Lateral Knee

Right Foot (Tri-Axis)
x-axis (Moment of Inertia 0.0000)
Translation: Anterior-Posterior Rotation: Inversion (+) / Eversion (-)
y-axis (Moment of Inertia 0.0038)
Translation: Medial-Lateral Rotation: Flexion (+) / Extension (-)
z-axis (Moment of Inertia -0.0038)
Translation: Superior-Inferior Rotation: Toe-out (+) / Toe-in (-)

Crossed-Axis(z): Principle X Intermediate

Principle Axis (x):	*Intermediate Axis (y):*
1st Positive: Right Toe	1st Positive: Right 1st Metatarsal
2nd Positive: Right Toe	2nd Positive: Right 1st Metatarsal
1st Negative: Right 5th Metatarsal	1st Negative: Right Heel
2nd Negative: Right 5th Metatarsal	2nd Negative: Right Heel

Trunk (Tri-Axis)

x-axis (Moment of Inertia 1.3080)
Translation: Anterior-Posterior Rotation: Right Lateral (+) / Left Lateral Flexion (-)
y-axis (Moment of Inertia 1.3080)
Translation: Medial-Lateral Rotation: Flexion (+) / Extension (-)
z-axis (Moment of Inertia 1.3080)
Translation: Superior-Inferior Rotation: Left Rotation (+) / Right Rotation (-)

Crossed-Axis(x): Intermediate X Principle

Principle Axis (z):	*Intermediate Axis (y):*
1st Positive: Right Shoulder	1st Positive: Left Shoulder
2nd Positive: Right Shoulder	2nd Positive: Left Shoulder
1st Negative: L4 – L5	1st Negative: L4 – L5
2nd Negative: L4 – L5	2nd Negative: L4 – L5

Left Thigh (Tri-Axis)

x-axis (Moment of Inertia 0.1052)
Translation: Anterior-Posterior Rotation: Abduction (+) Adduction (-)
y-axis (Moment of Inertia 0.1052)
Translation: Medial-Lateral Rotation: Flexion (+) / Extension (-)
z-axis (Moment of Inertia 0.0000)
Translation: Superior-Inferior Rotation: Internal (+) / External (-)

Crossed-Axis(x): Intermediate X Principle

Principle Axis (z):	*Intermediate Axis (y):*
1st Positive: Left Knee Joint Center	1st Positive: Left Lateral Knee
2nd Positive: Left Knee Joint Center	2nd Positive: Left Lateral Knee
1st Negative: Left Hip Joint Center	1st Negative: Left Medial Knee
2nd Negative: Left Hip Joint Center	2nd Negative: Left Medial Knee

Left Shank (Tri-Axis)

x-axis (Moment of Inertia 0.0505)
Translation: Anterior-Posterior Rotation: Varus (+) / Valgus (-)
y-axis (Moment of Inertia 0.0505)
Translation: Medial-Lateral Rotation: Flexion (+) / Extension (-)
z-axis (Moment of Inertia 0.0000)
Translation: Superior-Inferior Rotation: Internal (+) / External (+)

Crossed-Axis(x): Intermediate X Principle

Principle Axis (z):
1st Positive: Left Ankle Joint Center
2nd Positive: Left Ankle Joint Center
1st Negative: Left Knee Joint Center
2nd Negative: Left Knee Joint Center

Intermediate Axis (y):
1st Positive: Left Lateral Knee
2nd Positive: Left Lateral Knee
1st Negative: Left Medial Knee
2nd Negative: Left Medial Knee

Left Foot (Tri-Axis)
x-axis (Moment of Inertia 0.0000)
Translation: Anterior-Posterior   Rotation: Inversion (+) / Eversion (-)
y-axis (Moment of Inertia 0.0038)
Translation: Medial-Lateral   Rotation: Flexion (+) / Extension (-)
z-axis (Moment of Inertia -0.0038)
Translation: Superior-Inferior   Rotation: Toe-out (+) / Toe-in (-)
Crossed-Axis(z): Principle X Intermediate

Principle Axis (x):
1st Positive: Left Heel
2nd Positive: Left Heel
1st Negative: Left Toe
2nd Negative: Left Toe

Intermediate Axis (y):
1st Positive: Left 5th Metatarsal
2nd Positive: Left 5th Metatarsal
1st Negative: Left 1st Metatarsal
2nd Negative: Left 1st Metatarsal

Joint Angle Model:

Right Hip (Tri-Axis)
Rotation Axis Names

X (3rd Rotation)	Y (2nd Rotation)	Z (1st Rotation)
Internal(+)/External(-) Rotation	Adduction(+)/Abduction(-)	Flexion(+)/Extension(-)

Proximal Reference Frame
Crossed-Axis (y): Intermediate X Principle
Principle Axis (x): Positive: Right Shoulder   Negative: Right Hip
Intermediate Axis (z): Positive: Left Hip   Negative: Right Hip
Distal Reference Frame
Crossed-Axis (y): Intermediate X Principle
Principle Axis(x): Positive: Right Hip   Negative: Right Knee
Intermediate Axis (z): Positive: Left Hip   Negative: Right Hip

Right Knee (Tri-Axis)
Rotation Axis Names

X (3rd Rotation)	Y (2nd Rotation)	Z (1st Rotation)
Internal(+)/External(-) Rotation	Varus(+)/Valgus(-)	Flexion(+)/Extension(-)

Proximal Reference Frame
Crossed-Axis (y): Principle X Intermediate
Principle Axis (x): Positive: Right Hip   Negative: Right Knee
Intermediate Axis (z): Positive: Right Medial Knee   Negative: Right Lateral Knee

Distal Reference Frame
Crossed-Axis (y): Principle X Intermediate
Principle Axis(x): Positive: Right Knee Negative: Right Shank
Intermediate Axis (z): Positive: Right Medial Knee Negative: Right Lateral Knee

Right Ankle (Tri-Axis)
Rotation Axis Names

X (3rd Rotation)	Y (2nd Rotation)	Z (1st Rotation)
Toe-out(+)/Toe-in(-)	Inversion(+)/Eversion(-)	Flexion(+)/Extension(-)

Proximal Reference Frame
Crossed-Axis (y): Intermediate X Principle
Principle Axis (x): Positive: Right Knee Negative: Right Ankle
Intermediate Axis (z): Positive: Right Medial Knee Negative: Right Lateral Ankle
Distal Reference Frame
Crossed-Axis (x): Principle X Intermediate
Principle Axis(y): Positive: Right Toe Negative: Right Heel
Intermediate Axis (z): Positive: Right 1st Metatarsal Negative: Right 5th Metatarsal

Left Hip (Tri-Axis)
Rotation Axis Names

X (3rd Rotation)	Y (2nd Rotation)	Z (1st Rotation)
Internal(+)/External(-) Rotation	Adduction(+)/Abduction(-)	Flexion(+)/Extension(-)

Proximal Reference Frame
Crossed-Axis (y): Intermediate X Principle
Principle Axis (x): Positive: Left Hip Negative: Left Shoulder
Intermediate Axis (z): Positive: Left Hip Negative: Right Hip
Distal Reference Frame
Crossed-Axis (y): Intermediate X Principle
Principle Axis(x): Positive: Left Knee Negative: Left Hip
Intermediate Axis (z): Positive: Left Hip Negative: Right Hip

Left Knee (Tri-Axis)
Rotation Axis Names

X (3rd Rotation)	Y (2nd Rotation)	Z (1st Rotation)
Internal(+)/External(-) Rotation	Varus(+)/Valgus(-)	Flexion(+)/Extension(-)

Proximal Reference Frame
Crossed-Axis (y): Intermediate X Principle
Principle Axis (x): Positive: Left Knee Negative: Left Hip
Intermediate Axis (z): Positive: Left Lateral Knee Negative: Left Medial Knee
Distal Reference Frame
Crossed-Axis (y): Intermediate X Principle
Principle Axis(x): Positive: Left Shank Negative: Left Knee
Intermediate Axis (z): Positive: Left Lateral Knee Negative: Left Medial Knee

Left Ankle (Tri-Axis)

Rotation Axis Names

X (3rd Rotation)	Y (2nd Rotation)	Z (1st Rotation)
Toe-out(+)/Toe-in(-)	Inversion(+)/Eversion(-)	Flexion(+)/Extension(-)

Proximal Reference Frame

Crossed-Axis (y):	Intermediate X Principle	
Principle Axis (x):	Positive: Left Ankle	Negative: Left Knee
Intermediate Axis (z):	Positive: Left Lateral Ankle	Negative: Left Medial Ankle

Distal Reference Frame

Crossed-Axis (x):	Principle X Intermediate	
Principle Axis(y):	Positive: Left Heel	Negative: Left Toe
Intermediate Axis (z):	Positive: Left 5th Metatarsal	Negative: Left 1st Metatarsal

APPENDIX C

Results

TABLE 1 – Coefficient of Variance (CV) for Knee Flexion at Landing

Subject	Right Pre-Plan	Right Plan	Right Un-Plan	Left Pre-Plan	Left Plan	Left Un-Plan	Straight Ahead Run	AVG
M1	58.0	54.8	49.0	52.8	9.0	20.5	35.6	40.0
M2	69.1	45.6	83.9	5.7	40.2	84.0	2.8	47.3
M3	30.0	43.0	30.9	5.3	6.5	66.1	17.4	28.5
M4	75.0	77.8	48.8	21.3	26.5	88.6	67.9	58.0
M5	57.0	34.5	85.8	13.6	60.1	65.9	38.6	50.8
M6	33.2	86.1	81.9	15.2	41.0	15.4	18.1	41.6
M7	39.0	23.3	13.7	79.6	22.1	51.7	40.6	38.6
M8	37.0	26.0	37.1	20.6	49.4	20.8	17.2	29.7
M9	40.8	39.5	86.5	35.6	68.3	56.8	11.1	48.4
M10	39.0	45.2	68.9	18.6	14.3	67.4	14.8	38.3
M11	56.9	52.7	39.9	51.6	76.5	40.2	39.5	51.0
M12	20.0	23.6	19.7	27.1	10.3	27.8	18.0	20.9
M13	35.0	8.3	37.5	36.2	12.2	66.1	16.2	30.2
M14	75.5	37.8	35.0	17.7	10.1	35.4	5.2	31.0
M15	29.7	19.0	41.6	27.2	34.5	31.5	20.0	29.1
M16	35.5	71.9	36.0	74.2	42.2	17.9	15.0	41.8
M17	12.8	13.8	38.5	11.9	20.9	8.8	19.0	18.0
F1	42.9	13.6	24.0	24.6	19.5	46.6	14.4	26.5
F2	10.1	2.6	15.7	22.8	17.8	16.4	9.4	13.5
F3	55.6	34.6	38.7	15.4	7.9	9.0	26.6	26.8
F4	34.0	26.1	41.4	33.6	23.5	14.4	20.0	27.6
F5	42.9	38.5	17.6	3.4	22.6	12.0	34.7	24.5
F6	73.4	34.6	25.1	67.9	53.4	18.8	50.6	46.3
F7	7.2	20.8	14.9	12.6	23.1	44.3	3.9	18.1
F8	16.9	54.7	58.8	65.7	30.7	42.7	49.8	45.6
F9	54.0	7.5	70.5	63.1	71.0	40.3	24.8	47.3
F10	51.4	39.8	26.2	22.9	5.8	9.0	2.9	22.6
F11	57.3	46.4	54.5	39.0	68.6	10.8	31.8	44.1
F12	32.0	14.0	57.4	22.0	57.8	46.0	6.0	33.6
F13	39.2	81.7	46.7	26.5	74.6	32.0	43.5	49.2
F14	36.4	12.4	76.3	28.5	57.2	70.3	62.5	49.1
F15	62.9	75.5	61.5	12.6	24.7	8.3	27.7	39.0
F16	3.8	14.0	0.4	6.5	39.3	41.7	28.7	19.2

Men **Women**

TABLE 2 – Intraclass Correlation Coefficient (ICC)

	Stance Phase Duration	Peak Ground Reaction Force	Peak Ankle Flexion Moment	Max Ankle Inversion Angle	Max Knee Varus Angle	Max Knee Extension Angle	Peak Hip Flexion Moment	Max Hip Add Angle
ICC	.8756	.8665	.7699	.7140	.8620	.7334	.7945	.8728
SEM	.0018	16.0766	.0106	.7113	.5684	1.2392	.0068	.2853

TABLE 3 – Interaction and Main Effects Straight-Ahead compared to Cutting Maneuver

	Interaction Effects			Main Effects		
Variable	Cond* Gender	Cond* Sport	Cond* Gender* Sport	Cond	Gender	Sport
Duration of Stance Phase	0.028	0.306	0.861	0.001	0.436	0.835
Peak Ankle Flexion Moment	0.108	0.814	0.420	0.000	0.358	0.251
Maximum Ankle Plantarflexion Angle	0.992	0.274	0.268	0.159	0.922	0.040
Maximum Ankle Dorsiflexion Angle	0.220	0.016	0.566	0.109	0.954	0.088
Ankle Plantar/Dorsiflexion ROM	0.250	0.019	0.432	0.277	0.816	0.906
Peak Ankle Eversion Moment	0.997	0.626	0.437	0.000	0.065	0.817
Maximum Ankle Eversion Angle	0.323	0.746	0.454	0.000	0.850	0.894
Maximum Ankle Inversion Angle	0.743	0.699	0.485	0.000	0.088	0.386
Ankle Eversion/Inversion ROM	0.868	0.858	0.235	0.008	0.059	0.208
Peak Ankle Toe-out Moment	0.072	0.481	0.347	0.013	0.749	0.994
Maximum Ankle Toe-out Angle	0.618	0.888	0.883	0.181	0.019	0.456
Maximum Ankle Toe-in Angle	0.644	0.941	0.669	0.980	0.422	0.065
Ankle Toe-out/Toe-in ROM	0.684	0.838	0.655	0.478	0.105	0.117
Peak Knee Flexion Moment	0.261	0.493	0.006	0.007	0.229	0.539
Maximum Knee Flexion Angle	0.332	0.720	0.750	0.005	0.225	0.685
Maximum Knee Extension Angle	0.552	0.485	0.282	0.027	0.820	0.427
Knee Flexion/Extension ROM	0.761	0.432	0.404	0.314	0.412	0.594

TABLE 3 – Interaction and Main Effects Straight-Ahead cont.

Variable	Cond* Gender	Cond* Sport	Cond* Gender* Sport	Cond	Gender	Sport
Knee Flexion Angle at Landing	0.467	0.969	0.700	0.349	0.557	0.531
Peak Knee Varus Moment	0.239	0.302	0.654	0.000	0.206	0.488
Maximum Knee Varus Angle	0.891	0.548	0.536	0.082	0.198	0.208
Maximum Knee Valgus Angle	0.526	0.217	0.733	0.024	0.681	0.699
Knee Varus/Valgus ROM	0.268	0.728	0.421	0.305	0.237	0.252
Peak Knee External Rotation Moment	0.161	0.352	0.485	0.000	0.016	0.731
Maximum Knee External Rotation Angle	0.338	0.346	0.181	0.611	0.641	0.138
Maximum Knee Internal Rotation Angle	0.388	0.269	0.334	0.757	0.230	0.488
Knee External/Internal Rotation ROM	0.089	0.477	0.674	0.711	0.418	0.400
Peak Hip Extension Moment	0.187	0.578	0.018	0.009	0.248	0.741
Maximum Hip Extension Angle	0.245	0.996	0.715	0.007	0.105	0.898
Maximum Hip Flexion Angle	0.138	0.789	0.442	0.000	0.215	0.820
Hip Flexion/Extension ROM	0.247	0.482	0.049	0.002	0.821	0.679
Peak Hip Adduction Moment	0.325	0.347	0.320	0.000	0.268	0.595
Maximum Hip Adduction Angle	0.686	0.937	0.981	0.000	0.026	0.626
Maximum Hip Abduction Angle	0.782	0.985	0.934	0.000	0.047	0.544
Hip Adduction/Abduction ROM	0.747	0.916	0.903	0.002	0.896	0.758
Peak Hip External Rotation Moment	0.094	0.569	0.537	0.001	0.043	0.882
Maximum Hip External Rotation Angle	0.599	0.202	0.350	0.000	0.011	0.377
Maximum Hip Internal Rotation Angle	0.694	0.729	0.517	0.252	0.396	0.932
Hip External/Internal ROM	0.718	0.290	0.276	0.000	0.007	0.378
Maximum Left Trunk Rotation Angle	0.942	0.081	0.500	0.064	0.273	0.132
Maximum Right Trunk Rotation Angle	0.560	0.060	0.886	0.071	0.458	0.633

TABLE 3 - Interaction and Main Effects Straight-Ahead cont.

Variable	Cond* Gender	Cond* Sport	Cond* Gender* Sport	Cond	Gender	Sport
Percent Stance Phase Maximum Left Trunk Angle	0.838	0.417	0.012	0.000	0.703	0.699
Percent Stance Phase Maximum Right Trunk Angle	0.511	0.414	0.222	0.000	0.270	0.212
Peak GRF	0.196	0.735	0.038	0.003	0.021	0.563
Normalized GRF (%BW)	0.397	0.773	0.228	0.009	0.709	0.168
Maximum Activation of Hamstrings	0.536	0.871	0.447	0.406	0.578	0.510
Maximum Activation of Quadriceps	0.812	0.238	0.395	0.152	0.901	0.967

TABLE 4 - Interaction and Main Effects Right Timing Conditions

	Interaction Effects			Main Effects		
Variable	Cond* Gender	Cond* Sport	Cond* Gender* Sport	Cond	Gender	Sport
Duration of Stance Phase	0.186	0.002	0.665	0.217	0.223	0.268
Peak Ankle Flexion Moment	0.404	0.104	0.263	0.258	0.050	0.670
Maximum Ankle Plantarflexion Angle	0.864	0.229	0.335	0.394	0.918	0.028
Maximum Ankle Dorsiflexion Angle	0.444	0.533	0.175	0.229	0.864	0.009
Ankle Plantar/Dorsiflexion ROM	0.579	0.201	0.312	0.104	0.854	0.565
Peak Ankle Eversion Moment	0.908	0.022	0.782	0.314	0.041	0.522
Maximum Ankle Eversion Angle	0.860	0.415	0.728	0.696	0.498	0.693
Maximum Ankle Inversion Angle	0.336	0.550	0.153	0.311	0.286	0.367
Ankle Eversion/Inversion ROM	0.562	0.847	0.195	0.710	0.543	0.257
Peak Ankle Toe-out Moment	0.655	0.668	0.657	0.155	0.079	0.272
Maximum Ankle Toe-out Angle	0.464	0.086	0.305	0.004	0.148	0.595
Maximum Ankle Toe-in Angle	0.596	0.799	0.687	0.717	0.547	0.192
Ankle Toe-out/Toe-in ROM	0.864	0.094	0.294	0.034	0.203	0.152
Peak Knee Flexion Moment	0.558	0.074	0.133	0.119	0.113	0.867

TABLE 4 – Interaction and Main Effects Right Timing cont.

