

**The Effect of Leg Dominance on Lower Limb Kinematics During a 180° Pivot Maneuver in
Healthy Female Soccer Players at Three Different Stages of Physical Maturation**

by

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Abstract

The purpose of this study was to evaluate the effect of leg dominance on lower limb kinematics during a 180° pivot maneuver in healthy female soccer players at three different stages of maturation: pre-pubertal, pubertal, and post-pubertal. Twenty-seven athletes of four female soccer teams (Under 10, 12, 14, and 18 year old teams) were recruited from the Lakehead Express Soccer Club in Thunder Bay, Ontario, Canada. The modified Pubertal Maturation Observation Scale (PMOS) was used to classify nine participants into each maturational group: pre-pubertal (10.3 ± 1.1 years), pubertal (12 ± 1.4 years), or post-pubertal (14.8 ± 2.0 years). Testing involved the completion of a short maximal effort sprint coupled with a pivoting turn. This included a 3.5 m acceleration starting from a stationary position, immediately followed by a 180° pivot maneuver with either their dominant or non-dominant leg, and another 3.5 m acceleration towards and through the starting position. Trials were recorded using two Basler high-speed digital video cameras and timed using a wireless timing gate system. The angles of knee flexion, hip flexion, thigh and shank rotations, and hip abduction/adduction were evaluated at initial contact (IC), maximum knee flexion (MKF), and toe-off (TO) during the 180° pivot maneuver. To assess the interaction effects for each of the dependent variables, 2 (leg dominance) x 3 (maturation stage) x 3 (instants) factorial ANOVAs were used. Two significant interaction effects were observed between the post-pubertal and the pubertal groups for shank rotation angle. The post-pubertal group had a greater shank internal rotation angle with the non-dominant leg at both MKF and TO. In addition, there were significant main effects for knee and hip flexion angles, hip adduction/abduction angle, and thigh and shank rotation angles among instants. Although not statistically significant, there were noteworthy, practically important trends observed in the data. The dominant leg had smaller knee flexion angles at each event

within each group, smaller hip flexion angles within the post-pubertal group at IC and MKF and within the pubertal group, as well as larger adduction angles at MKF and TO within each group. Furthermore, the post-pubertal group had the largest peak hip abduction angles and hip flexion angles at IC when isolating on the dominant leg. The results of this study suggest that post-pubertal females pivoting with their dominant leg perform kinematic patterns that may lead to a greater risk for an ACL injury during a 180° pivot maneuver as compared to less mature players on the non-dominant leg. The use of the FIFA 11+ Warm-up Manual Part 1: Running Exercises by all participants in this study may have implications for the training of female soccer players, as statistically significant maturational differences were not observed.

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The Effect of Leg Dominance on Lower Limb Kinematics During a 180° Pivot Maneuver in Healthy Female Soccer Players at Three Different Stages of Physical Maturation

Soccer

European football (called soccer in North America) is the world's most popular sport, with 265 million people playing worldwide (Football worldwide, 2007). According to the Fédération Internationale de Football Association (FIFA), the distribution of these players can be broken down as 90% males and 10% females (Football worldwide, 2007). Regardless of the male dominance in participation, female soccer has 4.1 million women playing, constituting a 54% increase since the last official count in 2000 (Football worldwide, 2007). The objective of the game is to score more goals on the opposing team's net with a ball that is made of leather or other suitable material, and has a pressure equal 0.6 – 1.1 atmospheres (Football worldwide, 2007). The whole ball must completely cross over the goal line to count as a goal (Football worldwide, 2007). Based on the team's strategy to win, teams may have different positional shape combinations composed of defenders (central defenders and fullbacks), midfielders (centers and wingers), and attackers (Mohr, Krustup, & Bandsbo, 2003). The nature of soccer in all playing positions demands frequent cyclical high and low exercise intensities and tactical skills in order to succeed in the game.