Variable	Cond* Gender	Cond* Sport	Cond* Gender* Sport	Cond	Gender	Sport
Maximum Knee Flexion Angle	0.415	0.765	0.777	0.706	0.152	0.819
Maximum Knee Extension Angle	0.552	0.485	0.282	0.027	0.820	0.427
Knee Flexion/Extension ROM	0.761	0.432	0.404	0.314	0.412	0.594
Knee Flexion Angle at Landing	0.360	0.453	0.552	0.001	0.596	0.244
Peak Knee Varus Moment	0.877	0.022	0.684	0.532	0.108	0.377
Maximum Knee Varus Angle	0.897	0.197	0.665	0.252	0.215	0.094
Maximum Knee Valgus Angle	0.924	0.971	0.692	0.705	0.433	0.521
Knee Varus/Valgus ROM	0.990	0.365	0.651	0.571	0.554	0.273
Peak Knee External Rotation Moment	0.128	0.510	0.735	0.225	0.010	0.929
Maximum Knee External Rotation Angle	0.829	0.363	0.545	0.844	0.896	0.205
Maximum Knee Internal Rotation Angle	0.726	0.924	0.741	0.726	0.209	0.601
Knee External/Internal Rotation ROM	0.903	0.390	0.628	0.740	0.403	0.242
Peak Hip Extension Moment	0.353	0.078	0.355	0.027	0.064	0.557
Maximum Hip Extension Angle	0.328	0.046	0.023	0.571	0.327	0.509
Maximum Hip Flexion Angle	0.657	0.588	0.351	0.000	0.255	0.333
Hip Flexion/Extension ROM	0.747	0.058	0.065	0.743	0.655	0.891
Peak Hip Adduction Moment	0.603	0.057	0.857	0.486	0.218	0.270
Maximum Hip Adduction Angle	0.528	0.707	0.729	0.746	0.038	0.517
Maximum Hip Abduction Angle	0.546	0.937	0.666	0.052	0.054	0.757
Hip Adduction/Abduction ROM	0.186	0.549	0.885	0.186	0.477	0.821
Peak Hip External Rotation Moment	0.211	0.953	0.802	0.150	0.017	0.966
Maximum Hip External Rotation Angle	0.703	0.244	0.687	0.438	0.032	0.877

TABLE 4 - Interaction and Main Effects Right Timing cont.

Variable	Cond* Gender	Cond* Sport	Cond* Gender* Sport	Cond	Gender	Sport
Maximum Hip Internal Rotation Angle	0.563	0.204	0.259	0.411	0.739	0.449
Hip External/Internal ROM	0.933	0.557	0.712	0.442	0.037	0.903
Maximum Left Trunk Rotation Angle	0.356	0.302	0.437	0.009	0.565	0.279
Maximum Right Trunk Rotation Angle	0.647	0.643	0.948	0.000	0.845	0.127
Percent Stance Phase Maximum Left Trunk Angle	0.011	0.448	0.698	0.969	0.068	0.597
Percent Stance Phase Maximum Right Trunk Angle	0.075	0.313	0.400	0.374	0.161	0.768
Peak GRF	0.488	0.029	0.098	0.443	0.006	0.370
Normalized GRF (%BW)	0.409	0.025	0.109	0.446	0.323	0.301
Maximum Activation of Hamstrings	0.591	0.465	0.554	0.139	0.842	0.701
Maximum Activation of Quadriceps	0.195	0.377	0.363	0.725	0.766	0.624

TABLE 5 - Interaction and Main Effects Left Timing Condition

	Interaction Effects			Main Effects		
Variable	Cond* Gender	Cond* Sport	Cond* Gender* Sport	Cond	Gender	Sport
Duration of Stance Phase	0.897	0.608	0.187	0.502	0.759	0.144
Peak Ankle Flexion Moment	0.455	0.029	0.134	0.363	0.151	0.707
Maximum Ankle Plantarflexion Angle	0.235	0.976	0.436	0.173	0.806	0.481
Maximum Ankle Dorsiflexion Angle	0.201	0.320	0.540	0.472	0.388	0.009
Ankle Plantar/Dorsiflexion ROM	0.388	0.575	0.878	0.157	0.255	0.058
Peak Ankle Eversion Moment	0.840	0.751	0.551	0.362	0.167	0.377
Maximum Ankle Eversion Angle	0.286	0.239	0.098	0.917	0.573	0.823
Maximum Ankle Inversion Angle	0.979	0.701	0.214	0.632	0.170	0.385
Ankle Eversion/Inversion ROM	0.825	0.990	0.067	0.543	0.157	0.329
Peak Ankle Toe-out Moment	0.431	0.971	0.914	0.005	0.235	0.341

TABLE 5 – Interaction and Main Effects Left Timing cont.

Variable	Cond* Gender	Cond* Sport	Cond* Gender* Sport	Cond	Gender	Sport
Maximum Ankle Toe-out Angle	0.879	0.306	0.193	0.100	0.116	0.478
Maximum Ankle Toe-in Angle	0.500	0.065	0.863	0.200	0.767	0.223
Ankle Toe-out/Toe-in ROM	0.457	0.221	0.734	0.413	0.225	0.291
Peak Knee Flexion Moment	0.318	0.613	0.434	0.041	0.488	0.422
Maximum Knee Flexion Angle	0.783	0.200	0.275	0.605	0.233	0.178
Maximum Knee Extension Angle	0.418	0.415	0.212	0.144	0.450	0.486
Knee Flexion/Extension ROM	0.737	0.275	0.922	0.363	0.980	0.770
Knee Flexion Angle at Landing	0.068	0.683	0.256	0.068	0.226	0.178
Peak Knee Varus Moment	0.719	0.229	0.394	0.735	0.132	0.501
Maximum Knee Varus Angle	0.850	0.056	0.584	0.684	0.435	0.510
Maximum Knee Valgus Angle	0.850	0.056	0.584	0.684	0.435	0.510
Knee Varus/Valgus ROM	0.668	0.323	0.924	0.980	0.436	0.331
Peak Knee External Rotation Moment	0.886	0.086	0.127	0.260	0.033	0.752
Maximum Knee External Rotation Angle	0.806	0.148	0.591	0.536	0.442	0.078
Maximum Knee Internal Rotation Angle	0.092	0.170	0.162	0.575	0.011	0.120
Knee External/Internal Rotation ROM	0.358	0.623	0.717	0.559	0.167	0.149
Peak Hip Extension Moment	0.171	0.839	0.423	0.020	0.543	0.619
Maximum Hip Extension Angle	0.163	0.581	0.460	0.291	0.347	0.909
Maximum Hip Flexion Angle	0.766	0.593	0.768	0.611	0.923	0.836
Hip Flexion/Extension ROM	0.060	0.121	0.196	0.189	0.433	0.692
Peak Hip Adduction Moment	0.729	0.193	0.263	0.550	0.108	0.584
Maximum Hip Adduction Angle	0.839	0.202	0.740	0.617	0.013	0.521
Maximum Hip Abduction Angle	0.556	0.273	0.895	0.999	0.020	0.300

TABLE 5 - Interaction and Main Effects Left Timing cont.

Variable	Cond* Gender	Cond* Sport	Cond* Gender* Sport	Cond	Gender	Sport
Hip Adduction/Abduction ROM	0.747	0.944	0.959	0.439	0.935	0.502
Peak Hip External Rotation Moment	0.636	0.198	0.208	0.458	0.062	0.488
Maximum Hip External Rotation Angle	0.588	0.317	0.428	0.787	0.111	0.749
Maximum Hip Internal Rotation Angle	0.225	0.570	0.086	0.702	0.215	0.994
Hip External/Internal ROM	0.408	0.509	0.199	0.646	0.073	0.766
Maximum Left Trunk Rotation Angle	0.115	0.259	0.098	0.009	0.925	0.082
Maximum Right Trunk Rotation Angle	0.175	0.822	0.274	0.003	0.663	0.106
Percent Stance Phase Maximum Left Trunk Angle	0.076	0.031	0.585	0.489	0.617	0.665
Percent Stance Phase Maximum Right Trunk Angle	0.685	0.124	0.061	0.199	0.985	0.790
Peak GRF	0.147	0.904	0.627	0.358	0.012	0.992
Normalized GRF (%BW)	0.319	0.841	0.863	0.873	0.563	0.618
Maximum Activation of Hamstrings	0.673	0.414	0.294	0.208	0.521	0.986
Maximum Activation of Quadriceps	0.647	0.277	0.201	0.669	0.743	0.868

TABLE 6 - Main Effects for Leg Dominance

	Preplanned			Planned			Unplanned		
Variable	Cnd	Gndr	Sprt	Cnd	Gndr	Sprt	Cnd	Gndr	Sprt
Duration of Stance Phase	.443	.445	.571	.279	.716	.241	.526	.819	.055
Peak Ankle Flexion Moment	.000	.113	.288	.000	.047	.573	.000	.082	.441
Maximum Ankle Plantarflexion Angle	.707	.903	.079	.634	.759	.081	.760	.987	.280
Maximum Ankle Dorsiflexion Angle	.163	.801	.010	.343	.848	.008	.396	.375	.004
Ankle Plantar/Dorsiflexion ROM	.101	.684	.575	.136	.560	.298	.342	.486	.233
Peak Ankle Eversion Moment	.000	.090	.310	.000	.146	.232	.000	.048	.914
Maximum Ankle Eversion Angle	.463	.706	.636	.235	.843	.774	.284	.900	.851

TABLE 6 - Main Effects Leg Dominance cont.

Variable	Preplanned Cnd	Preplanned Gndr	Preplanned Sprt	Planned Cnd	Planned Gndr	Planned Sprt	Unplanned Cnd	Unplanned Gndr	Unplanned Sprt
Maximum Ankle Inversion Angle	.486	.117	.503	.775	.113	.339	.578	.307	.211
Ankle Eversion/Inversion ROM	.216	.079	.198	.306	.174	.277	.803	.421	.205
Peak Ankle Toe-out Moment	.523	.652	.686	.601	.713	.944	.571	.899	.908
Maximum Ankle Toe-out Angle	.277	.021	.907	.955	.062	.396	.158	.076	.419
Maximum Ankle Toe-in Angle	.471	.550	.226	.885	.608	.150	.851	.570	.261
Ankle Toe-out/Toe-in ROM	.735	.114	.202	.848	.125	.216	.263	.224	.171
Peak Knee Flexion Moment	.304	.259	.470	.195	.306	.994	.968	.329	.584
Maximum Knee Flexion Angle	.267	.719	.396	.117	.934	.245	.286	.760	.502
Maximum Knee Extension Angle	.408	.595	.863	.161	.606	.573	.197	.997	.642
Knee Flexion/Extension ROM	.936	.728	.596	.819	.563	.680	.732	.665	.828
Knee Flexion Angle at Landing	.823	.158	.395	.806	.214	.349	.245	.467	.147
Peak Knee Varus Moment	.304	.259	.470	.047	.206	.227	.011	.058	.400
Maximum Knee Varus Angle	.315	.255	.265	.164	.266	.061	.165	.229	.264
Maximum Knee Valgus Angle	.287	.946	.844	.102	.957	.720	.124	.776	.977
Knee Varus/Valgus ROM	.720	.357	.466	.643	.416	.227	.462	.446	.377
Peak Knee External Rotation Moment	.027	.013	.806	.728	.004	.365	.906	.124	.177
Maximum Knee External Rotation Angle	.216	.598	.075	.164	.529	.037	.367	.793	.270
Maximum Knee Internal Rotation Angle	.386	.015	.806	.292	.090	.893	.273	.196	.921
Knee External/Internal Rotation ROM	.394	.165	.148	.460	.219	.101	.946	.453	.437
Peak Hip Extension Moment	.276	.272	.659	.190	.402	.712	.968	.329	.584
Maximum Hip Extension Angle	.822	.367	.900	.623	.298	.748	.289	.303	.487
Maximum Hip Flexion Angle	.742	.528	.794	.167	.461	.677	.121	.615	.998

TABLE 6 - Main Effects Leg Dominance cont.

	Preplanned			Planned			Unplanned		
Variable	Cnd	Gndr	Sprt	Cnd	Gndr	Sprt	Cnd	Gndr	Sprt
Hip Flexion/Extension ROM	.625	.976	.818	.356	.972	.810	.030	.708	.491
Peak Hip Adduction Moment	.157	.264	.299	.063	.215	.141	.019	.188	.655
Maximum Hip Adduction Angle	.859	.015	.746	.944	.029	.341	.728	.016	.413
Maximum Hip Abduction Angle	.877	.061	.676	.815	.020	.478	.266	.038	.338
Hip Adduction/Abduction ROM	.981	.929	.777	.747	.334	.931	.085	.841	.638
Peak Hip External Rotation Moment	.004	.026	.720	.930	.008	.744	.765	.153	.277
Maximum Hip External Rotation Angle	.711	.092	.897	.354	.029	.498	.075	.070	.945
Maximum Hip Internal Rotation Angle	.726	.547	.840	.210	.466	.388	.667	.512	.847
Hip External/Internal ROM	.792	.083	.956	.254	.025	.727	.068	.067	.995
Maximum Left Trunk Rotation Angle	.014	.653	.774	.112	.545	.497	.762	.209	.784
Maximum Right Trunk Rotation Angle	.019	.377	.925	.368	.869	.889	.569	.569	.961
Percent Stance Phase Maximum Left Trunk Angle	.000	.409	.649	.000	.070	.645	.000	.480	.845
Percent Stance Phase Maximum Right Trunk Angle	.000	.779	.840	.000	.149	.055	.000	.458	.200
Peak GRF	.774	.011	.961	.257	.009	.664	.420	.007	.456
Normalized GRF (%BW)	.752	.352	.519	.170	.383	.830	.473	.249	.397
Maximum Activation of Hamstrings	.401	.401	.534	.351	.741	.341	.602	.882	.296
Maximum Activation of Quadriceps	.037	.704	.817	.404	.266	.656	.572	.841	.413

Significance Found Type I error $\alpha<0.05$

Type II error $\beta<0.20$

TABLE 7 – Stance Phase Duration (milliseconds ms) *

	WOMEN	MEN	TOTAL
Ball Sports	0.2443 ± 0.0404	0.2804 ± 0.0272	0.2624 ± 0.0381
Non-Ball Sports	0.2600 ± 0.0334	0.2735 ± 0.0407	0.2671 ± 0.0370
Right Preplanned	*0.2531 ± 0.0363*	*0.2763 ± 0.0349*	*0.2651 ± 0.0371*
Ball Sport	0.2622 ± 0.0498	0.2909 ± 0.0497	0.2766 ± 0.0501
Non-Ball Sports	0.2589 ± 0.0340	0.2602 ± 0.0318	0.2595 ± 0.0319
Right Planned	*0.2603 ± 0.0401*	*0.2728 ± 0.0417*	*0.2668 ± 0.0408*
Ball Sports	0.2819 ± 0.0554	0.2944 ± 0.0468	0.2881 ± 0.0497
Non-Ball Sports	0.2553 ± 0.0181	0.2593 ± 0.0447	0.2574 ± 0.0339
Right Unplanned	*0.2669 ± 0.0399*	*0.2737 ± 0.0476*	*0.2704 ± 0.0434*
Ball Sports	0.2782 ± 0.0445	0.2774 ± 0.0179	0.2778 ± 0.0326
Non-Ball Sports	0.2657 ± 0.0412	0.2544 ± 0.0554	0.2598 ± 0.0482
Left Preplanned	*0.2712 ± 0.0417*	*0.2639 ± 0.0445*	*0.2674 ± 0.0426*
Ball Sports	0.2872 ± 0.0458	0.2760 ± 0.0434	0.2816 ± 0.0433
Non-Ball Sports	0.2644 ± 0.0350	0.2657 ± 0.0403	0.2651 ± 0.0368
Left Planned	*0.2743 ± 0.0404*	*0.2700 ± 0.0406*	*0.2721 ± 0.0399*
Ball Sports	0.2776 ± 0.0486	0.2851 ± 0.0386	0.2814 ± 0.0423
Non-Ball Sports	0.2614 ± 0.0220	0.2513 ± 0.0470	0.2561 ± 0.0367
Left Unplanned	*0.2685 ± 0.0356*	*0.2652 ± 0.0457*	*0.2668 ± 0.0406*
Ball Sports	0.2387 ± 0.0389	0.2385 ± 0.0167	0.2386 ± 0.0296
Non-Ball Sports	0.2426 ± 0.0302	0.2379 ± 0.0263	0.2402 ± 0.0275
Straight Ahead	*0.2408 ± 0.0333*	*0.2381 ± 0.0219*	*0.2395 ± 0.0279*

TABLE 8 – Peak Ankle Plantarflexion Moment (BW*BH) * ***

	WOMEN	**MEN**	**TOTAL**
Ball Sports	0.3685 ± 0.1448	0.5510 ± 0.2026	0.4598 ± 0.1939
Non-Ball Sports	0.3777 ± 0.1030	0.4274 ± 0.1182	0.4039 ± 0.1111
Right Preplanned	*0.3737 ± 0.1186*	*0.4783 ± 0.1649*	*0.4276 ± 0.1517*
Ball Sports	0.3557 ± 0.0964	0.4603 ± 0.1139	0.4080 ± 0.1150
Non-Ball Sports	0.3802 ± 0.0960	0.4408 ± 0.1401	0.4121 ± 0.1219
Right Planned	*0.3695 ± 0.0937*	*0.4489 ± 0.1265*	*0.4104 ± 0.1172*
Ball Sports	0.3815 ± 0.0819	0.4743 ± 0.1474	0.4279 ± 0.1243
Non-Ball Sports	0.3993 ± 0.2234	0.4488 ± 0.1454	0.4254 ± 0.1828
Right Unplanned	*0.3915 ± 0.1714*	*0.4593 ± 0.1422*	*0.4264 ± 0.1583*
Ball Sports	0.1133 ± 0.0864	0.1584 ± 0.1642	0.1359 ± 0.1282
Non-Ball Sports	0.1084 ± 0.0500	0.0968 ± 0.0485	0.1023 ± 0.0482
Left Preplanned	*0.1105 ± 0.0658*	*0.1222 ± 0.1114*	*0.1165 ± 0.0909*
Ball Sports	0.1037 ± 0.0513	0.1981 ± 0.1783	0.1509 ± 0.1352
Non-Ball Sports	0.1110 ± 0.0430	0.1040 ± 0.0482	0.1073 ± 0.0447
Left Planned	*0.1078 ± 0.0453*	*0.1427 ± 0.1245*	*0.1258 ± 0.0950*
Ball Sports	0.0715 ± 0.0117	0.0923 ± 0.0483	0.0819 ± 0.0355
Non-Ball Sports	0.1079 ± 0.0420	0.1595 ± 0.0565	0.1351 ± 0.0555
Left Unplanned	*0.0920 ± 0.0366*	*0.1319 ± 0.0619*	*0.1125 ± 0.0544*
Ball Sports	0.1642 ± 0.1667	0.2729 ± 0.2340	0.2144 ± 0.1997
Non-Ball Sports	0.2071 ± 0.1362	0.1010 ± 0.1315	0.1540 ± 0.1404
Straight-Ahead	*0.1871 ± 0.1472*	*0.1747 ± 0.1954*	*0.1811 ± 0.1691*

TABLE 9 – Maximum Ankle Plantarflexion Angle (deg) •

	WOMEN		MEN		TOTAL	
Ball Sports	15.8535	± 8.7025	21.8378	± 8.5308	18.8457	± 8.8422
Non-Ball Sports	28.9491	± 5.0088	23.3627	± 8.4917	26.0089	± 7.4443
Right Preplanned	*23.2198*	*± 9.4176*	*22.7348*	*± 8.2735*	*22.9699*	*± 8.7098*
Ball Sports	18.1639	± 9.8342	21.7740	± 8.1302	19.9690	± 8.8686
Non-Ball Sports	28.7200	± 5.3702	24.9085	± 8.5956	26.7140	± 7.3200
Right Planned	*24.1017*	*± 9.1277*	*23.6179*	*± 8.2991*	*23.8525*	*± 8.5763*
Ball Sports	19.3091	± 5.0910	23.7294	± 9.0515	21.5192	± 7.4186
Non-Ball Sports	28.3350	± 4.7463	22.1135	± 10.4252	25.0605	± 8.6337
Right Unplanned	*24.3862*	*± 6.6156*	*22.7789*	*± 9.6192*	*23.5582*	*± 8.2126*
Ball Sports	20.8980	± 2.9795	23.4835	± 7.8439	22.1907	± 5.8561
Non-Ball Sports	26.3123	± 7.0871	21.4629	± 9.3280	23.7600	± 8.4863
Left Preplanned	*23.9435*	*± 6.1672*	*22.2949*	*± 8.5479*	*23.0942*	*± 7.4204*
Ball Sports	22.6407	± 5.7211	23.6161	± 9.4458	23.1284	± 7.5195
Non-Ball Sports	27.1262	± 5.8682	23.1203	± 8.0874	25.0178	± 7.2271
Left Planned	*25.1638*	*± 6.0613*	*23.3245*	*± 8.3852*	*24.2163*	*± 7.2972*
Ball Sports	20.3458	± 4.0472	25.9321	± 7.8475	23.1390	± 6.6622
Non-Ball Sports	26.7290	± 6.6205	22.7521	± 9.3725	24.6359	± 8.2197
Left Unplanned	*23.9364*	*± 6.3737*	*24.0616*	*± 8.6665*	*24.0009*	*± 7.5233*
Ball Sports	19.8395	± 3.9654	17.9219	± 2.5130	18.9544	± 3.3888
Non-Ball Sports	20.1156	± 3.5159	22.2653	± 13.8037	21.1905	± 9.7939
Straight-Ahead	*19.9868*	*± 3.5973*	*20.4038*	*± 10.4883*	*20.1881*	*± 7.5887*

TABLE 10 – Maximum Ankle Dorsiflexion Angle (deg) •

	WOMEN		MEN		TOTAL	
Ball Sports	20.5234	± 5.0086	19.9557	± 3.7713	20.2395	± 4.2696
Non-Ball Sports	14.5782	± 5.7679	17.3528	± 7.0391	16.0385	± 6.4488
Right Preplanned	*17.1792*	*± 6.0874*	*18.4246*	*± 5.9117*	*17.8208*	*± 5.9366*
Ball Sports	21.9819	± 3.2113	19.2471	± 4.3732	20.6145	± 3.9497
Non-Ball Sports	14.8134	± 5.9811	16.3644	± 8.114	15.6297	± 7.0321
Right Planned	*17.9496*	*± 6.0575*	*17.5514*	*± 6.8076*	*17.7445*	*± 6.3571*
Ball Sports	21.9267	± 5.164	23.8961	± 4.9745	22.9114	± 4.9772
Non-Ball Sports	17.0190	± 7.0739	15.9485	± 6.6155	16.4556	± 6.6652
Right Unplanned	*19.1661*	*± 6.6089*	*19.2211*	*± 7.0819*	*19.1944*	*± 6.7492*
Ball Sports	24.4179	± 7.8682	21.1562	± 6.5412	22.7870	± 7.1544
Non-Ball Sports	17.0743	± 5.0142	15.9654	± 7.3872	16.4907	± 6.2276
Left Preplanned	*20.2871*	*± 7.2339*	*18.1028*	*± 7.3263*	*19.1619*	*± 7.2523*
Ball Sports	23.3244	± 9.0678	22.8745	± 6.6348	23.0994	± 7.6369
Non-Ball Sports	15.5858	± 6.3629	15.5733	± 8.2492	15.5792	± 7.2124
Left Planned	*18.9714*	*± 8.3787*	*18.5797*	*± 8.2767*	*18.7696*	*± 8.1975*
Ball Sports	23.5778	± 4.3276	17.8376	± 6.0188	20.7077	± 5.8511
Non-Ball Sports	16.6082	± 5.0233	15.6163	± 7.9884	16.0862	± 6.5864
Left Unplanned	*19.6574*	*± 5.8052*	*16.5310*	*± 7.1239*	*18.0468*	*± 6.6098*
Ball Sports	21.1711	± 3.8971	19.9035	± 7.5529	20.5861	± 5.6388
Non-Ball Sports	21.0990	± 4.9323	24.6822	± 10.6369	22.8906	± 8.2205
Straight-Ahead	*21.1326*	*± 4.3213*	*22.6342*	*± 9.4280*	*21.8575*	*± 7.1547*

TABLE 11 – Ankle Dorsi/Plantarflexion ROM (deg)

	WOMEN		MEN		TOTAL	
Ball Sports	36.5123	± 4.8551	41.7935	± 5.9981	39.1529	± 5.9155
Non-Ball Sports	43.5273	± 5.1444	40.7155	± 4.9498	42.0474	± 5.1081
Right Preplanned	*40.4582*	*± 6.0383*	*41.1594*	*± 5.2509*	*40.8194*	*± 5.5681*
Ball Sports	40.1458	± 7.4644	41.0211	± 7.6327	40.5835	± 7.2670
Non-Ball Sports	43.5334	± 5.0281	41.2729	± 4.6174	42.3437	± 4.8209
Right Planned	*42.0513*	*± 6.2276*	*41.1693*	*± 5.8186*	*41.5969*	*± 5.9420*
Ball Sports	41.2358	± 3.0074	47.6255	± 12.1852	44.4306	± 9.1485
Non-Ball Sports	45.3540	± 6.3518	39.7203	± 6.4799	42.3889	± 6.8759
Right Unplanned	*43.5523*	*± 5.4394*	*42.9754*	*± 9.7663*	*43.2551*	*± 7.8515*
Ball Sports	45.3158	± 9.7592	44.6397	± 5.5751	44.9778	± 7.6437
Non-Ball Sports	43.2407	± 7.5351	37.4283	± 6.0198	40.1815	± 7.2280
Left Preplanned	*44.1486*	*± 8.3372*	*40.3977*	*± 6.7397*	*42.2163*	*± 7.6758*
Ball Sports	45.9650	± 6.1577	46.7716	± 5.4736	46.3683	± 5.6128
Non-Ball Sports	42.7120	± 6.9931	38.6936	± 6.2634	40.5970	± 6.7527
Left Planned	*44.1352*	*± 6.6352*	*42.0198*	*± 7.0778*	*43.0455*	*± 6.8438*
Ball Sports	43.9237	± 5.9887	43.7698	± 5.7114	43.8467	± 5.6227
Non-Ball Sports	43.3372	± 5.5620	36.4474	± 12.7258	39.7110	± 10.3545
Left Unplanned	*43.5938*	*± 5.5620*	*39.4625*	*± 10.8225*	*41.4655*	*± 8.8012*
Ball Sports	41.0106	± 4.7282	39.8856	± 8.7799	40.4914	± 6.6059
Non-Ball Sports	41.2478	± 5.5476	46.4836	± 23.0821	43.8657	± 16.4410
Straight-Ahead	*41.1371*	*± 4.9984*	*43.6559*	*± 18.1111*	*42.3531*	*± 12.9006*

TABLE 12 – Peak Ankle Eversion Moment (BW*BH) + * ***

	WOMEN		MEN		TOTAL	
Ball Sports	0.1146	± 0.0468	0.2014	± 0.1629	0.1580	± 0.1236
Non-Ball Sports	0.1037	± 0.0374	0.1418	± 0.0651	0.1238	± 0.0559
Right Preplanned	*0.1085*	*± 0.0406*	*0.1663*	*± 0.1151*	*0.1383*	*± 0.0909*
Ball Sports	0.1203	± 0.0540	0.2229	± 0.2131	0.1716	± 0.1586
Non-Ball Sports	0.1139	± 0.0274	0.1456	± 0.0670	0.1306	± 0.0533
Right Planned	*0.1167*	*± 0.0397*	*0.1774*	*± 0.1452*	*0.1480*	*± 0.1106*
Ball Sports	0.0999	± 0.0400	0.1875	± 0.1315	0.1437	± 0.1038
Non-Ball Sports	0.1346	± 0.0751	0.1863	± 0.0826	0.1618	± 0.0814
Right Unplanned	*0.1194*	*± 0.0630*	*0.1868*	*± 0.1016*	*0.1541*	*± 0.0905*
Ball Sports	0.3956	± 0.1363	0.4245	± 0.1283	0.4101	± 0.1280
Non-Ball Sports	0.3494	± 0.1283	0.4153	± 0.0822	0.3841	± 0.1088
Left Preplanned	*0.3696*	*± 0.1295*	*0.4191*	*± 0.1000*	*0.3951*	*± 0.1161*
Ball Sports	0.4040	± 0.1233	0.4779	± 0.1916	0.4410	± 0.1595
Non-Ball Sports	0.3702	± 0.1387	0.3987	± 0.1299	0.3852	± 0.1311
Left Planned	*0.3850*	*± 0.1290*	*0.4313*	*± 0.1577*	*0.4089*	*± 0.1442*
Ball Sports	0.4116	± 0.1580	0.4522	± 0.1492	0.4319	± 0.1491
Non-Ball Sports	0.3551	± 0.1217	0.4601	± 0.1706	0.4104	± 0.1550
Left Unplanned	*0.3798*	*± 0.1368*	*0.4569*	*± 0.1573*	*0.4195*	*± 0.1506*
Ball Sports	0.1184	± 0.1135	0.1384	± 0.2017	0.1276	± 0.1533
Non-Ball Sports	0.1181	± 0.1864	0.2420	± 0.1342	0.1801	± 0.1694
Straight-Ahead	*0.1182*	*± 0.1513*	*0.1976*	*± 0.1678*	*0.1566*	*± 0.1617*

TABLE 13 – Maximum Ankle Eversion Angle (deg) *

	WOMEN	MEN	TOTAL
Ball Sports	22.8262 ± 5.7305	24.7376 ± 10.089	23.7819 ± 7.9448
Non-Ball Sports	22.6283 ± 6.2912	24.0495 ± 6.6381	23.3763 ± 6.3367
Right Preplanned	*22.7149 ± 5.8528*	*24.3328 ± 7.9422*	*23.5484 ± 6.9477*
Ball Sports	23.5116 ± 6.5832	24.7105 ± 9.5793	24.1110 ± 7.921
Non-Ball Sports	20.2900 ± 8.4944	23.0569 ± 5.9913	21.7463 ± 7.2133
Right Planned	*21.6994 ± 7.6513*	*23.7378 ± 7.4368*	*22.7495 ± 7.4943*
Ball Sports	22.8472 ± 5.8285	23.1074 ± 8.6229	22.9773 ± 7.0721
Non-Ball Sports	22.1590 ± 5.2351	24.0561 ± 5.8351	23.1575 ± 5.4911
Right Unplanned	*22.4601 ± 5.3226*	*23.6655 ± 6.8751*	*23.0810 ± 6.1063*
Ball Sports	29.0532 ± 11.8674	21.6396 ± 4.2354	25.3464 ± 9.3850
Non-Ball Sports	23.3308 ± 4.2605	24.6700 ± 4.3546	24.0357 ± 4.2451
Left Preplanned	*25.8343 ± 8.6378*	*23.4222 ± 4.4449*	*24.5917 ± 6.8082*
Ball Sports	25.2868 ± 11.4688	23.6208 ± 5.0721	24.4538 ± 8.5632
Non-Ball Sports	25.3345 ± 5.5264	25.4097 ± 4.5754	25.3741 ± 4.9033
Left Planned	*25.3136 ± 8.3008*	*24.6731 ± 4.7167*	*24.9836 ± 6.5975*
Ball Sports	26.3550 ± 13.6682	24.1038 ± 7.016	25.2294 ± 10.5027
Non-Ball Sports	23.1824 ± 4.9954	24.8660 ± 7.1119	24.0685 ± 6.0931
Left Unplanned	*24.5704 ± 9.5226*	*24.5522 ± 6.8600*	*24.5610 ± 8.1262*
Ball Sports	7.5644 ± 4.8693	8.0296 ± 4.2774	7.7791 ± 4.4201
Non-Ball Sports	7.0362 ± 4.6467	7.7856 ± 6.0559	7.4109 ± 5.2288
Straight-Ahead	*7.2827 ± 4.5860*	*7.8902 ± 5.1769*	*7.5759 ± 4.8015*

TABLE 14 – Maximum Ankle Inversion Angle (deg) *

	WOMEN	MEN	TOTAL
Ball Sports	1.9832 ± 16.418	-7.0529 ± 9.0397	-2.5349 ± 13.5686
Non-Ball Sports	-5.2657 ± 7.3990	-5.7821 ± 7.9107	-5.5375 ± 7.4626
Right Preplanned	*-2.0943 ± 12.2805*	*-6.3054 ± 8.1400*	*-4.2636 ± 10.411*
Ball Sports	2.5650 ± 15.0099	-7.5172 ± 9.4302	-2.4761 ± 13.1299
Non-Ball Sports	-4.9014 ± 9.3390	-3.7670 ± 10.5617	-4.3043 ± 9.7405
Right Planned	*-1.6348 ± 12.2991*	*-5.3112 ± 9.9857*	*-3.5287 ± 11.1465*
Ball Sports	1.0234 ± 13.4349	-1.8243 ± 11.0435	-0.4004 ± 11.907
Non-Ball Sports	-4.4654 ± 6.8942	-5.6003 ± 6.8233	-5.0627 ± 6.6890
Right Unplanned	*-2.0640 ± 10.2692*	*-4.0455 ± 8.6944*	*-3.0848 ± 9.3936*
Ball Sports	2.3030 ± 10.4559	-6.2460 ± 3.9626	-1.9715 ± 8.7967
Non-Ball Sports	-3.9074 ± 4.8719	-1.4436 ± 7.1968	-2.6107 ± 6.1679
Left Preplanned	*-1.1904 ± 8.1556*	*-3.4211 ± 6.3998*	*-2.3395 ± 7.2759*
Ball Sports	0.9422 ± 11.2537	-1.9745 ± 6.5104	-0.5161 ± 8.9613
Non-Ball Sports	-2.0896 ± 12.7587	-5.9301 ± 6.1141	-4.1109 ± 9.7427
Left Planned	*-0.7632 ± 11.8275*	*-4.3013 ± 6.3991*	*-2.5858 ± 9.4484*
Ball Sports	0.4307 ± 6.8180	-5.8476 ± 4.2000	-2.7084 ± 6.3405
Non-Ball Sports	-4.6490 ± 5.3480	-3.8625 ± 9.3961	-4.2350 ± 7.5510
Left Unplanned	*-2.4266 ± 6.3730*	*-4.6799 ± 7.5690*	*-3.5874 ± 6.9994*
Ball Sports	11.8558 ± 6.9784	6.8229 ± 8.4268	9.5329 ± 7.7947
Non-Ball Sports	9.2919 ± 7.0821	6.8292 ± 4.0656	8.0606 ± 5.7216
Straight-Ahead	*10.4884 ± 6.9067*	*6.8265 ± 6.0177*	*8.7206 ± 6.6432*

TABLE 15 – Ankle Eversion/Inversion ROM (deg) *

	WOMEN		MEN		TOTAL	
Ball Sports	24.8094	± 18.4235	17.6847	± 6.4047	21.2470	± 13.7571
Non-Ball Sports	17.3627	± 4.1172	18.2674	± 6.1022	17.8389	± 5.1349
Right Preplanned	*20.6206*	*± 12.6241*	*18.0275*	*± 6.0345*	*19.2848*	*± 9.7285*
Ball Sports	26.0765	± 20.435	17.1933	± 8.1407	21.6349	± 15.6386
Non-Ball Sports	15.3886	± 4.3259	19.2899	± 8.834	17.4419	± 7.1654
Right Planned	*20.0646*	*± 14.3875*	*18.4266*	*± 8.3595*	*19.2208*	*± 11.518*
Ball Sports	23.8706	± 17.7951	21.2832	± 11.9873	22.5769	± 14.6382
Non-Ball Sports	17.6936	± 4.7426	18.4558	± 7.0722	18.0947	± 5.9294
Right Unplanned	*20.3960*	*± 12.1934*	*19.6200*	*± 9.1693*	*19.9963*	*± 10.5776*
Ball Sports	31.3562	± 12.3849	17.3949	± 6.1385	24.3756	± 11.8601
Non-Ball Sports	19.4234	± 6.4947	23.2264	± 10.1777	21.4250	± 8.6224
Left Preplanned	*24.6440*	*± 11.0104*	*20.8252*	*± 9.0082*	*22.6767*	*± 10.0577*
Ball Sports	26.2290	± 12.5975	21.6463	± 7.4083	23.9377	± 10.2093
Non-Ball Sports	23.2448	± 14.3036	19.4796	± 6.8375	21.2631	± 10.8645
Left Planned	*24.5504*	*± 13.2262*	*20.3718*	*± 6.9345*	*22.3978*	*± 10.5138*
Ball Sports	26.7857	± 12.4531	18.2563	± 6.8787	22.5210	± 10.6302
Non-Ball Sports	18.5335	± 6.3711	21.0035	± 9.9332	19.8335	± 8.3054
Left Unplanned	*22.1438*	*± 10.0775*	*19.8723*	*± 8.6710*	*20.9736*	*± 9.3020*
Ball Sports	19.4202	± 8.2816	14.8525	± 6.9507	17.3120	± 7.7485
Non-Ball Sports	16.3281	± 5.4112	14.6148	± 4.1889	15.4715	± 4.7577
Straight-Ahead	*17.7711*	*± 6.8252*	*14.7167*	*± 5.2958*	*16.2965*	*± 6.2230*