Physical demands. Time motion analysis can be used to analyze player performances during competitive play in many different sports (Ben Abdelkrim, El Fazaa, & El Ati, 2007; Sheppard, Gabbett, & Reeberg Stanganelli, 2009). Specifically in soccer, video tracking positions the cameras at a height of about 15 m and at a distance of 30-40 m from the touchline in order to track player movements (Mohr, Krustup, & Bandsbo 2003; Mohr, Krustup, Andersson, Kirkendal, & Bandsbo, 2008). This technique has allowed researchers to examine the

physical and tactical performance characteristics that are essential to success in the sport. Mohr et al. (2003) assessed physical fitness and the effect of fatigue through the time motion analysis technique in 129 match performances in 18 top-class male soccer players (playing for a professional European team) and 24 moderate professional male soccer players (playing in the top Danish league and ranked higher than 20th on the official FIFA list). These athletes were found to cover an average total distance of 10.86 ± 0.18 km per one 90-minute game (Mohr et al., 2003). Mohr, Krstrup, Andersson, Kirkendal, and Bangsbo (2008) subsequently examined the physical demands and match performances of elite women soccer players. When comparing the total distance covered between females and males, Mohr et al. (2008) determined that the difference was insignificant (10.33 ± 0.15 vs. 10.86 ± 0.18 km, respectively). Bangsbo (1994) proposed that the total distance covered in a soccer match could be categorized into four locomotor categories: standing, walking, low-intensity running (encompassing jogging, low-speed running, and backward running), and high-intensity running (consisting of moderate-speed running, high-speed running, and sprinting). Sprinting is characterized as a maximal effort high-intensity run over a short distance (runs higher than 61% of their peak velocity) (Buchheit & Mendez-Villanueva, 2014; Mohr et al., 2003). Mohr et al. (2003) observed that players sprint 39 ± 2 times (Mohr et al., 2003) in a 90-minute game, which suggests that they perform a maximal effort sprint approximately every 2.3 minutes ($90 \text{ minutes} / 39 \text{ sprints} = 2.3 \text{ minutes/sprint}$).

Randers, Anderson, Rasmussen, Larsen, and Krstrup (2014) evaluated total traveling distance in 86 youth soccer players from 16 different Danish football club teams competing in various 20-minute games. Forty-five players under 10 years of age (8-9 year olds) playing 5 on 5 and 8 on 8 games were identified as traveling a total distance of 1.75 ± 0.24 and 1.77 ± 0.31 km, respectively. Forty-one under 13 years of age (11-12 year olds) playing 20-minute 8 on 8 games

and 11 on 11 games, were observed to cover a total distance of 1.82 ± 0.32 and 2.04 ± 0.33 km, respectively. In a 90-minute respective comparison, U10 players would travel an approximate distance of 7.9 – 8.0 km per game ($90 \text{ min.} / 20 \text{ min.} = 4.5$) ($4.5 \times 1.75 \text{ km} = 7.87 \text{ km}$) and ($4.5 \times 1.77 \text{ km} = 7.97 \text{ km}$), while U13 players would travel approximately 8.2 – 9.1 km per game ($4.5 \times 1.82 \text{ km} = 8.19 \text{ km}$) and ($4.5 \times 2.03 = 9.13 \text{ km}$). In the mathematical comparison, younger elite athletes would perform relatively similar total distances per match. It is difficult to directly compare the physical demands of youth soccer matches as the games are usually played on smaller sized fields (Rampinini et al., 2007).

Buchheit, Mendez-villanueva, Simpson, and Bourdon (2010) evaluated 99 national soccer players on six different teams: U13, U14, U15, U16, U17, and U18 during 42 international games. A global positioning system (GPS) was used to evaluate the players' repeated-sprint sequences (RSS). Repeated-sprint sequences were defined as a minimum of two consecutive sprints with a maximum of a 60 second rest interval in-between. Statistically significant findings determined that the younger teams performed more RSS than the older teams in sequential ascending order; with the exception of U18 being greater than the U17. This study did not evaluate the running velocities per age group, so, even though the younger players may have performed more RSS and longer sprints per sequence, the running velocity rate was not clearly defined. Buchheit et al. (2010) stated that even though there are large differences in the physical demands between age groups, technically there are minimal differences in their activity profiles. Reilly, Williams, Nevill, and Franks (2000) suggested that the most crucial moments in soccer involve these high-speed, RSS anaerobic activities. High-speed anaerobic activity directly contributes to which team will win or lose the match (Reilly et al., 2000). This suggests that it is important for players to be able to repeatedly perform high-speed running activities in order to

win more matches (Luhtanen, 1994).