TABLE 16 - Peak Ankle Toe-out Rotation Moment (BW*BH) * **

	WOMEN		MEN		TOTAL	
Ball Sports	0.0746	± 0.0196	0.0992	± 0.0437	0.0869	± 0.0350
Non-Ball Sports	0.0877	± 0.0324	0.1061	± 0.0521	0.0974	± 0.0438
Right Preplanned	*0.0820*	*± 0.0275*	*0.1032*	*± 0.0475*	*0.0929*	*± 0.0400*
Ball Sports	0.0764	± 0.0438	0.1256	± 0.0660	0.1010	± 0.0595
Non-Ball Sports	0.0971	± 0.0439	0.1280	± 0.0728	0.1133	± 0.0613
Right Planned	*0.0880*	*± 0.0437*	*0.1270*	*± 0.0679*	*0.1081*	*± 0.0599*
Ball Sports	0.0720	± 0.0446	0.1110	± 0.0654	0.0915	± 0.0575
Non-Ball Sports	0.1201	± 0.0828	0.1184	± 0.0584	0.1193	± 0.0690
Right Unplanned	*0.0991*	*± 0.0712*	*0.1154*	*± 0.0595*	*0.1075*	*± 0.0649*
Ball Sports	0.1256	± 0.0900	0.0653	± 0.0450	0.0955	± 0.0752
Non-Ball Sports	0.0835	± 0.0486	0.0707	± 0.0292	0.0768	± 0.0390
Left Preplanned	*0.1019*	*± 0.0705*	*0.0685*	*± 0.0353*	*0.0847*	*± 0.0569*
Ball Sports	0.1506	± 0.0675	0.0985	± 0.0931	0.1246	± 0.0826
Non-Ball Sports	0.1044	± 0.0749	0.1061	± 0.0383	0.1053	± 0.0568
Left Planned	*0.1246*	*± 0.0733*	*0.1030*	*± 0.064*	*0.1135*	*± 0.0684*
Ball Sports	0.1429	± 0.1067	0.1112	± 0.0789	0.1270	± 0.0917
Non-Ball Sports	0.1023	± 0.0780	0.1068	± 0.0562	0.1047	± 0.0655
Left Unplanned	*0.1201*	*± 0.0907*	*0.1086*	*± 0.0642*	*0.1142*	*± 0.0772*
Ball Sports	0.0639	± 0.0467	0.0482	± 0.0321	0.0566	± 0.0398
Non-Ball Sports	0.0466	± 0.0257	0.0736	± 0.0256	0.0601	± 0.0284
Straight-Ahead	*0.0547*	*± 0.0367*	*0.0627*	*± 0.0303*	*0.0586*	*± 0.0334*

TABLE 17 – Maximum Ankle Toe-out Rotation Angle (deg) + **

	WOMEN		MEN		TOTAL	
Ball Sports	25.4160	± 30.8777	6.3853	± 10.0164	15.9007	± 24.1632
Non-Ball Sports	14.0885	± 7.2696	13.4006	± 13.3961	13.7264	± 10.6461
Right Preplanned	*19.0443*	*± 21.0533*	*10.5120*	*± 12.2977*	*14.6488*	*± 17.3821*
Ball Sports	16.5275	± 17.3997	3.9296	± 12.8359	10.2286	± 16.0780
Non-Ball Sports	13.0447	± 5.8864	10.3457	± 17.5352	11.6242	± 13.0789
Right Planned	*14.5684*	*± 11.9484*	*7.7038*	*± 15.6633*	*11.0321*	*± 14.2031*
Ball Sports	30.0296	± 26.9944	14.0843	± 12.421	22.0569	± 21.817
Non-Ball Sports	12.3602	± 8.2802	16.0381	± 16.0809	14.2960	± 12.7801
Right Unplanned	*20.0906*	*± 20.2485*	*15.2336*	*± 14.2933*	*17.5885*	*± 17.3324*
Ball Sports	15.3430	± 11.2463	6.0735	± 11.214	10.7082	± 11.8131
Non-Ball Sports	13.6721	± 7.0292	9.9184	± 14.7296	11.6964	± 11.5822
Left Preplanned	*14.4031*	*± 8.8134*	*8.3352*	*± 13.153*	*11.2772*	*± 11.5063*
Ball Sports	11.5500	± 4.9992	6.9507	± 11.2704	9.2503	± 8.7095
Non-Ball Sports	16.4196	± 10.3477	10.3984	± 13.1278	13.2506	± 11.9708
Left Planned	*14.2892*	*± 8.5632*	*8.9787*	*± 12.1505*	*11.5535*	*± 10.7449*
Ball Sports	13.4530	± 3.6847	10.9099	± 10.6519	12.1814	± 7.7701
Non-Ball Sports	18.4098	± 9.6723	10.5786	± 11.6035	14.2881	± 11.1821
Left Unplanned	*16.2412*	*± 7.8597*	*10.7150*	*± 10.8771*	*13.3944*	*± 9.7969*
Ball Sports	19.4723	± 13.0351	8.9022	± 13.0740	14.5938	± 13.6477
Non-Ball Sports	16.5530	± 8.2228	19.2601	± 10.9796	17.9065	± 9.4744
Straight-Ahead	*17.9153*	*± 10.4355*	*14.8210*	*± 12.6076*	*16.4215*	*± 11.4335*

TABLE 18 – Maximum Ankle Toe-in Rotation Angle (deg)

	WOMEN		MEN		TOTAL	
Ball Sports	22.7078	± 39.2302	14.0278	± 22.0007	18.3678	± 30.8868
Non-Ball Sports	6.0576	± 20.9699	5.4772	± 21.9022	5.7521	± 20.8658
Right Preplanned	*13.3420*	*± 30.3793*	*8.9980*	*± 21.6832*	*11.1042*	*± 25.9336*
Ball Sports	23.6027	± 38.1311	13.5339	± 23.3860	18.5683	± 30.8348
Non-Ball Sports	8.4427	± 22.3111	5.8169	± 23.4929	7.0607	± 22.3386
Right Planned	*15.0752*	*± 30.1232*	*8.9945*	*± 23.0406*	*11.9427*	*± 26.4633*
Ball Sports	22.9451	± 40.9433	14.9266	± 18.1594	18.9358	± 30.7118
Non-Ball Sports	7.7229	± 23.2088	3.6973	± 22.7052	5.6042	± 22.3926
Right Unplanned	*14.3826*	*± 31.9163*	*8.3211*	*± 21.1210*	*11.2600*	*± 26.6459*
Ball Sports	21.7947	± 25.8032	15.2112	± 20.6952	18.5030	± 22.7296
Non-Ball Sports	9.7177	± 22.2339	8.4694	± 25.1390	9.0607	± 23.1539
Left Preplanned	*15.0014*	*± 23.8382*	*11.2455*	*± 22.9737*	*13.0665*	*± 23.1063*
Ball Sports	20.0135	± 16.9577	15.8916	± 19.3094	17.9525	± 17.5893
Non-Ball Sports	4.0555	± 16.8032	6.9961	± 23.1822	5.6032	± 19.9116
Left Planned	*11.0371*	*± 18.2335*	*10.6589*	*± 21.5053*	*10.8423*	*± 19.6753*
Ball Sports	17.3081	± 14.8502	10.6741	± 24.2044	13.9911	± 19.5966
Non-Ball Sports	6.6293	± 20.9338	8.8059	± 25.6022	7.7749	± 22.8856
Left Unplanned	*11.3013*	*± 18.7581*	*9.5752*	*± 24.2755*	*10.4121*	*± 21.4558*
Ball Sports	20.5075	± 29.9042	17.8407	± 24.2565	19.2767	± 26.3477
Non-Ball Sports	9.3043	± 19.3573	1.7705	± 16.9203	5.5374	± 17.9890
Straight-Ahead	*14.5325*	*± 24.5780*	*8.6577*	*± 21.1794*	*11.6964*	*± 22.7866*

TABLE 19 – Ankle Toe-out/Toe-in Rotation ROM (deg) **

	WOMEN		MEN		TOTAL	
Ball Sports	48.1238	± 60.1907	20.4130	± 14.5809	34.2684	± 44.4632
Non-Ball Sports	20.1461	± 18.7979	18.8778	± 14.4391	19.4785	± 16.1777
Right Preplanned	*32.3863*	*± 42.9313*	*19.5099*	*± 14.0573*	*25.7530*	*± 31.7090*
Ball Sports	40.1303	± 47.2904	17.4635	± 12.0774	28.7969	± 35.1827
Non-Ball Sports	21.4873	± 18.8690	16.1626	± 9.4549	18.6848	± 14.5051
Right Planned	*29.6436*	*± 34.2881*	*16.6982*	*± 10.2674*	*22.9748*	*± 25.4356*
Ball Sports	52.9746	± 64.6312	29.0109	± 23.1619	40.9927	± 48.2716
Non-Ball Sports	20.0832	± 17.8463	19.7354	± 18.9473	19.9002	± 17.9188
Right Unplanned	*34.4732*	*± 46.0947*	*23.5547*	*± 20.6217*	*28.8485*	*± 35.2037*
Ball Sports	37.1377	± 33.6793	21.2847	± 19.9801	29.2112	± 27.8466
Non-Ball Sports	23.3898	± 18.6806	18.3878	± 15.4311	20.7571	± 16.7553
Left Preplanned	*29.4045*	*± 26.2573*	*19.5806*	*± 16.9057*	*24.3437*	*± 22.1571*
Ball Sports	31.5634	± 16.772	22.8422	± 18.1499	27.2028	± 17.3881
Non-Ball Sports	20.4752	± 17.3804	17.3945	± 12.9203	18.8537	± 14.8399
Left Planned	*25.3263*	*± 17.4900*	*19.6377*	*± 15.0024*	*22.3958*	*± 16.2563*
Ball Sports	31.1137	± 14.2395	21.5840	± 22.0639	26.3488	± 18.5127
Non-Ball Sports	25.0392	± 21.1836	19.3845	± 17.0386	22.0631	± 18.7887
Left Unplanned	*27.6968*	*± 18.1693*	*20.2902*	*± 18.6307*	*23.8813*	*± 18.5048*
Ball Sports	39.9798	± 21.7184	26.7429	± 22.8575	33.8705	± 22.3766
Non-Ball Sports	25.8573	± 17.7003	21.0305	± 26.2636	23.4439	± 21.7788
Straight-Ahead	*32.4478*	*± 20.2974*	*23.4787*	*± 24.1034*	*28.1179*	*± 22.2831*

TABLE 20 – Peak Knee Flexion Moment (BW*BH) * **

	WOMEN		MEN		TOTAL	
Ball Sports	0.1972	± 0.0654	0.3402	± 0.1247	0.2687	± 0.1211
Non-Ball Sports	0.2420	± 0.0928	0.2329	± 0.0869	0.2372	± 0.0873
Right Preplanned	*0.2224*	*± 0.0826*	*0.2771*	*± 0.1142*	*0.2506*	*± 0.1024*
Ball Sports	0.1861	± 0.0424	0.2684	± 0.0781	0.2273	± 0.0739
Non-Ball Sports	0.2410	± 0.1076	0.2608	± 0.1029	0.2514	± 0.1027
Right Planned	*0.2170*	*± 0.0877*	*0.2639*	*± 0.0909*	*0.2412*	*± 0.0911*
Ball Sports	0.2385	± 0.0672	0.3051	± 0.0851	0.2718	± 0.0814
Non-Ball Sports	0.2606	± 0.1606	0.2664	± 0.0959	0.2637	± 0.1268
Right Unplanned	*0.2509*	*± 0.1253*	*0.2823*	*± 0.0910*	*0.2671*	*± 0.1084*
Ball Sports	0.2589	± 0.1019	0.2325	± 0.1105	0.2457	± 0.1031
Non-Ball Sports	0.2167	± 0.0909	0.2478	± 0.0745	0.2331	± 0.0819
Left Preplanned	*0.2352*	*± 0.0950*	*0.2415*	*± 0.0881*	*0.2384*	*± 0.0902*
Ball Sports	0.2576	± 0.0666	0.3015	± 0.1682	0.2796	± 0.1250
Non-Ball Sports	0.2322	± 0.1201	0.2535	± 0.1119	0.2434	± 0.1131
Left Planned	*0.2433*	*± 0.0982*	*0.2733*	*± 0.1351*	*0.2587*	*± 0.1178*
Ball Sports	0.2812	± 0.1247	0.2886	± 0.1470	0.2849	± 0.1310
Non-Ball Sports	0.2245	± 0.0980	0.2853	± 0.0985	0.2565	± 0.1005
Left Unplanned	*0.2493*	*± 0.1104*	*0.2867*	*± 0.1165*	*0.2685*	*± 0.1134*
Ball Sports	0.1852	± 0.0838	0.2604	± 0.1186	0.2199	± 0.1044
Non-Ball Sports	0.1758	± 0.0830	0.1902	± 0.0679	0.1830	± 0.0737
Straight-Ahead	*0.1802*	*± 0.0805*	*0.2203*	*± 0.0959*	*0.1996*	*± 0.0890*

TABLE 21 – Maximum Knee Flexion Angle (deg) *

	WOMEN	MEN	TOTAL
Ball Sports	26.8100 ± 10.4272	29.4871 ± 3.4083	28.1486 ± 7.5811
Non-Ball Sports	26.8640 ± 5.6757	29.3690 ± 7.7370	28.1824 ± 6.7749
Right Preplanned	*26.8404 ± 7.7893*	*29.4176 ± 6.1670*	*28.1680 ± 7.0119*
Ball Sports	26.3371 ± 9.2955	29.9182 ± 4.9064	28.1276 ± 7.3786
Non-Ball Sports	25.3567 ± 6.4079	30.1663 ± 11.5049	27.8881 ± 9.5141
Right Planned	*25.7856 ± 7.5308*	*30.0641 ± 9.1377*	*27.9897 ± 8.5468*
Ball Sports	27.7141 ± 6.6826	31.2793 ± 4.5454	29.4967 ± 5.7939
Non-Ball Sports	25.1460 ± 5.7313	31.0201 ± 11.4649	28.2376 ± 9.4552
Right Unplanned	*26.2695 ± 6.0920*	*31.1268 ± 9.0389*	*28.7718 ± 8.0203*
Ball Sports	35.1045 ± 13.6383	29.8327 ± 6.9109	32.4686 ± 10.7412
Non-Ball Sports	29.9266 ± 7.7472	27.1504 ± 6.3075	28.4654 ± 6.9711
Left Preplanned	*32.1919 ± 10.6513*	*28.2548 ± 6.4915*	*30.1637 ± 8.8454*
Ball Sports	37.1985 ± 13.3183	31.6182 ± 7.7039	34.4083 ± 10.8463
Non-Ball Sports	29.7532 ± 8.2776	27.1544 ± 5.6477	28.3854 ± 6.9411
Left Planned	*33.0105 ± 11.0474*	*28.9924 ± 6.7324*	*30.9406 ± 9.1668*
Ball Sports	36.1246 ± 13.991	28.8651 ± 5.4104	32.4948 ± 10.8648
Non-Ball Sports	29.1969 ± 8.2071	30.9913 ± 9.0424	30.1413 ± 8.4656
Left Unplanned	*32.2278 ± 11.2615*	*30.1158 ± 7.6245*	*31.1398 ± 9.4690*
Ball Sports	8.1605 ± 22.1060	21.3658 ± 8.8896	14.2553 ± 18.0059
Non-Ball Sports	13.7621 ± 16.1321	17.9582 ± 18.1494	15.8601 ± 16.7291
Straight-Ahead	*11.1480 ± 18.6527*	*19.4186 ± 14.5198*	*15.1407 ± 17.0157*

TABLE 22 – Maximum Knee Extension Angle (deg) * **

	WOMEN	MEN	TOTAL
Ball Sports	5.6759 ± 19.8842	2.2847 ± 9.5377	3.9803 ± 15.0852
Non-Ball Sports	3.0986 ± 7.9491	4.6654 ± 9.6408	3.9232 ± 8.6719
Right Preplanned	*4.2262 ± 13.9139*	*3.6851 ± 9.3730*	*3.9474 ± 11.6082*
Ball Sports	4.9798 ± 20.3022	1.5613 ± 8.7315	3.2706 ± 15.1185
Non-Ball Sports	3.6048 ± 9.2989	3.0587 ± 8.6367	3.3174 ± 8.7067
Right Planned	*4.2064 ± 14.5425*	*2.4421 ± 8.4335*	*3.2975 ± 11.6403*
Ball Sports	5.8150 ± 19.6706	0.0333 ± 7.5360	2.9242 ± 14.6217
Non-Ball Sports	3.7585 ± 9.7080	4.9513 ± 13.8256	4.3863 ± 11.7403
Right Unplanned	*4.6582 ± 14.3578*	*2.9263 ± 11.6208*	*3.7660 ± 12.8423*
Ball Sports	-2.6099 ± 17.0665	2.9307 ± 8.3188	0.1604 ± 13.215
Non-Ball Sports	1.4867 ± 8.3508	2.9664 ± 10.2524	2.2266 ± 9.1028
Left Preplanned	*-0.3056 ± 12.574*	*2.9508 ± 9.1510*	*1.3226 ± 10.9434*
Ball Sports	-6.3880 ± 16.3083	0.5115 ± 8.5572	-2.9382 ± 13.014
Non-Ball Sports	0.5074 ± 10.3845	1.7984 ± 8.6101	1.1529 ± 9.2777
Left Planned	*-2.5093 ± 13.2808*	*1.2354 ± 8.3224*	*-0.6370 ± 11.067*
Ball Sports	-5.8575 ± 15.5853	1.8181 ± 9.1238	-2.0197 ± 12.8993
Non-Ball Sports	2.5837 ± 8.9221	-2.9319 ± 11.3290	-0.1741 ± 10.2913
Left Unplanned	*-1.1094 ± 12.5825*	*-0.8538 ± 10.3765*	*-0.9816 ± 11.3456*
Ball Sports	17.0901 ± 18.1357	0.5415 ± 10.8782	9.4523 ± 16.9555
Non-Ball Sports	11.7525 ± 15.0236	17.4287 ± 11.6560	14.5906 ± 13.3164
Straight-Ahead	*14.2433 ± 16.1682*	*10.1914 ± 13.9242*	*12.2872 ± 14.9989*

TABLE 23 – Knee Flexion/Extension ROM (deg)

	WOMEN		MEN		TOTAL	
Ball Sports	32.4860	± 12.9031	31.7718	± 9.3188	32.1289	± 10.8193
Non-Ball Sports	29.9625	± 7.7668	34.0344	± 6.8019	32.1056	± 7.3692
Right Preplanned	*31.0665*	*± 10.0219*	*33.1027*	*± 7.7400*	*32.1155*	*± 8.8375*
Ball Sports	31.3169	± 13.7951	31.4795	± 9.4724	31.3982	± 11.3689
Non-Ball Sports	28.9615	± 8.6614	33.2250	± 6.1330	31.2054	± 7.5454
Right Planned	*29.9920*	*± 10.8439*	*32.5063*	*± 7.4558*	*31.2872*	*± 9.1947*
Ball Sports	33.5291	± 16.8736	31.3127	± 10.5564	32.4209	± 13.5707
Non-Ball Sports	28.9044	± 9.6985	35.9714	± 17.8023	32.6239	± 14.6085
Right Unplanned	*30.9277*	*± 13.0256*	*34.0531*	*± 15.0214*	*32.5378*	*± 13.9596*
Ball Sports	32.4946	± 5.4362	32.7634	± 7.0719	32.6290	± 6.0615
Non-Ball Sports	31.4133	± 5.3446	30.0213	± 8.8521	30.6807	± 7.2377
Left Preplanned	*31.8864*	*± 5.2309*	*31.1504*	*± 8.0478*	*31.5072*	*± 6.7342*
Ball Sports	30.8105	± 6.3225	32.1297	± 6.7003	31.4701	± 6.2959
Non-Ball Sports	30.2606	± 8.5760	29.7543	± 6.6308	29.9941	± 7.3986
Left Planned	*30.5012*	*± 7.4360*	*30.7324*	*± 6.5590*	*30.6203*	*± 6.8879*
Ball Sports	30.2671	± 6.2979	30.6831	± 8.2354	30.4751	± 7.0466
Non-Ball Sports	31.7805	± 4.9319	32.0097	± 6.8648	31.9011	± 5.8640
Left Unplanned	*31.1184*	*± 5.4258*	*31.4634*	*± 7.2384*	*31.2961*	*± 6.3267*
Ball Sports	25.2506	± 6.8183	21.9074	± 7.4083	23.7075	± 7.0087
Non-Ball Sports	25.5145	± 9.5215	35.3869	± 25.1094	30.4507	± 19.0401
Straight-Ahead	*25.3914*	*± 8.0791*	*29.6100*	*± 20.2119*	*27.4279*	*± 15.0635*

TABLE 24 – Knee Flexion Angle at Landing (deg) **

	WOMEN		MEN		TOTAL	
Ball Sports	6.3057	± 13.2692	1.9851	± 7.2696	4.1454	± 10.5205
Non-Ball Sports	0.7718	± 9.7873	-0.4561	± 8.5603	0.0896	± 8.8675
Right Preplanned	*3.3543*	*± 11.4682*	*0.5491*	*± 7.9102*	*1.8640*	*± 9.6806*
Ball Sports	6.8142	± 10.5902	1.7859	± 5.7761	4.3000	± 8.6005
Non-Ball Sports	1.1816	± 10.9484	1.4859	± 10.9241	1.3507	± 10.6094
Right Planned	*3.8102*	*± 10.7916*	*1.6094*	*± 8.9253*	*2.6410*	*± 9.7445*
Ball Sports	8.9814	± 11.0783	7.8400	± 6.1223	8.4107	± 8.6194
Non-Ball Sports	3.0499	± 11.2070	3.6298	± 10.3134	3.3721	± 10.3979
Right Unplanned	*5.8180*	*± 11.1704*	*5.3634*	*± 8.8571*	*5.5765*	*± 9.8435*
Ball Sports	5.7762	± 13.575	1.9830	± 5.3175	3.8796	± 10.0984
Non-Ball Sports	3.8720	± 8.8056	-2.3305	± 8.9467	0.6075	± 9.1982
Left Preplanned	*4.7051*	*± 10.7712*	*-0.5543*	*± 7.7728*	*1.9957*	*± 9.5769*
Ball Sports	6.9644	± 16.3553	4.0411	± 5.9815	5.5028	± 11.9279
Non-Ball Sports	3.0566	± 10.7697	-2.9685	± 7.5406	-0.1145	± 9.4622
Left Planned	*4.7663*	*± 13.1479*	*-0.0822*	*± 7.6188*	*2.2686*	*± 10.7754*
Ball Sports	9.1820	± 13.4289	5.8449	± 7.7869	7.5134	± 10.6872
Non-Ball Sports	3.4671	± 11.1119	0.3051	± 8.6164	1.8029	± 9.7278
Left Unplanned	*5.9673*	*± 12.1062*	*2.5862*	*± 8.5087*	*4.2255*	*± 10.3848*
Ball Sports	4.6551	± 14.1839	9.9974	± 9.6873	7.1208	± 12.1399
Non-Ball Sports	6.8508	± 9.9337	4.3354	± 25.5355	5.5092	± 19.2356
Straight-Ahead	*5.7530*	*± 11.8193*	*6.7620*	*± 19.8912*	*6.2575*	*± 16.0632*

TABLE 25 – Peak Knee Varus Moment (BW*BH) * ***

	WOMEN	MEN	TOTAL
Ball Sports	0.1668 ± 0.0894	0.2510 ± 0.2028	0.2089 ± 0.1568
Non-Ball Sports	0.1204 ± 0.0511	0.1757 ± 0.1124	0.1495 ± 0.0910
Right Preplanned	*0.1407 ± 0.0718*	*0.2067 ± 0.1549*	*0.1747 ± 0.1246*
Ball Sports	0.1758 ± 0.0632	0.2489 ± 0.2031	0.2124 ± 0.1494
Non-Ball Sports	0.1332 ± 0.0514	0.1820 ± 0.1014	0.1589 ± 0.0833
Right Planned	*0.1518 ± 0.0590*	*0.2095 ± 0.1497*	*0.1816 ± 0.1170*
Ball Sports	0.1590 ± 0.0706	0.2120 ± 0.1242	0.1855 ± 0.1009
Non-Ball Sports	0.1639 ± 0.0991	0.2314 ± 0.1374	0.1994 ± 0.1225
Right Unplanned	*0.1618 ± 0.0851*	*0.2234 ± 0.1285*	*0.1935 ± 0.1124*
Ball Sports	0.1478 ± 0.0956	0.1854 ± 0.1662	0.1666 ± 0.1317
Non-Ball Sports	0.1162 ± 0.0717	0.1316 ± 0.0614	0.1243 ± 0.0650
Left Preplanned	*0.1300 ± 0.0816*	*0.1538 ± 0.1150*	*0.1423 ± 0.0994*
Ball Sports	0.1334 ± 0.0877	0.2032 ± 0.1697	0.1683 ± 0.1347
Non-Ball Sports	0.1293 ± 0.0531	0.1312 ± 0.0502	0.1303 ± 0.0501
Left Planned	*0.1311 ± 0.0677*	*0.1609 ± 0.1164*	*0.1464 ± 0.0957*
Ball Sports	0.0926 ± 0.0261	0.1477 ± 0.0633	0.1202 ± 0.0546
Non-Ball Sports	0.1196 ± 0.0630	0.1776 ± 0.1102	0.1501 ± 0.0934
Left Unplanned	*0.1078 ± 0.0508*	*0.1653 ± 0.0926*	*0.1374 ± 0.0797*
Ball Sports	0.0270 ± 0.0182	0.0243 ± 0.0192	0.0258 ± 0.0180
Non-Ball Sports	0.0423 ± 0.0608	0.0720 ± 0.1018	0.0571 ± 0.0825
Straight-Ahead	*0.0351 ± 0.0453*	*0.0515 ± 0.0795*	*0.0431 ± 0.0635*

TABLE 26 – Maximum Knee Varus Angle (deg)

	WOMEN	MEN	TOTAL
Ball Sports	5.5891 ± 13.7299	0.8545 ± 8.4073	3.2218 ± 11.2100
Non-Ball Sports	0.3117 ± 4.0014	-2.9786 ± 7.8298	-1.4200 ± 6.3732
Right Preplanned	*2.6206 ± 9.5527*	*-1.4003 ± 8.0481*	*0.5492 ± 8.9065*
Ball Sports	6.8723 ± 14.5457	2.0663 ± 11.1516	4.4693 ± 12.699
Non-Ball Sports	-0.2694 ± 4.1393	-3.7742 ± 7.9758	-2.1140 ± 6.5310
Right Planned	*2.8551 ± 10.3517*	*-1.3693 ± 9.5496*	*0.6789 ± 10.0212*
Ball Sports	7.3452 ± 16.1523	1.7849 ± 9.7097	4.5651 ± 13.1244
Non-Ball Sports	0.0988 ± 4.3792	-3.0240 ± 7.9430	-1.5448 ± 6.5296
Right Unplanned	*3.2691 ± 11.3301*	*-1.0439 ± 8.7633*	*1.0473 ± 10.1667*
Ball Sports	1.2611 ± 9.3485	-0.6968 ± 10.6906	0.2821 ± 9.7014
Non-Ball Sports	0.0529 ± 8.3848	-2.7200 ± 6.6399	-1.4065 ± 7.4373
Left Preplanned	*0.5815 ± 8.5344*	*-1.8869 ± 8.2892*	*-0.6901 ± 8.3706*
Ball Sports	2.0932 ± 8.1284	-0.2669 ± 9.2541	0.9132 ± 8.4569
Non-Ball Sports	-1.9867 ± 6.6062	-3.4054 ± 5.8017	-2.7334 ± 6.0627
Left Planned	*-0.2017 ± 7.3535*	*-2.1131 ± 7.3200*	*-1.1864 ± 7.2856*
Ball Sports	0.9186 ± 10.2092	-2.7474 ± 11.2761	-0.9144 ± 10.5075
Non-Ball Sports	-0.6981 ± 8.2884	-2.1344 ± 7.7878	-1.4540 ± 7.8358
Left Unplanned	*0.0092 ± 8.8891*	*-2.3868 ± 9.0495*	*-1.2251 ± 8.9143*
Ball Sports	9.5506 ± 12.5599	1.5704 ± 7.5324	5.8674 ± 10.939
Non-Ball Sports	5.1794 ± 7.0824	4.1593 ± 9.1687	4.6693 ± 7.9319
Straight-Ahead	*7.2193 ± 9.8885*	*3.0498 ± 8.2979*	*5.2064 ± 9.2388*

TABLE 27 – Maximum Knee Valgus Angle (deg) *

	WOMEN		MEN		TOTAL	
Ball Sports	10.9272	± 7.6236	12.2569	± 6.1539	11.5921	± 6.6917
Non-Ball Sports	12.2869	± 7.5172	14.3454	± 9.8180	13.3704	± 8.6271
Right Preplanned	*11.6921*	*± 7.3397*	*13.4855*	*± 8.3394*	*12.6159*	*± 7.8008*
Ball Sports	10.5156	± 7.6695	12.3193	± 6.2717	11.4174	± 6.7954
Non-Ball Sports	12.2077	± 6.8948	14.2237	± 8.6729	13.2688	± 7.7335
Right Planned	*11.4674*	*± 7.0451*	*13.4396*	*± 7.6154*	*12.4834*	*± 7.2983*
Ball Sports	12.1271	± 6.6554	12.7330	± 6.5622	12.4300	± 6.3575
Non-Ball Sports	11.7238	± 5.9412	15.8175	± 8.7249	13.8784	± 7.6263
Right Unplanned	*11.9002*	*± 6.0487*	*14.5474*	*± 7.8369*	*13.2639*	*± 7.0472*
Ball Sports	15.0481	± 8.8172	13.6776	± 6.0449	14.3628	± 7.2974
Non-Ball Sports	13.0643	± 6.5998	12.2452	± 4.9632	12.6332	± 5.6437
Left Preplanned	*13.9322*	*± 7.4405*	*12.8350*	*± 5.2997*	*13.3670*	*± 6.3485*
Ball Sports	14.6228	± 8.3898	14.2428	± 6.8597	14.4328	± 7.3651
Non-Ball Sports	13.7067	± 7.7675	12.8995	± 5.7964	13.2818	± 6.6171
Left Planned	*14.1075*	*± 7.7816*	*13.4526*	*± 6.0835*	*13.7701*	*± 6.8556*
Ball Sports	15.1939	± 8.2634	15.6930	± 5.4162	15.4434	± 6.7173
Non-Ball Sports	13.5735	± 6.9051	12.6789	± 5.5769	13.1026	± 6.0789
Left Unplanned	*14.2824*	*± 7.3097*	*13.9200*	*± 5.5528*	*14.0957*	*± 6.3637*
Ball Sports	7.7695	± 13.0661	9.6514	± 10.6372	8.6381	± 11.5525
Non-Ball Sports	7.7392	± 10.1873	2.7887	± 13.3845	5.2639	± 11.7715
Straight-Ahead	*7.7533*	*± 11.1829*	*5.7299*	*± 12.3452*	*6.7765*	*± 11.5908*

TABLE 28 – Knee Varus/Valgus ROM (deg)

	WOMEN		MEN		TOTAL	
Ball Sports	16.5164	± 12.2691	13.1114	± 10.1314	14.8139	± 10.9532
Non-Ball Sports	12.5986	± 10.6461	11.3669	± 7.9602	11.9503	± 9.0804
Right Preplanned	*14.3126*	*± 11.1664*	*12.0852*	*± 8.6555*	*13.1652*	*± 9.8582*
Ball Sports	17.3878	± 13.9884	14.3856	± 13.6081	15.8867	± 13.3494
Non-Ball Sports	11.9383	± 9.9210	10.4496	± 6.3322	11.1548	± 8.0235
Right Planned	*14.3225*	*± 11.7711*	*12.0703*	*± 9.7971*	*13.1623*	*± 10.6887*
Ball Sports	19.4723	± 16.6876	14.5179	± 11.9972	16.9951	± 14.1974
Non-Ball Sports	11.8225	± 9.0200	12.7934	± 8.6084	12.3335	± 8.5709
Right Unplanned	*15.1693*	*± 13.0439*	*13.5035*	*± 9.8196*	*14.3112*	*± 11.3438*
Ball Sports	16.3092	± 12.5273	12.9808	± 12.0618	14.6450	± 11.9399
Non-Ball Sports	13.1172	± 11.2284	9.5252	± 7.2044	11.2267	± 9.2402
Left Preplanned	*14.5137*	*± 11.5191*	*10.9481*	*± 9.3181*	*12.6769*	*± 10.4348*
Ball Sports	16.7161	± 10.3922	13.9759	± 11.0338	15.3460	± 10.395
Non-Ball Sports	11.7200	± 10.3217	9.4941	± 7.1779	10.5484	± 8.6264
Left Planned	*13.9058*	*± 10.3233*	*11.3395*	*± 8.9334*	*12.5838*	*± 9.5684*
Ball Sports	16.1125	± 9.9430	12.9456	± 13.5866	14.5290	± 11.5554
Non-Ball Sports	12.8754	± 12.4278	10.5445	± 10.3483	11.6486	± 11.1184
Left Unplanned	*14.2916*	*± 11.1656*	*11.5332*	*± 11.4431*	*12.8706*	*± 11.2192*
Ball Sports	17.3200	± 12.2052	11.2219	± 11.7145	14.5055	± 11.9027
Non-Ball Sports	12.9185	± 7.7883	6.9480	± 4.6747	9.9333	± 6.9290
Straight-Ahead	*14.9726*	*± 9.9668*	*8.7796*	*± 8.3286*	*11.9829*	*± 9.5809*

TABLE 29 – Peak Knee External Rotation Moment (BW*BH) + * ***

	WOMEN		MEN		TOTAL	
Ball Sports	0.0503	± 0.0348	0.0961	± 0.0508	0.0732	± 0.0481
Non-Ball Sports	0.0550	± 0.0337	0.0772	± 0.0371	0.0667	± 0.0364
Right Preplanned	*0.0529*	*± 0.0331*	*0.0850*	*± 0.0428*	*0.0694*	*± 0.0412*
Ball Sports	0.0529	± 0.0466	0.1204	± 0.0589	0.0866	± 0.0619
Non-Ball Sports	0.0602	± 0.0371	0.1006	± 0.0440	0.0815	± 0.0448
Right Planned	*0.0570*	*± 0.0402*	*0.1088*	*± 0.0499*	*0.0837*	*± 0.0519*
Ball Sports	0.0531	± 0.0382	0.0911	± 0.0489	0.0721	± 0.0466
Non-Ball Sports	0.0865	± 0.0541	0.0776	± 0.0439	0.0818	± 0.0478
Right Unplanned	*0.0719*	*± 0.0494*	*0.0832*	*± 0.0450*	*0.0777*	*± 0.0468*
Ball Sports	0.0624	± 0.0385	0.1058	± 0.0515	0.0841	± 0.0491
Non-Ball Sports	0.0836	± 0.0475	0.1098	± 0.0605	0.0974	± 0.0549
Left Preplanned	*0.0743*	*± 0.0437*	*0.1082*	*± 0.0553*	*0.0917*	*± 0.0522*
Ball Sports	0.0597	± 0.0373	0.1364	± 0.0700	0.0980	± 0.0670
Non-Ball Sports	0.0839	± 0.0534	0.0727	± 0.0342	0.0780	± 0.0434
Left Planned	*0.0733*	*± 0.0472*	*0.0989*	*± 0.0595*	*0.0865*	*± 0.0546*
Ball Sports	0.0493	± 0.0338	0.0849	± 0.0453	0.0671	± 0.0426
Non-Ball Sports	0.0786	± 0.0418	0.0966	± 0.0693	0.0881	± 0.0571
Left Unplanned	*0.0658*	*± 0.0401*	*0.0918*	*± 0.0592*	*0.0792*	*± 0.0518*
Ball Sports	0.0242	± 0.0176	0.0264	± 0.0121	0.0252	± 0.0147
Non-Ball Sports	0.0332	± 0.0146	0.0454	± 0.0442	0.0393	± 0.0324
Straight-Ahead	*0.0290*	*± 0.0162*	*0.0372*	*± 0.0347*	*0.0330*	*± 0.0266*

TABLE 30 – Maximum Knee External Rotation Angle (deg)

	WOMEN		MEN		TOTAL	
Ball Sports	3.8886	± 3.7911	5.1664	± 6.5148	4.5275	± 5.1635
Non-Ball Sports	2.7280	± 4.0089	1.8851	± 1.6012	2.2843	± 2.9345
Right Preplanned	*3.2357*	*± 3.8306*	*3.2362*	*± 4.4865*	*3.2360*	*± 4.1162*
Ball Sports	4.4704	± 5.3844	5.4423	± 7.4786	4.9564	± 6.2808
Non-Ball Sports	2.6949	± 3.1988	1.3970	± 1.2724	2.0118	± 2.4084
Right Planned	*3.4717*	*± 4.2286*	*3.0627*	*± 5.1084*	*3.2610*	*± 4.6339*
Ball Sports	4.3071	± 4.6514	4.2134	± 6.1768	4.2602	± 5.2533
Non-Ball Sports	2.8745	± 3.2308	4.0601	± 7.4856	3.4985	± 5.7468
Right Unplanned	*3.5013*	*± 3.8419*	*4.1232*	*± 6.77*	*3.8217*	*± 5.4713*
Ball Sports	9.1718	± 12.7038	4.3664	± 5.5059	6.7691	± 9.7311
Non-Ball Sports	2.0006	± 2.8401	2.6986	± 3.3308	2.3680	± 3.0431
Left Preplanned	*5.1380*	*± 9.075*	*3.3853*	*± 4.2807*	*4.2351*	*± 6.9684*
Ball Sports	10.5175	± 12.8866	4.9097	± 6.3934	7.7136	± 10.197
Non-Ball Sports	1.6682	± 3.4772	2.8147	± 4.3548	2.2716	± 3.8989
Left Planned	*5.5398*	*± 9.6659*	*3.6773*	*± 5.2082*	*4.5804*	*± 7.6323*
Ball Sports	9.7966	± 12.2215	4.2401	± 5.0236	7.0184	± 9.4286
Non-Ball Sports	1.9616	± 2.6271	4.3552	± 8.9026	3.2214	± 6.6485
Left Unplanned	*5.3894*	*± 8.9186*	*4.3078*	*± 7.3518*	*4.8322*	*± 8.0381*
Ball Sports	7.2862	± 7.7051	3.3966	± 4.2324	5.4910	± 6.4204
Non-Ball Sports	2.8164	± 3.5678	5.2062	± 12.2699	4.0113	± 8.8159
Straight-Ahead	*4.9023*	*± 6.0939*	*4.4307*	*± 9.4244*	*4.6746*	*± 7.7371*