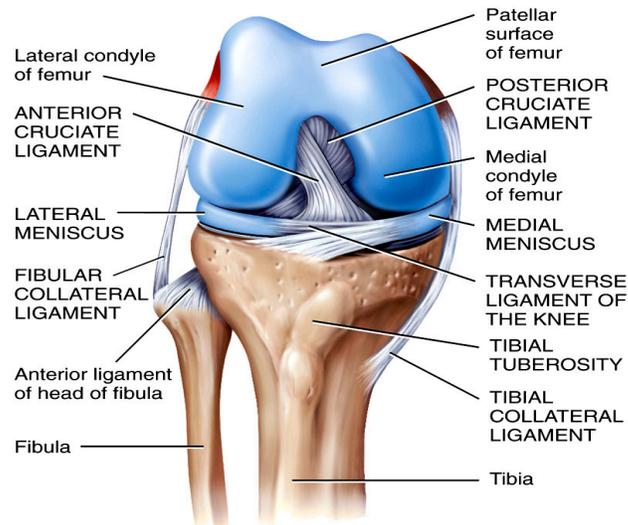
Technical skills. Although anaerobic and aerobic fitness are important physical characteristics of players, soccer is characterized by many motor skills including heading, tackling, kicking, jumping, accelerating, and decelerating runs, and turning (Kaplan, Erkmén, & Taskin, 2009). According to Verheijen (1998), a professional soccer player makes between 1400 and 1600 runs during each match, equating to a change in direction approximately every 3.5-4 s (1600 runs / 90 minutes to 1400 runs / 90 minutes). This suggests that the ability to change direction in conjunction with high-speed anaerobic activities is important in the game of soccer (Sheppard & Young, 2006). Bloomfield, Polman, and O'Donoghue (2007) observed that all playing positions perform the same number of 90° to 180° turns at approximately 90 to 100 per match. Bloomfield et al. (2007) speculated that this could be related to efforts in close encounters to evade an opponent or different aspects of plays where players are facing their own goal and the ball is kicked over their head (e.g., goal-kick). Such activities, however, may lead to producing a detrimental shearing force on the lower limbs especially at the knee (Besier, Lloyd, Ackland, & Cochrane, 2001). A shear force is a force that acts on an object in a direction, which is perpendicular to the extension of the knee joint; for example, attackers or defenders planting their foot down and pivoting 90° to 180° (Hewett, Myer, & Ford, 2005). According to FIFA (2007), the female youth championships (U19 in 2002, 2004; U20 in 2006) had approximately 2.7 injuries per 90-minute match, with 11% identified as knee injuries. Additionally, Kibler (1993) examined injuries to both preadolescent and adolescent players (12-19 years of age) and determined that 15.8% of the 179 injuries recorded (23.8 per 10,000 player hours) were knee related. A higher knee injury rate is suggested with a younger age range of players; however, the field size and number of players inhibits direct comparisons (Besier et al., 2001).

Anterior Cruciate Ligament

The knee joint is the largest and most complex joint of the body (Figure 1) (Nordin & Frankel, 2012). The knee is a two-joint structure composed of the tibiofemoral and the patellofemoral joint. The knee is positioned between the body's two longest lever arms, the femur and the tibia, which makes it particularly susceptible to injury (Nordin & Frankel, 2012). This is because it is a dynamic, weight-bearing joint that almost solely depends on the ligaments and muscles for stability (Saladin, 2009). Anterior and posterior muscles surrounding the knee (quadriceps and hamstring muscle groups, respectively) in combination with a series of ligaments provide stability (Saladin, 2009). The knee functions as a modified hinge joint, which enables movement in one plane (monoaxial) (Saladin, 2009). However, when the knee is flexed, it is also capable of gliding and rotating (Saladin, 2009). Gliding describes a simple back-and-forth and side-to-side movement of the tibia on the femur with limited range of motion, while rotation occurs when the femur revolves around the longitudinal axis (Tortora & Derrickson, 2009). The functional integration of the structures of the knee enables it to uphold high forces and torques (Nordin & Frankel, 2012).

In response to varying forces, the anterior cruciate ligament (ACL) acts alongside the osseous configuration and three other major ligaments (posterior cruciate, medial collateral, and lateral collateral ligaments) to provide static stability (Amis & Dawkins, 1991; Nordin & Frankel, 2012). When exposed to dynamic loading forces, the flexor (hamstrings) and extensor (quadriceps) muscles of the knee act as the predominant stabilizers (Solomonow et al., 1987). The co-contraction of these muscles protects the knee as a whole and its ligaments against unfavourable and traumatic movement patterns (Ford, Myer, & Hewett, 2010). In addition, two C-shaped menisci (medial and lateral) aid in body weight shock absorption and prevent the

femur from rocking and gliding side-to-side on the tibia (Figure 1) (Saladin, 2009). The interaction between the dynamic and the static control systems is unclear (Wojtys & Huston, 1994). However, if any of the knee structures are injured, the knee joint may become unstable (Nordin & Frankel, 2012).