TABLE 31 – Maximum Knee Internal Rotation Angle (deg) +

	WOMEN	MEN	TOTAL
Ball Sports	7.0288 ± 9.4516	1.6574 ± 2.0137	4.3431 ± 7.1323
Non-Ball Sports	3.2391 ± 2.0868	3.3734 ± 2.7491	3.3098 ± 2.3914
Right Preplanned	*4.8971 ± 6.4673*	*2.6668 ± 2.5553*	*3.7482 ± 4.9144*
Ball Sports	6.9950 ± 10.1661	1.8780 ± 2.5777	4.4365 ± 7.6037
Non-Ball Sports	3.1109 ± 1.8317	3.5120 ± 2.5477	3.3220 ± 2.1862
Right Planned	*4.8102 ± 6.8621*	*2.8392 ± 2.6135*	*3.7948 ± 5.1467*
Ball Sports	7.4308 ± 9.8954	1.8750 ± 2.1413	4.6529 ± 7.4579
Non-Ball Sports	3.0555 ± 2.2087	4.9800 ± 6.4623	4.0684 ± 4.9014
Right Unplanned	*4.9697 ± 6.8407*	*3.7015 ± 5.2623*	*4.3164 ± 6.0162*
Ball Sports	3.6140 ± 1.7733	1.6519 ± 1.3013	2.6329 ± 1.8082
Non-Ball Sports	4.4382 ± 2.0436	1.9672 ± 1.7411	3.1377 ± 2.2313
Left Preplanned	*4.0776 ± 1.9140*	*1.8374 ± 1.5381*	*2.9236 ± 2.0476*
Ball Sports	2.1128 ± 1.2742	2.0794 ± 1.9544	2.0961 ± 1.5851
Non-Ball Sports	4.6397 ± 2.1882	2.3040 ± 1.9130	3.4104 ± 2.3224
Left Planned	*3.5342 ± 2.2089*	*2.2116 ± 1.8718*	*2.8528 ± 2.1189*
Ball Sports	2.7863 ± 1.5116	2.4711 ± 2.0169	2.6287 ± 1.7201
Non-Ball Sports	4.5428 ± 2.2185	2.3411 ± 1.6471	3.3840 ± 2.1954
Left Unplanned	*3.7743 ± 2.0854*	*2.3946 ± 1.7481*	*3.0636 ± 2.0141*
Ball Sports	2.5040 ± 1.5986	1.9908 ± 1.6284	2.2671 ± 1.5664
Non-Ball Sports	4.0670 ± 2.3791	6.7230 ± 11.1099	5.3950 ± 7.8818
Straight-Ahead	*3.3376 ± 2.1393*	*4.6949 ± 8.5667*	*3.9929 ± 6.0694*

TABLE 32 – Knee External/Internal Rotation ROM (deg)

	WOMEN	MEN	TOTAL
Ball Sports	10.9175 ± 11.2999	6.8238 ± 5.8291	8.8706 ± 8.8953
Non-Ball Sports	5.9671 ± 4.3794	5.2585 ± 3.0264	5.5941 ± 3.6381
Right Preplanned	*8.1329 ± 8.2302*	*5.9030 ± 4.304*	*6.9842 ± 6.5034*
Ball Sports	11.4654 ± 11.7814	7.3203 ± 6.7394	9.3928 ± 9.4684
Non-Ball Sports	5.8059 ± 3.4618	4.9090 ± 2.5769	5.3338 ± 2.9763
Right Planned	*8.2819 ± 8.3857*	*5.9019 ± 4.7185*	*7.0558 ± 6.7493*
Ball Sports	11.7379 ± 12.5405	6.0884 ± 5.5335	8.9131 ± 9.7626
Non-Ball Sports	5.9300 ± 3.3098	9.0401 ± 13.7299	7.5669 ± 10.0831
Right Unplanned	*8.4710 ± 8.8092*	*7.8247 ± 10.9436*	*8.1380 ± 9.8165*
Ball Sports	12.7858 ± 13.2202	6.0183 ± 5.4750	9.4020 ± 10.3358
Non-Ball Sports	6.4389 ± 3.2195	4.6658 ± 2.6743	5.5057 ± 3.0017
Left Preplanned	*9.2157 ± 9.2742*	*5.2227 ± 3.9667*	*7.1587 ± 7.2313*
Ball Sports	12.6303 ± 12.9058	6.9891 ± 6.5979	9.8097 ± 10.2729
Non-Ball Sports	6.3079 ± 3.2771	5.1187 ± 3.5956	5.6820 ± 3.4072
Left Planned	*9.0740 ± 9.1019*	*5.8889 ± 4.9494*	*7.4332 ± 7.3277*
Ball Sports	12.5829 ± 12.2319	6.7113 ± 5.1571	9.6471 ± 9.5191
Non-Ball Sports	6.5044 ± 3.1405	6.6963 ± 8.0851	6.6054 ± 6.0891
Left Unplanned	*9.1637 ± 8.64911*	*6.7024 ± 6.8369*	*7.8958 ± 7.7458*
Ball Sports	9.7902 ± 8.5537	5.3874 ± 3.7076	7.7581 ± 6.8942
Non-Ball Sports	6.8834 ± 3.8548	11.9292 ± 23.3168	9.4063 ± 16.3535
Straight-Ahead	*8.2399 ± 6.4062*	*9.1255 ± 17.5875*	*8.6675 ± 12.8194*

TABLE 33 – Peak Hip Extension Moment (BW*BH) * **

	WOMEN		MEN		TOTAL	
Ball Sports	0.1678	± 0.0385	0.2765	± 0.1061	0.2221	± 0.0952
Non-Ball Sports	0.2047	± 0.0719	0.2181	± 0.0703	0.2118	± 0.0694
Right Preplanned	*0.1885*	*± 0.0609*	*0.2422*	*± 0.0887*	*0.2162*	*± 0.0801*
Ball Sports	0.1596	± 0.0466	0.2142	± 0.0734	0.1869	± 0.0655
Non-Ball Sports	0.2185	± 0.0792	0.2276	± 0.0739	0.2233	± 0.0745
Right Planned	*0.1927*	*± 0.0716*	*0.2221*	*± 0.0717*	*0.2078*	*± 0.0721*
Ball Sports	0.1959	± 0.028	0.2616	± 0.0697	0.2288	± 0.0613
Non-Ball Sports	0.2333	± 0.1264	0.2585	± 0.0643	0.2466	± 0.0966
Right Unplanned	*0.2169*	*± 0.0959*	*0.2598*	*± 0.0644*	*0.2390*	*± 0.0828*
Ball Sports	0.2230	± 0.0897	0.1992	± 0.0957	0.2111	± 0.09
Non-Ball Sports	0.1907	± 0.0953	0.2065	± 0.058	0.1990	± 0.0761
Left Preplanned	*0.2049*	*± 0.0913*	*0.2035*	*± 0.0731*	*0.2041*	*± 0.0811*
Ball Sports	0.2232	± 0.0692	0.2509	± 0.1422	0.2371	± 0.1084
Non-Ball Sports	0.2029	± 0.0978	0.2203	± 0.0797	0.2120	± 0.0866
Left Planned	*0.2118*	*± 0.0844*	*0.2329*	*± 0.1067*	*0.2227*	*± 0.0957*
Ball Sports	0.2419	± 0.0952	0.2310	± 0.1179	0.2364	± 0.1031
Non-Ball Sports	0.1939	± 0.098	0.2709	± 0.0619	0.2344	± 0.088
Left Unplanned	*0.2149*	*± 0.0967*	*0.2545*	*± 0.0882*	*0.2353*	*± 0.0931*
Ball Sports	0.1497	± 0.0566	0.2193	± 0.0887	0.1818	± 0.0786
Non-Ball Sports	0.1572	± 0.0587	0.1647	± 0.0474	0.1609	± 0.0516
Straight-Ahead	*0.1537*	*± 0.0557*	*0.1881*	*± 0.0709*	*0.1703*	*± 0.0647*

TABLE 34 – Maximum Hip Extension Angle (deg) *

	WOMEN		MEN		TOTAL	
Ball Sports	14.5917	± 11.4937	14.0543	± 5.6752	14.3230	± 8.7129
Non-Ball Sports	15.4858	± 7.4751	10.1675	± 13.2912	12.6867	± 10.982
Right Preplanned	*15.0946*	*± 9.1023*	*11.7680*	*± 10.7394*	*13.3809*	*± 9.9677*
Ball Sports	15.8537	± 6.9795	10.1197	± 10.1673	12.9867	± 8.8908
Non-Ball Sports	14.1095	± 5.8373	10.0370	± 10.8720	11.9661	± 8.8661
Right Planned	*14.8726*	*± 6.2014*	*10.0711*	*± 10.2594*	*12.3991*	*± 8.7517*
Ball Sports	14.1857	± 11.9517	16.5097	± 5.1921	15.3477	± 8.9344
Non-Ball Sports	14.3424	± 8.1441	7.8657	± 13.1566	10.9336	± 11.2723
Right Unplanned	*14.2739*	*± 9.6186*	*11.4250*	*± 11.2563*	*12.8062*	*± 10.4312*
Ball Sports	14.7710	± 9.7855	11.4614	± 6.1250	13.1162	± 8.0286
Non-Ball Sports	14.4823	± 6.6914	12.8167	± 8.1443	13.6057	± 7.3345
Left Preplanned	*14.6086*	*± 7.8870*	*12.2586*	*± 7.2008*	*13.3980*	*± 7.5171*
Ball Sports	13.8894	± 12.0313	13.8853	± 6.3759	13.8874	± 9.2505
Non-Ball Sports	13.8273	± 7.5596	12.0956	± 8.0216	12.9159	± 7.6395
Left Planned	*13.8545*	*± 9.4011*	*12.8325*	*± 7.2293*	*13.3280*	*± 8.2359*
Ball Sports	13.8735	± 10.8136	10.0892	± 3.7152	11.9813	± 8.0122
Non-Ball Sports	14.3275	± 6.8381	8.4490	± 13.2246	11.2336	± 10.8315
Left Unplanned	*14.1288*	*± 8.4715*	*9.1244*	*± 10.2100*	*11.5508*	*± 9.6028*
Ball Sports	22.0695	± 5.3052	15.0765	± 6.3284	18.8420	± 6.6277
Non-Ball Sports	22.9467	± 3.3019	14.8560	± 3.1134	18.9013	± 5.2026
Straight-Ahead	*22.5373*	*± 4.2093*	*14.9505*	*± 4.5426*	*18.8747*	*± 5.7729*

TABLE 35 – Maximum Hip Flexion Angle (deg) * **

	WOMEN	MEN	TOTAL
Ball Sports	28.3166 ± 19.3561	33.3483 ± 4.1729	30.8324 ± 13.703
Non-Ball Sports	30.0483 ± 12.8248	35.7621 ± 9.4109	33.0556 ± 11.2238
Right Preplanned	*29.2907 ± 15.4392*	*34.7682 ± 7.6057*	*32.1124 ± 12.1814*
Ball Sports	29.6094 ± 17.6522	31.4823 ± 5.3496	30.5458 ± 12.5686
Non-Ball Sports	30.6838 ± 10.8052	39.2197 ± 11.2326	35.1764 ± 11.5823
Right Planned	*30.2138 ± 13.6825*	*36.0337 ± 9.8544*	*33.2119 ± 12.043*
Ball Sports	14.1857 ± 11.9517	16.5097 ± 5.1921	15.3477 ± 8.9344
Non-Ball Sports	14.3424 ± 8.14406	7.8657 ± 13.1566	10.9336 ± 11.2723
Right Unplanned	*14.2739 ± 9.6186*	*11.4250 ± 11.2563*	*12.8062 ± 10.4312*
Ball Sports	31.9021 ± 19.5254	30.4564 ± 4.6093	31.1792 ± 13.6501
Non-Ball Sports	31.2519 ± 10.8795	32.0931 ± 10.0032	31.6946 ± 10.1402
Left Preplanned	*31.5363 ± 14.6879*	*31.4192 ± 8.0587*	*31.4760 ± 11.5586*
Ball Sports	30.5256 ± 18.5439	31.7526 ± 9.0317	31.1391 ± 14.0273
Non-Ball Sports	29.4953 ± 11.9719	30.3871 ± 8.1069	29.9647 ± 9.8372
Left Planned	*29.9461 ± 14.6379*	*30.9494 ± 8.248*	*30.4629 ± 11.6068*
Ball Sports	32.2487 ± 17.6115	31.9723 ± 9.2253	32.1105 ± 13.5076
Non-Ball Sports	29.7116 ± 10.9356	30.8513 ± 9.5679	30.3115 ± 9.9631
Left Unplanned	*30.8216 ± 13.7672*	*31.3129 ± 9.1505*	*31.0747 ± 11.4356*
Ball Sports	17.8930 ± 8.5634	28.0377 ± 5.6772	22.5752 ± 8.8206
Non-Ball Sports	19.6479 ± 4.3309	24.3457 ± 3.603	21.9968 ± 4.5493
Straight-Ahead	*18.8290 ± 6.4519*	*25.9280 ± 4.7939*	*22.2561 ± 6.6721*

TABLE 36 – Hip Extension/Flexion ROM (deg) * ***

	WOMEN	MEN	TOTAL
Ball Sports	42.9083 ± 8.3862	47.4025 ± 6.0919	45.1554 ± 7.4179
Non-Ball Sports	45.5341 ± 7.2528	45.9297 ± 15.2531	45.7423 ± 11.8216
Right Preplanned	*44.3853 ± 7.6155*	*46.5361 ± 12.0559*	*45.4933 ± 10.0524*
Ball Sports	45.4631 ± 11.8341	41.6020 ± 12.9438	43.5325 ± 12.0821
Non-Ball Sports	44.7933 ± 7.8847	49.2567 ± 13.4424	47.1424 ± 11.1005
Right Planned	*45.0863 ± 9.4495*	*46.1047 ± 13.3996*	*45.6110 ± 11.4847*
Ball Sports	45.2688 ± 10.6583	49.4951 ± 8.0710	47.3820 ± 9.3437
Non-Ball Sports	44.7743 ± 6.4911	44.8454 ± 15.7191	44.8117 ± 11.9278
Right Unplanned	*44.9906 ± 8.2447*	*46.7600 ± 12.9992*	*45.9021 ± 10.824*
Ball Sports	46.6731 ± 12.0475	41.9177 ± 4.0790	44.2954 ± 8.9864
Non-Ball Sports	45.7342 ± 5.2056	44.9099 ± 10.3934	45.3003 ± 8.1385
Left Preplanned	*46.1449 ± 8.5288*	*43.6778 ± 8.3251*	*44.8740 ± 8.3856*
Ball Sports	44.4150 ± 11.0401	45.6379 ± 7.3587	45.0265 ± 9.0360
Non-Ball Sports	43.3226 ± 5.5199	42.4827 ± 9.9449	42.8805 ± 7.9485
Left Planned	*43.8005 ± 8.0819*	*43.7819 ± 8.8600*	*43.7909 ± 8.3587*
Ball Sports	46.1222 ± 9.6624	42.0614 ± 8.9157	44.0918 ± 9.1770
Non-Ball Sports	44.0391 ± 5.3150	39.3004 ± 11.7265	41.5450 ± 9.3391
Left Unplanned	*44.9504 ± 7.3178*	*40.4373 ± 10.4461*	*42.6255 ± 9.2146*
Ball Sports	39.9625 ± 8.8145	43.1142 ± 5.1341	41.4171 ± 7.2460
Non-Ball Sports	42.5946 ± 4.7059	39.2017 ± 3.7144	40.8982 ± 4.4545
Straight-Ahead	*41.3663 ± 6.7984*	*40.8785 ± 4.6480*	*41.1308 ± 5.7620*

TABLE 37 – Peak Hip Adduction Moment (BW*BH) *

	WOMEN		MEN		TOTAL	
Ball Sports	0.1261	± 0.0960	0.1842	± 0.1551	0.1552	± 0.1275
Non-Ball Sports	0.0842	± 0.0377	0.1248	± 0.0978	0.1055	± 0.0764
Right Preplanned	*0.1025*	*± 0.0700*	*0.1492*	*± 0.1237*	*0.1266*	*± 0.1025*
Ball Sports	0.1470	± 0.0783	0.1828	± 0.1326	0.1649	± 0.1063
Non-Ball Sports	0.0952	± 0.0434	0.1347	± 0.0935	0.1160	± 0.0750
Right Planned	*0.1179*	*± 0.0645*	*0.1545*	*± 0.1101*	*0.1368*	*± 0.0914*
Ball Sports	0.1226	± 0.0662	0.1592	± 0.0898	0.1409	± 0.0782
Non-Ball Sports	0.1234	± 0.0678	0.1488	± 0.1215	0.1368	± 0.0980
Right Unplanned	*0.1231*	*± 0.0649*	*0.1531*	*± 0.1066*	*0.1385*	*± 0.0888*
Ball Sports	0.0990	± 0.0698	0.1355	± 0.1046	0.1172	± 0.0875
Non-Ball Sports	0.0976	± 0.0484	0.1049	± 0.0500	0.1014	± 0.0480
Left Preplanned	*0.0982*	*± 0.0566*	*0.1175*	*± 0.0758*	*0.1081*	*± 0.0669*
Ball Sports	0.0934	± 0.0585	0.1634	± 0.1118	0.1284	± 0.0931
Non-Ball Sports	0.0976	± 0.0465	0.0935	± 0.0412	0.0954	± 0.0426
Left Planned	*0.0958*	*± 0.0502*	*0.1223*	*± 0.0831*	*0.1094*	*± 0.0694*
Ball Sports	0.0667	± 0.0299	0.1068	± 0.0526	0.0868	± 0.0461
Non-Ball Sports	0.0881	± 0.0444	0.1218	± 0.0950	0.1058	± 0.0754
Left Unplanned	*0.0787*	*± 0.0391*	*0.1157*	*± 0.0786*	*0.0978*	*± 0.0645*
Ball Sports	0.0254	± 0.0166	0.0165	± 0.0177	0.0213	± 0.0170
Non-Ball Sports	0.0368	± 0.0590	0.0476	± 0.0480	0.0422	± 0.0522
Straight-Ahead	*0.0315*	*± 0.0435*	*0.0343*	*± 0.0402*	*0.0328*	*± 0.0412*