(d) Anterior deep view

Figure 09.15d Tortora - PAP 12/e
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Figure 1. Deep anatomy anterior view of the right knee. Adapted from “*Principles of Anatomy and Physiology*” (p. 291), by G. J. Tortora, and B. Derrickson, 2009, Hoboken, NJ: John Wiley & Sons.

Anterior cruciate ligament injury. The ACL predominantly acts to restrain anterior tibial translation on the femur, especially with shallow knee flexion angles (approximately 5-20°) (Nordin & Frankel, 2012; Shimokochi & Shultz, 2008). Nordin and Frankel (2012) stated that when the ACL is anteriorly displaced more than 7 mm, the ligament would rupture and, therefore, completely fail. The minimum and maximum limiting force of the ACL is at 90° and at 10-20° of knee flexion, respectively (Yamamoto et al., 2004). Approximately 70% of ACL injuries are non-contact in nature while the other 30% represent injuries resulting from contact

(Arendt, Kirkley, & Engebretsen, 2001; Hewett, Myer, & Ford, 2006). A non-contact injury occurs in the absence of external factors (i.e., body-to-body) (Myklebust et al., 2003; Olsen, Myklebust, Engebretsen, & Bahr, 2004). Video analysis has shown that most non-contact ACL injuries are seen when the body's centre of gravity is behind and away from the base of support, and occur between 17-50 ms after initial ground contact (IC) (Krosshaug et al., 2007). When the body is positioned with the weight on the back heel, an excessive increase in quadriceps contraction occurs, which reduces the effectiveness of the hamstrings, resulting in an imbalanced muscle co-contraction (Shimokochi & Shultz, 2008). This imbalance creates a perpendicular shear force on the tibia, which the knee and specifically the ACL are unable to withstand (Hewett et al., 2005). Furthermore, injuries to this ligament typically occur when the foot is firmly planted on the ground and at a considerable lateral distance from the medial axis of the body (Figure 2) (Hewett et al., 2005). When the foot is firmly planted on the ground, hip adduction angles greater than 5° have been shown to increase the risk of an ACL injury. At IC, however, greater hip abduction angles have been correlated with increased risk of ACL injuries during cutting maneuvers (Sigward, Pollard, Havens, & Powers, 2012). In addition to an increase risk of injury to the ACL, the knee is generally positioned near full extension ($0-30^{\circ}$ flexion) in valgus alignment, with the femur internally rotated, and the tibia externally rotated (Hewett et al., 2005; Kristianslund, Faul, Bahr, Myklebust, & Krosshaug, 2014). In contrast, Krosshaug et al. (2007) observed the mean knee and hip flexion angles to be significantly greater in female basketball players than their counter male athletes at both IC (15° vs. 9°) and 50 milliseconds after IC (27° vs. 19°), which forced a greater knee valgus collapse towards an ACL injury. Although this finding contradicts a more erect posture typically seen in an ACL injury, it was observed in athletes landing from a jump [not pivoting]. Anterior cruciate ligament injuries may

also occur if the person is performing a sharp deceleration, landing maneuver, or lateral pivoting movement (Boden, Dean, Feagin, & Garrett, 2000; Olsen et al., 2004). The photo sequence in Figure 2 illustrates a soccer player attempting to perform a lateral pivoting movement with a valgus collapse and resulting ACL injury (Alentorn-Geli et al., 2009, p. 707).



Figure 2. ACL injury as a result of a valgus collapse and lateral pivoting movement in a soccer player. Adapted from “Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 1: Mechanisms of injury and underlying risk factors,” by E. Alentorn-Geli, G.D. Myer, H.J. Silvers, G. Samitier, D. Romero, C. Lazaro-Haro, R. Cugat, 2009, *Sports Knee Surgery, Sports Traumatology, Arthroscopy*, 17, p. 707. Copyright 2009 by Springer-Verlag.

With the exponential increase of female soccer participation, there is a 3-3.6 times greater ACL injury rate in female athletes when compared to males (Agel, Arendt, & Bershadsky, 2005). Consequently, ACL injuries are associated with short and long-term detrimental health effects including physical inactivity and premature development of osteoarthritis (Lohmander, Ostenberg, Euglund, & Roos, 2004; Myklebust & Bahr, 2005). Although several etiologies have been proposed to explain the increased prevalence of ACL injury rates in females, there is no literature to explain the detailed developmental changes related to the knee that may account for the greater prevalence of ACL injuries in females prior to the onset of puberty (Beasley & Cudik, 2003).