TABLE 38 – Maximum Hip Adduction Angle (deg) + *

	WOMEN		MEN		TOTAL	
Ball Sports	-10.0010	± 4.3316	-15.8972	± 6.1820	-12.9491	± 5.9715
Non-Ball Sports	-11.9813	± 5.1006	-16.0409	± 6.3892	-14.1179	± 6.0259
Right Preplanned	*-11.1149*	*± 4.7339*	*-15.9818*	*± 6.1073*	*-13.6221*	*± 5.9376*
Ball Sports	-10.6545	± 4.3085	-14.4785	± 6.0170	-12.5665	± 5.4050
Non-Ball Sports	-12.6393	± 7.8480	-16.6588	± 6.8749	-14.7548	± 7.4336
Right Planned	*-11.7710*	*± 6.4272*	*-15.7610*	*± 6.4332*	*-13.8264*	*± 6.6451*
Ball Sports	-10.3571	± 6.4037	-16.4821	± 6.9125	-13.4196	± 7.1471
Non-Ball Sports	-12.2400	± 7.4326	-16.9337	± 8.5881	-14.7104	± 8.1992
Right Unplanned	*-11.4162*	*± 6.8408*	*-16.7478*	*± 7.7109*	*-14.1628*	*± 7.6803*
Ball Sports	-10.5976	± 2.9918	-16.6682	± 4.9233	-13.6329	± 5.0240
Non-Ball Sports	-11.5423	± 6.6415	-15.9038	± 9.1842	-13.8379	± 8.1722
Left Preplanned	*-11.1290*	*± 5.2288*	*-16.2186*	*± 7.5290*	*-13.7509*	*± 6.9160*
Ball Sports	-8.9432	± 3.2683	-16.3746	± 5.2282	-12.6589	± 5.6934
Non-Ball Sports	-12.2157	± 5.4235	-16.3433	± 7.8771	-14.3881	± 6.9700
Left Planned	*-10.7840*	*± 4.7720*	*-16.3562*	*± 6.7196*	*-13.6545*	*± 6.4225*
Ball Sports	-9.3129	± 5.0541	-16.7417	± 6.3939	-13.0273	± 6.7466
Non-Ball Sports	-13.3105	± 6.5525	-17.6171	± 7.7303	-15.5771	± 7.3377
Left Unplanned	*-11.5615*	*± 6.1083*	*-17.2567*	*± 7.01011*	*-14.4954*	*± 7.1004*
Ball Sports	1.3580	± 4.5564	-1.6010	± 3.2663	-0.0077	± 4.1452
Non-Ball Sports	0.6759	± 4.7721	-1.6981	± 4.7989	-0.5111	± 4.7830
Straight-Ahead	*0.9942*	*± 4.5175*	*-1.6565*	*± 4.0628*	*-0.2855*	*± 4.4368*

TABLE 39 – Maximum Hip Abduction Angle (deg) + * **

	WOMEN		MEN		TOTAL	
Ball Sports	20.7457	± 11.3266	28.0648	± 4.1588	24.4052	± 9.0342
Non-Ball Sports	23.6124	± 8.7127	27.2461	± 8.3730	25.5249	± 8.5010
Right Preplanned	*22.3582*	*± 9.6933*	*27.5832*	*± 6.7892*	*25.0499*	*± 8.6094*
Ball Sports	21.2428	± 10.8215	29.1916	± 6.3587	25.2172	± 9.4721
Non-Ball Sports	22.9274	± 9.0625	28.8855	± 9.3152	26.0633	± 9.4462
Right Planned	*22.1904*	*± 9.5598*	*29.0116*	*± 7.9997*	*25.7043*	*± 9.3178*
Ball Sports	21.7994	± 10.7632	30.3734	± 7.3158	26.0864	± 9.8975
Non-Ball Sports	25.2731	± 9.8447	29.2940	± 10.0875	27.3894	± 9.9100
Right Unplanned	*23.7534*	*± 10.0596*	*29.7384*	*± 8.8096*	*26.8366*	*± 9.7707*
Ball Sports	21.3845	± 5.3387	27.4054	± 5.3946	24.3950	± 6.0288
Non-Ball Sports	23.6865	± 6.6131	27.5105	± 9.8457	25.6991	± 8.4708
Left Preplanned	*22.6794*	*± 6.0097*	*27.4672*	*± 8.0897*	*25.1459*	*± 7.4536*
Ball Sports	19.8584	± 4.7333	27.6968	± 4.7978	23.7776	± 6.1242
Non-Ball Sports	23.9441	± 7.0606	28.5883	± 8.2864	26.3885	± 7.8844
Left Planned	*22.1566*	*± 6.3191*	*28.2212*	*± 6.8891*	*25.2808*	*± 7.2057*
Ball Sports	19.2222	± 4.1264	27.0678	± 7.9986	23.1450	± 7.3457
Non-Ball Sports	24.6967	± 7.5888	29.0434	± 7.1905	26.9845	± 7.5113
Left Unplanned	*22.3016*	*± 6.7374*	*28.2299*	*± 7.3539*	*25.3556*	*± 7.5743*
Ball Sports	5.4953	± 3.9133	8.1616	± 3.5123	6.7259	± 3.8355
Non-Ball Sports	6.5770	± 4.6589	9.0898	± 3.8117	7.8334	± 4.3120
Straight-Ahead	*6.0722*	*± 4.2105*	*8.6920*	*± 3.5770*	*7.3369*	*± 4.0718*

TABLE 40 – Hip Adduction/Abduction ROM (deg) *

	WOMEN		MEN		TOTAL	
Ball Sports	10.7447	± 8.7555	12.1676	± 3.8123	11.4562	± 6.5294
Non-Ball Sports	11.6311	± 5.6508	11.2052	± 4.7777	11.4069	± 5.0648
Right Preplanned	*11.2433*	*± 6.9209*	*11.6014*	*± 4.3044*	*11.4278*	*± 5.6347*
Ball Sports	10.5883	± 8.3316	14.7131	± 7.4985	12.6507	± 7.9101
Non-Ball Sports	10.2881	± 5.5558	12.2267	± 3.8835	11.3084	± 4.7168
Right Planned	*10.4194*	*± 6.6522*	*13.2505*	*± 5.5821*	*11.8779*	*± 6.1958*
Ball Sports	11.4423	± 7.7242	13.8912	± 5.0921	12.6668	± 6.4124
Non-Ball Sports	13.0331	± 5.7247	12.3603	± 7.0327	12.6790	± 6.2780
Right Unplanned	*12.3371*	*± 6.4813*	*12.9907*	*± 6.1763*	*12.6738*	*± 6.2350*
Ball Sports	10.7869	± 7.7843	10.7372	± 3.2667	10.7621	± 5.7352
Non-Ball Sports	12.1442	± 5.0689	11.6067	± 3.0068	11.8613	± 4.0020
Left Preplanned	*11.5504*	*± 6.1988*	*11.2487*	*± 3.0466*	*11.3949*	*± 4.7619*
Ball Sports	10.9152	± 6.9571	11.3222	± 4.5401	11.1187	± 5.6478
Non-Ball Sports	11.7284	± 4.6496	12.2451	± 2.3638	12.0004	± 3.5316
Left Planned	*11.3727*	*± 5.5735*	*11.8651*	*± 3.3305*	*11.6263*	*± 4.4911*
Ball Sports	9.9093	± 7.4934	10.3261	± 3.3188	10.1177	± 5.5719
Non-Ball Sports	11.3862	± 4.3067	11.4264	± 4.5278	11.4073	± 4.3005
Left Unplanned	*10.7401*	*± 5.7380*	*10.9733*	*± 3.9967*	*10.8602*	*± 4.8409*
Ball Sports	6.8532	± 2.3792	6.5606	± 1.4074	6.7182	± 1.9180
Non-Ball Sports	7.2529	± 1.9073	7.3916	± 2.3133	7.3223	± 2.0494
Straight-Ahead	*7.0664*	*± 2.0706*	*7.0355*	*± 1.9559*	*7.0515*	*± 1.9799*

TABLE 41 – Peak Hip External Rotation Moment (BW*BH) + * *

	WOMEN		MEN		TOTAL	
Ball Sports	0.0498	± 0.0351	0.0910	± 0.0454	0.0704	± 0.0445
Non-Ball Sports	0.0616	± 0.0411	0.0759	± 0.0449	0.0691	± 0.0426
Right Preplanned	*0.0565*	*± 0.0378*	*0.0821*	*± 0.0444*	*0.0697*	*± 0.0427*
Ball Sports	0.0545	± 0.0468	0.1149	± 0.0523	0.0847	± 0.0571
Non-Ball Sports	0.0603	± 0.0387	0.1035	± 0.0509	0.0830	± 0.0495
Right Planned	*0.0578*	*± 0.0411*	*0.1082*	*± 0.0502*	*0.0838*	*± 0.0520*
Ball Sports	0.0589	± 0.0360	0.0998	± 0.0557	0.0793	± 0.0498
Non-Ball Sports	0.0830	± 0.0512	0.0812	± 0.0488	0.0820	± 0.0485
Right Unplanned	*0.0724*	*± 0.0454*	*0.0888*	*± 0.0509*	*0.0809*	*± 0.0483*
Ball Sports	0.0667	± 0.0398	0.1128	± 0.0519	0.0897	± 0.0505
Non-Ball Sports	0.0874	± 0.0504	0.1164	± 0.0592	0.1026	± 0.0557
Left Preplanned	*0.0783*	*± 0.0458*	*0.1149*	*± 0.0546*	*0.0972*	*± 0.0531*
Ball Sports	0.0557	± 0.0361	0.1206	± 0.0672	0.0882	± 0.0618
Non-Ball Sports	0.0882	± 0.0564	0.0776	± 0.0339	0.0827	± 0.0449
Left Planned	*0.0740*	*± 0.0500*	*0.0953*	*± 0.0530*	*0.0850*	*± 0.0519*
Ball Sports	0.0569	± 0.0392	0.0870	± 0.0547	0.0719	± 0.0483
Non-Ball Sports	0.0907	± 0.0471	0.1006	± 0.0636	0.0959	± 0.0551
Left Unplanned	*0.0759*	*± 0.0458*	*0.0950*	*± 0.0587*	*0.0857*	*± 0.0529*
Ball Sports	0.0484	± 0.0214	0.0481	± 0.0149	0.0483	± 0.0179
Non-Ball Sports	0.0560	± 0.0213	0.0562	± 0.0217	0.0561	± 0.0208
Straight-Ahead	*0.0524*	*± 0.0209*	*0.0528*	*± 0.0189*	*0.0526*	*± 0.0196*

TABLE 42 – Maximum Hip External Rotation Angle (deg) + *

	WOMEN		MEN		TOTAL	
Ball Sports	8.7195	± 6.9385	11.4307	± 2.4819	10.0751	± 5.2002
Non-Ball Sports	7.4963	± 3.1634	11.2405	± 4.4583	9.4669	± 4.2514
Right Preplanned	*8.0315*	*± 4.9987*	*11.3188*	*± 3.6742*	*9.7249*	*± 4.6093*
Ball Sports	8.0820	± 4.8109	10.9861	± 3.3889	9.5340	± 4.2724
Non-Ball Sports	7.8714	± 2.9201	12.9124	± 6.0504	10.5246	± 5.3648
Right Planned	*7.9635*	*± 3.7172*	*12.1192*	*± 5.0846*	*10.1043*	*± 4.8838*
Ball Sports	8.9534	± 6.0027	10.9323	± 3.3247	9.9429	± 4.7735
Non-Ball Sports	8.3077	± 3.2705	12.7089	± 5.6940	10.6241	± 5.1051
Right Unplanned	*8.5902*	*± 4.4975*	*11.9774*	*± 4.8161*	*10.3351*	*± 4.9024*
Ball Sports	8.5102	± 4.0340	9.2106	± 3.1795	8.8604	± 3.5083
Non-Ball Sports	8.5467	± 3.3273	11.2392	± 5.5236	9.9638	± 4.6993
Left Preplanned	*8.5308*	*± 3.5233*	*10.4039*	*± 4.6917*	*9.4957*	*± 4.2106*
Ball Sports	7.5172	± 3.9348	9.7902	± 4.4523	8.6537	± 4.2055
Non-Ball Sports	8.1709	± 4.3402	10.8395	± 4.7098	9.5754	± 4.6192
Left Planned	*7.8849*	*± 4.0437*	*10.4074*	*± 4.4938*	*9.1844*	*± 4.4047*
Ball Sports	7.9248	± 3.3861	10.9067	± 5.6501	9.4158	± 4.7350
Non-Ball Sports	7.7285	± 2.5729	10.0137	± 4.3008	8.9313	± 3.6830
Left Unplanned	*7.8144*	*± 2.8508*	*10.3814*	*± 4.752*	*9.1368*	*± 4.0984*
Ball Sports	3.2637	± 0.9965	6.2975	± 3.0533	4.6639	± 2.6190
Non-Ball Sports	4.0832	± 1.5524	7.2091	± 1.9357	5.6462	± 2.3407
Straight-Ahead	*3.7008*	*± 1.3452*	*6.8184*	*± 2.4130*	*5.2058*	*± 2.4742*

TABLE 43 – Maximum Hip Internal Rotation Angle (deg)

	WOMEN	MEN	TOTAL
Ball Sports	1.3221 ± 1.5765	1.7690 ± 0.9161	1.5456 ± 1.2602
Non-Ball Sports	1.4164 ± 1.0611	1.4096 ± 2.4542	1.4128 ± 1.874
Right Preplanned	*1.3751 ± 1.2637*	*1.5576 ± 1.9329*	*1.4691 ± 1.6202*
Ball Sports	2.2453 ± 1.4962	1.9395 ± 1.4817	2.0924 ± 1.4393
Non-Ball Sports	1.2674 ± 0.6474	1.4470 ± 2.2204	1.3619 ± 1.6309
Right Planned	*1.6953 ± 1.1704*	*1.6498 ± 1.9128*	*1.6718 ± 1.5723*
Ball Sports	1.3136 ± 1.8143	2.2633 ± 0.8784	1.7884 ± 1.4554
Non-Ball Sports	1.3699 ± 1.1757	1.2756 ± 2.8895	1.3203 ± 2.1889
Right Unplanned	*1.3453 ± 1.4335*	*1.6823 ± 2.2884*	*1.5189 ± 1.9002*
Ball Sports	1.5258 ± 0.8386	1.6924 ± 0.6128	1.6091 ± 0.7109
Non-Ball Sports	1.1961 ± 0.5967	1.8309 ± 1.7823	1.5302 ± 1.3611
Left Preplanned	*1.3403 ± 0.7069*	*1.7739 ± 1.3902*	*1.5637 ± 1.1176*
Ball Sports	0.9668 ± 0.9597	2.0947 ± 0.9327	1.5308 ± 1.0812
Non-Ball Sports	1.1946 ± 1.1115	1.6344 ± 1.4882	1.4261 ± 1.3067
Left Planned	*1.0949 ± 1.0203*	*1.8239 ± 1.2753*	*1.4705 ± 1.1992*
Ball Sports	1.0900 ± 0.9026	1.5549 ± 0.5769	1.3225 ± 0.7667
Non-Ball Sports	1.4075 ± 0.8796	1.6801 ± 2.2828	1.5510 ± 1.7231
Left Unplanned	*1.2686 ± 0.8746*	*1.6285 ± 1.7493*	*1.4540 ± 1.3864*
Ball Sports	1.2258 ± 0.9726	1.4639 ± 1.3806	1.3357 ± 1.1324
Non-Ball Sports	1.1489 ± 0.6517	1.1804 ± 0.4541	1.1646 ± 0.5429
Straight-Ahead	*1.1848 ± 0.7870*	*1.3019 ± 0.9302*	*1.2413 ± 0.8456*

TABLE 44 – Hip External/Internal Rotation ROM (deg) + *

	WOMEN	MEN	TOTAL
Ball Sports	10.0416 ± 5.5898	13.1997 ± 2.7587	11.6206 ± 4.5408
Non-Ball Sports	8.9127 ± 2.9961	12.6501 ± 6.2582	10.8798 ± 5.2200
Right Preplanned	*9.4066 ± 4.1976*	*12.8764 ± 4.9962*	*11.1941 ± 4.8828*
Ball Sports	10.3273 ± 4.1265	12.9256 ± 4.2144	11.6264 ± 4.2278
Non-Ball Sports	9.1389 ± 3.0063	14.3594 ± 7.3020	11.8865 ± 6.1521
Right Planned	*9.6588 ± 3.4644*	*13.7690 ± 6.0977*	*11.7762 ± 5.3449*
Ball Sports	10.2671 ± 4.5675	13.1956 ± 4.1491	11.7313 ± 4.4590
Non-Ball Sports	9.6776 ± 3.2909	13.9845 ± 7.4895	11.9444 ± 6.1433
Right Unplanned	*9.9355 ± 3.7699*	*13.6596 ± 6.178*	*11.8540 ± 5.4146*
Ball Sports	10.0360 ± 3.8319	10.9031 ± 3.3580	10.4696 ± 3.4905
Non-Ball Sports	9.7428 ± 3.0901	13.0701 ± 6.6301	11.4940 ± 5.3978
Left Preplanned	*9.8711 ± 3.3149*	*12.1778 ± 5.4921*	*11.0594 ± 4.6479*
Ball Sports	8.4840 ± 3.4036	11.8849 ± 4.1632	10.1845 ± 4.0571
Non-Ball Sports	9.3655 ± 4.042	12.4738 ± 5.5672	11.0015 ± 5.0300
Left Planned	*8.9798 ± 3.6812*	*12.2314 ± 4.9013*	*10.6549 ± 4.5920*
Ball Sports	9.0148 ± 2.7463	12.4616 ± 5.7622	10.7382 ± 4.6909
Non-Ball Sports	9.1360 ± 2.5858	11.6938 ± 5.7953	10.4822 ± 4.6353
Left Unplanned	*9.0830 ± 2.5665*	*12.0100 ± 5.6120*	*10.5908 ± 4.5871*
Ball Sports	4.4895 ± 1.2192	7.7614 ± 2.2773	5.9996 ± 2.4054
Non-Ball Sports	5.2321 ± 1.6234	8.3895 ± 2.1615	6.8108 ± 2.4634
Straight-Ahead	*4.8856 ± 1.4498*	*8.1203 ± 2.1481*	*6.4471 ± 2.4289*

TABLE 45 – Maximum Left Trunk Angle (deg) ** ***

	WOMEN		MEN		TOTAL	
Ball Sports	25.6241	± 6.2283	23.5282	± 4.5169	24.5761	± 5.3389
Non-Ball Sports	21.7294	± 4.0126	22.5052	± 5.3651	22.1604	± 4.6931
Right Preplanned	*23.5469*	*± 5.3592*	*22.9264*	*± 4.9103*	*23.2173*	*± 5.0511*
Ball Sports	23.3718	± 6.1484	22.0714	± 4.5131	22.7216	± 5.2253
Non-Ball Sports	21.4204	± 5.2781	22.5043	± 5.2684	22.0226	± 5.1452
Right Planned	*22.3311*	*± 5.5809*	*22.3261*	*± 4.8269*	*22.3284*	*± 5.1080*
Ball Sports	24.4192	± 5.1606	19.0211	± 5.8702	21.7202	± 6.0034
Non-Ball Sports	18.7329	± 5.6402	19.5724	± 6.5805	19.1993	± 6.0174
Right Unplanned	*21.3865*	*± 5.9951*	*19.3454*	*± 6.1122*	*20.3022*	*± 6.0485*
Ball Sports	19.9924	± 5.5728	17.4978	± 4.4491	18.7451	± 5.0145
Non-Ball Sports	21.8739	± 3.1204	22.6703	± 5.2906	22.2931	± 4.2999
Left Preplanned	*21.0507*	*± 4.3063*	*20.5405*	*± 5.4820*	*20.7879*	*± 4.8771*
Ball Sports	17.5737	± 5.3996	17.4389	± 4.7717	17.5063	± 4.8959
Non-Ball Sports	20.3854	± 2.8440	22.1645	± 6.1239	21.3218	± 4.8144
Left Planned	*19.1553*	*± 4.2487*	*20.2186*	*± 5.9481*	*19.7031*	*± 5.1423*
Ball Sports	20.1306	± 5.7711	21.4431	± 7.1693	20.7868	± 6.2895
Non-Ball Sports	22.6183	± 3.3851	22.3043	± 5.5237	22.4530	± 4.5138
Left Unplanned	*21.5299*	*± 4.5889*	*21.9497*	*± 6.0521*	*21.7462*	*± 5.3132*
Ball Sports	20.5959	± 2.7071	17.8358	± 2.5880	19.3220	± 2.9165
Non-Ball Sports	22.1197	± 2.5873	22.1107	± 2.7662	22.1149	± 2.5874
Straight-Ahead	*21.3578*	*± 2.6640*	*20.2786*	*± 3.3935*	*20.8182*	*± 3.0437*

TABLE 46 – Maximum Right Trunk Angle (deg) ** ***

	WOMEN		MEN		TOTAL	
Ball Sports	20.0082	± 7.6759	16.5333	± 2.9603	18.2708	± 5.8727
Non-Ball Sports	13.8804	± 5.8320	15.6336	± 5.4777	14.8544	± 5.5402
Right Preplanned	*16.7400*	*± 7.2299*	*16.0041*	*± 4.5136*	*16.3491*	*± 5.8532*
Ball Sports	17.1416	± 6.6718	14.9057	± 4.3548	16.0236	± 5.5357
Non-Ball Sports	12.0220	± 7.1301	14.8561	± 6.5590	13.5965	± 6.7682
Right Planned	*14.4111*	*± 7.1754*	*14.8765*	*± 5.5957*	*14.6584*	*± 6.2824*
Ball Sports	17.2413	± 6.9060	13.6300	± 3.9997	15.4357	± 5.7365
Non-Ball Sports	10.5442	± 8.0258	12.8000	± 6.3516	11.7974	± 7.0151
Right Unplanned	*13.6695*	*± 8.0378*	*13.1418*	*± 5.3730*	*13.3892*	*± 6.6445*
Ball Sports	13.1672	± 5.8174	10.5099	± 3.8546	11.8385	± 4.9374
Non-Ball Sports	15.7411	± 3.1792	14.5228	± 5.9676	15.0999	± 4.7633
Left Preplanned	*14.6150*	*± 4.5460*	*12.8704*	*± 5.4542*	*13.7163*	*± 5.0344*
Ball Sports	12.2928	± 7.0156	10.9774	± 2.2750	11.6351	± 5.0567
Non-Ball Sports	14.4626	± 3.9412	14.6584	± 6.1519	14.5657	± 5.0830
Left Planned	*13.5133*	*± 5.4044*	*13.1427*	*± 5.1688*	*13.3224*	*± 5.2043*
Ball Sports	13.2567	± 6.4375	14.2846	± 5.1773	13.7707	± 5.6376
Non-Ball Sports	16.7009	± 3.751	16.0117	± 6.8279	16.3382	± 5.4487
Left Unplanned	*15.1941*	*± 5.2148*	*15.3006*	*± 6.0863*	*15.2489*	*± 5.5921*
Ball Sports	15.4000	± 3.8381	12.8663	± 2.7858	14.2306	± 3.5110
Non-Ball Sports	14.5882	± 3.5446	16.5405	± 3.1003	15.6294	± 3.3477
Straight-Ahead	*14.9941*	*± 3.5742*	*14.9658*	*± 3.4236*	*14.9800*	*± 3.4343*

TABLE 47 – Percentage of Stance Phase for Maximum Trunk Angle (%) * ***

	WOMEN	MEN	TOTAL
Ball Sports	33.3324 ± 37.8368	14.5733 ± 14.8528	23.9529 ± 29.2799
Non-Ball Sports	14.0727 ± 16.0866	14.4321 ± 17.6458	14.2723 ± 16.4753
Right Preplanned	*23.0605 ± 29.0148*	*14.4902 ± 16.0586*	*18.5076 ± 23.0689*
Ball Sports	16.9327 ± 23.7432	28.8842 ± 35.5273	22.9084 ± 29.6849
Non-Ball Sports	0.6565 ± 0.9451	34.2948 ± 31.3598	19.3445 ± 28.5803
Right Planned	*8.2521 ± 17.6831*	*32.0669 ± 32.1564*	*20.9037 ± 28.6479*
Ball Sports	7.4277 ± 12.2010	28.8832 ± 33.5478	18.1555 ± 26.6849
Non-Ball Sports	9.8586 ± 12.6317	35.6981 ± 34.4206	24.2139 ± 29.4533
Right Unplanned	*8.7242 ± 12.0480*	*32.8920 ± 33.1728*	*21.5633 ± 27.9940*
Ball Sports	70.4619 ± 15.9232	72.9380 ± 16.0343	71.6999 ± 15.4056
Non-Ball Sports	74.0966 ± 14.9599	78.0270 ± 21.4224	76.1652 ± 18.2481
Left Preplanned	*72.5064 ± 14.9749*	*75.9315 ± 19.0058*	*74.2709 ± 16.9926*
Ball Sports	59.7644 ± 26.7471	68.1814 ± 15.8912	63.9729 ± 21.5827
Non-Ball Sports	77.7687 ± 18.8779	72.1557 ± 25.1684	74.8145 ± 21.9865
Left Planned	*69.8918 ± 23.6922*	*70.5192 ± 21.3326*	*70.2150 ± 22.1531*
Ball Sports	78.5403 ± 22.6479	71.1458 ± 19.0852	74.8431 ± 20.4834
Non-Ball Sports	77.2186 ± 16.3809	57.3670 ± 28.5816	66.7704 ± 25.1281
Left Unplanned	*77.7969 ± 18.6746*	*63.0407 ± 25.3961*	*70.1952 ± 23.2818*
Ball Sports	56.2336 ± 33.4484	16.4788 ± 34.7882	37.8852 ± 38.5896
Non-Ball Sports	29.0052 ± 36.8901	68.4517 ± 25.8839	50.0433 ± 36.5125
Straight-Ahead	*42.6194 ± 36.6615*	*46.1776 ± 39.2253*	*44.3985 ± 37.2994*

TABLE 48 – Percentage of Stance Phase for Minimum Trunk Angle (%) * ***

	WOMEN	MEN	TOTAL
Ball Sports	66.6045 ± 29.8846	74.9534 ± 18.9993	70.7790 ± 24.4451
Non-Ball Sports	72.1235 ± 9.6159	67.8715 ± 13.3913	69.7613 ± 11.7362
Right Preplanned	*69.5480 ± 20.9071*	*70.7876 ± 15.7843*	*70.2065 ± 18.0662*
Ball Sports	71.0046 ± 24.4078	65.7723 ± 17.9221	68.3884 ± 20.7503
Non-Ball Sports	74.3997 ± 11.6791	50.2356 ± 16.9901	60.9752 ± 19.0169
Right Planned	*72.8153 ± 18.0719*	*56.6330 ± 18.5727*	*64.2185 ± 19.8203*
Ball Sports	70.1637 ± 21.5654	60.8225 ± 22.4401	65.4931 ± 21.6922
Non-Ball Sports	74.4266 ± 15.0178	60.1498 ± 20.1643	66.4950 ± 19.0109
Right Unplanned	*72.4373 ± 17.8025*	*60.4268 ± 20.4368*	*66.0567 ± 19.8942*
Ball Sports	15.9338 ± 18.4509	20.1924 ± 19.4093	18.0631 ± 18.3270
Non-Ball Sports	17.7902 ± 21.1156	10.0981 ± 21.5184	13.7417 ± 21.1010
Left Preplanned	*16.9780 ± 19.3617*	*14.2546 ± 20.687*	*15.5750 ± 19.7891*
Ball Sports	37.5160 ± 28.5262	22.2011 ± 16.7995	29.8586 ± 23.8533
Non-Ball Sports	14.7736 ± 22.0852	23.0781 ± 32.7023	19.1444 ± 27.7426
Left Planned	*24.7234 ± 26.8590*	*22.7170 ± 26.6006*	*23.6898 ± 26.3247*
Ball Sports	24.5396 ± 17.8835	12.3616 ± 13.6853	18.4506 ± 16.5523
Non-Ball Sports	17.8869 ± 15.2288	39.8707 ± 33.9194	29.4573 ± 28.3817
Left Unplanned	*20.7975 ± 16.2245*	*28.5434 ± 30.2019*	*24.7878 ± 24.3911*
Ball Sports	37.6957 ± 35.6604	52.2899 ± 32.7510	44.4315 ± 33.7654
Non-Ball Sports	49.8631 ± 34.9991	4.2594 ± 12.0474	25.5411 ± 33.9430
Straight-Ahead	*43.7794 ± 34.5273*	*24.8439 ± 33.1530*	*34.3117 ± 34.5855*

TABLE 49 – Peak Vertical Ground Reaction Force (N) + *

	WOMEN		MEN		TOTAL	
Ball Sports	1455.80	± 140.0048	2024.33	± 604.0198	1740.07	± 514.2529
Non-Ball Sports	1577.22	± 317.8333	1887.03	± 492.6811	1740.28	± 437.6333
Right Preplanned	*1524.10*	*± 256.0992*	*1943.57*	*± 527.4508*	*1740.19*	*± 463.8609*
Ball Sports	1507.29	± 186.8873	1808.13	± 484.1805	1657.71	± 385.5967
Non-Ball Sports	1597.43	± 292.6879	1996.39	± 325.2771	1807.41	± 364.5037
Right Planned	*1557.99*	*± 248.5804*	*1918.87*	*± 395.6619*	*1743.90*	*± 375.2114*
Ball Sports	1481.55	± 224.5570	1843.55	± 448.2537	1662.55	± 388.9626
Non-Ball Sports	1710.32	± 341.1725	2059.54	± 486.5800	1894.12	± 449.6730
Right Unplanned	*1610.23*	*± 309.8191*	*1970.60*	*± 469.6092*	*1795.88*	*± 434.4087*
Ball Sports	1665.05	± 244.4682	1827.16	± 338.8710	1746.11	± 296.0720
Non-Ball Sports	1563.97	± 159.4009	1957.27	± 514.5446	1770.97	± 429.3929
Left Preplanned	*1608.19*	*± 200.3483*	*1903.70*	*± 443.1081*	*1760.42*	*± 373.4699*
Ball Sports	1669.30	± 280.8942	1925.11	± 587.9395	1797.21	± 462.1424
Non-Ball Sports	1535.31	± 275.4635	2012.84	± 507.1018	1786.64	± 471.4970
Left Planned	*1593.93*	*± 277.0253*	*1976.71*	*± 525.6006*	*1791.12*	*± 460.2632*
Ball Sports	1605.50	± 337.9955	2019.69	± 717.3859	1812.59	± 580.0357
Non-Ball Sports	1575.72	± 169.6766	2058.32	± 445.1130	1829.72	± 416.1095
Left Unplanned	*1588.75*	*± 247.5556*	*2042.41*	*± 552.1057*	*1822.45*	*± 483.8889*
Ball Sports	1507.97	± 216.3994	1593.00	± 258.3402	1547.22	± 230.5847
Non-Ball Sports	1465.64	± 268.6811	1703.54	± 359.8633	1584.59	± 330.4762
Straight-Ahead	*1485.40*	*± 237.9957*	*1656.17*	*± 314.0431*	*1567.84*	*± 285.7489*

TABLE 50 – Peak Ground Reaction Force (as % of BW) *

	WOMEN		MEN		TOTAL	
Ball Sports	2.4667	± 0.2124	2.8855	± 0.6141	2.6761	± 0.4921
Non-Ball Sports	2.5911	± 0.2278	2.6400	± 0.5948	2.6168	± 0.4479
Right Preplanned	*2.5367*	*± 0.2231*	*2.7411*	*± 0.5966*	*2.6420*	*± 0.4605*
Ball Sports	2.4875	± 0.2408	2.5315	± 0.5018	2.5095	± 0.3788
Non-Ball Sports	2.5695	± 0.2172	2.7648	± 0.3388	2.6723	± 0.2973
Right Planned	*2.5336*	*± 0.2238*	*2.6687*	*± 0.4159*	*2.6032*	*± 0.3387*
Ball Sports	2.4607	± 0.2890	2.5226	± 0.4752	2.4917	± 0.3792
Non-Ball Sports	2.7983	± 0.5258	2.8443	± 0.5565	2.8225	± 0.5276
Right Unplanned	*2.6506*	*± 0.4591*	*2.7118*	*± 0.5343*	*2.6821*	*± 0.4925*
Ball Sports	2.7408	± 0.3766	2.6767	± 0.2619	2.7087	± 0.3134
Non-Ball Sports	2.6018	± 0.3067	2.6423	± 0.4783	2.6231	± 0.3958
Left Preplanned	*2.6626*	*± 0.3346*	*2.6565*	*± 0.3934*	*2.6595*	*± 0.3604*
Ball Sports	2.7588	± 0.3984	2.7093	± 0.4445	2.7341	± 0.4063
Non-Ball Sports	2.5643	± 0.3958	2.7266	± 0.4782	2.6497	± 0.4369
Left Planned	*2.6494*	*± 0.3962*	*2.7195*	*± 0.4503*	*2.6855*	*± 0.4198*
Ball Sports	2.6703	± 0.5372	2.7386	± 0.4860	2.7044	± 0.4934
Non-Ball Sports	2.5394	± 0.5072	2.8324	± 0.3091	2.6936	± 0.4297
Left Unplanned	*2.5967*	*± 0.5070*	*2.7938*	*± 0.3802*	*2.6982*	*± 0.4503*
Ball Sports	2.5028	± 0.3250	2.5458	± 0.1244	2.5227	± 0.2445
Non-Ball Sports	2.4059	± 0.2005	2.3020	± 0.2466	2.3540	± 0.2237
Straight-Ahead	*2.4511*	*± 0.2605*	*2.4065*	*± 0.2332*	*2.4296*	*± 0.2443*

TABLE 51 – Maximum Activation of Hamstrings (MVC)

	WOMEN	MEN	TOTAL
Ball Sports	1.6862 ± 2.8354	0.4186 ± 0.2609	1.0524 ± 2.0432
Non-Ball Sports	0.5786 ± 0.3097	0.9260 ± 0.9201	0.7716 ± 0.7206
Right Preplanned	*1.0955 ± 1.9546*	*0.7171 ± 0.7536*	*0.8945 ± 1.4337*
Ball Sports	0.6349 ± 0.3927	0.2297 ± 0.1647	0.4323 ± 0.3576
Non-Ball Sports	0.5276 ± 0.3330	0.7593 ± 1.1194	0.6564 ± 0.8504
Right Planned	*0.5777 ± 0.3530*	*0.5413 ± 0.8873*	*0.5583 ± 0.6804*
Ball Sports	0.9142 ± 0.6811	0.5059 ± 0.3482	0.7100 ± 0.5612
Non-Ball Sports	0.8072 ± 0.4967	1.7902 ± 3.7120	1.3533 ± 2.7657
Right Unplanned	*0.8571 ± 0.5703*	*1.2614 ± 2.8671*	*1.0719 ± 2.1052*
Ball Sports	2.0868 ± 4.1331	0.5100 ± 0.6470	1.2984 ± 2.9575
Non-Ball Sports	0.5595 ± 0.2743	0.9420 ± 1.3194	0.7609 ± 0.9707
Left Preplanned	*1.2277 ± 2.7359*	*0.7641 ± 1.0882*	*0.9889 ± 2.0387*
Ball Sports	0.6345 ± 0.3649	0.4540 ± 0.6630	0.5443 ± 0.5226
Non-Ball Sports	0.6281 ± 0.3760	0.7701 ± 0.7357	0.7028 ± 0.5820
Left Planned	*0.6309 ± 0.3587*	*0.6399 ± 0.7035*	*0.6355 ± 0.5548*
Ball Sports	0.6119 ± 0.3601	0.6690 ± 0.7103	0.6404 ± 0.5418
Non-Ball Sports	1.0943 ± 1.3492	0.9352 ± 0.9184	1.0106 ± 1.1124
Left Unplanned	*0.8833 ± 1.0411*	*0.8256 ± 0.8258*	*0.8536 ± 0.9219*
Ball Sports	0.5725 ± 0.3593	0.5998 ± 0.4457	0.5851 ± 0.3841
Non-Ball Sports	0.3943 ± 0.1653	0.6788 ± 0.9472	0.5460 ± 0.6942
Straight-Ahead	*0.4834 ± 0.2842*	*0.6450 ± 0.7491*	*0.5642 ± 0.5620*

TABLE 52 – Maximum Activation of Quadriceps (MVC) ***

	WOMEN	MEN	TOTAL
Ball Sports	0.9042 ± 1.7267	0.1977 ± 0.1267	0.5509 ± 1.2320
Non-Ball Sports	0.3597 ± 0.0998	0.7535 ± 1.7440	0.5785 ± 1.2864
Right Preplanned	*0.6138 ± 1.1670*	*0.5246 ± 1.3403*	*0.5664 ± 1.2427*
Ball Sports	0.2133 ± 0.1276	0.4632 ± 0.2442	0.3383 ± 0.2277
Non-Ball Sports	0.3257 ± 0.1466	0.9524 ± 1.1335	0.6739 ± 0.8898
Right Planned	*0.2733 ± 0.1452*	*0.7510 ± 0.8982*	*0.5271 ± 0.6961*
Ball Sports	0.6166 ± 1.1194	0.3481 ± 0.1678	0.4823 ± 0.7815
Non-Ball Sports	0.5425 ± 0.6506	0.9178 ± 2.1592	0.7510 ± 1.6368
Right Unplanned	*0.5770 ± 0.8661*	*0.6832 ± 1.6482*	*0.6334 ± 1.3205*
Ball Sports	1.2846 ± 2.3045	0.3623 ± 0.3911	0.8235 ± 1.6586
Non-Ball Sports	0.3018 ± 0.1720	0.8320 ± 1.5320	0.5809 ± 1.1228
Left Preplanned	*0.7318 ± 1.5472*	*0.6386 ± 1.1977*	*0.6838 ± 1.3570*
Ball Sports	0.6338 ± 0.3616	0.5900 ± 0.7025	0.6119 ± 0.5373
Non-Ball Sports	0.3987 ± 0.1812	0.5965 ± 0.9481	0.5028 ± 0.6887
Left Planned	*0.5016 ± 0.2904*	*0.5938 ± 0.8311*	*0.5491 ± 0.6221*
Ball Sports	0.4986 ± 0.3546	0.3303 ± 0.2009	0.4145 ± 0.2903
Non-Ball Sports	1.1132 ± 2.2237	0.8141 ± 1.7061	0.9558 ± 1.9175
Left Unplanned	*0.8443 ± 1.6693*	*0.6149 ± 1.30871*	*0.7261 ± 1.4752*
Ball Sports	0.2661 ± 0.1539	0.2766 ± 0.3294	0.2710 ± 0.2389
Non-Ball Sports	0.2266 ± 0.1230	0.4420 ± 0.7839	0.3415 ± 0.5710
Straight-Ahead	*0.2464 ± 0.1354*	*0.3711 ± 0.6163*	*0.3087 ± 0.4424*

*Main Effect for Cutting Maneuver
** Main Effect for Timing Condition
*** Main Effect for Leg Dominance
+Main Effect for Gender
• Main Effect for Sport

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