Human Motor Development and ACL Injuries

Motor development is “the study of the changes in human motor behaviour over the lifespan, the processes that underlie these changes, and the factors that affect them” (Payne & Isaacs, 2008, p. 3). Humans spend approximately one-quarter of the lifespan growing and developing physically, emotionally, and socially (Payne & Isaacs, 2008). The physical changes are most apparent during approximately a six-year growing period called adolescence, which varies between genders and from person to person (Payne & Isaacs, 2008). In females, the age of menarche is often used to estimate maturation in conjunction with their peak growth spurt in height (Payne & Isaacs, 2008). Menarche occurs in the later stage of puberty following the female’s peak growth spurt (Payne & Isaacs, 2008). The rate of growth in height is referred to as peak height velocity (PHV) and is estimated to occur in North American females around 11.8 years of age (Payne & Isaacs, 2008). Motor performance developmental challenges, which occur during adolescence, have been referred to as adolescent awkwardness (Payne & Isaacs, 2008). In particular, balance abilities may be disrupted for up to 6 months in females (Tanner & Davies, 1985).

Anatomical positioning of the centre of gravity changes with age in proportion to height (Payne & Isaacs, 2008). Prior to adolescence (pre-pubertal), children’s centre of gravity is higher because they are top heavy (Payne & Isaacs, 2008). The centre of gravity descends in proportion to increase in stature (Payne & Isaacs, 2008). Issacs (1976) suggested that a higher centre of gravity in children inhibits their ability to decelerate quickly from a maximal effort forward movement. Such movement is an essential requirement in performing movement such as a 180° pivot maneuver in soccer.

Before the onset of puberty, there are no known gender differences that would lead one

gender to be at greater risk for an ACL injury (Beasley & Cudik, 2003; Quatman, Ford, Myer, & Hewett, 2006). However, developmental performance trends suggest that females' running speeds peak at 14-15 years of age on average with year-to-year improvements (Fortney, 1983).

Structural changes. Phenotypic differences are most apparent during adolescence (Haywood, Robertson, & Getchell, 2012). In relation to shoulder development, females grow wider through their hips during this adolescent period (Malina, Bouchard, & Bar-Or, 2004). Haubenstricker and Sapp (1980) suggested that elementary and middle schoolgirls had superior static balancing ability. The broader pelvis and shorter limbs decreased their center of gravity, which enabled the advantageous balance technique (Haubenstricker & Sapp, 1980). Although this structure is advantageous in balance events, it may place females at greater risk during more dynamic events including running and pivoting turns (Buchanan, 2003; Haubenstricker & Sapp, 1980). Accordingly, taller females with longer legs may have a functional advantage over those with shorter leg lengths.

In addition to leg length, researchers also propose the Quadriceps-angle (Q-angle) in lower extremity alignment as a possible etiology for ACL injuries (Tillman, Bauer, Cauraugh, & Trimble, 2005). The Q-angle is defined as the angle between a line drawn from the anterior superior iliac spine to the centre of the patella (representing the quadriceps muscles) and a line drawn from the central patella to the tibial tubercle (representing the pull of the patellar tendon) (Kent, 2006). Soderman, Alfredson, Pietila, and Werner (2001) conducted a longitudinal study with female second and third division Swedish soccer players and found no relationship between lower extremity injury and Q-angle. Conversely, Buchanan (2003) reported that a higher Q-angle in female collegiate basketball players altered lower extremity biomechanics during single leg landings. The kinematic analysis suggested that females of all maturation stages had valgus

alignment during the landing task. Furthermore, an increased Q-angle (in accordance with ankle strength) accounted for 35.2-46% of the valgus alignment. Therefore, when higher loads are applied to the knee, there is a higher risk of ACL injury (Buchanan, 2003).

Sex hormones. Another proposed theory to explain higher ACL injury rates in females is based on gender-related hormones (Hewett, Zazulak, & Myer, 2007). Sex hormone fluctuations related to a female's monthly menstrual cycle and resulting levels of estrogen and progesterone, may lead to increased non-contact ACL injuries in female athletes (Hewett et al., 2007). In fertile females, the menstrual cycle can be divided into three phases: follicular (day 0-9), ovulatory (day 10-14), and luteal (day 15-28) (Silverthorn, 2013). In a systematic review completed by Hewett et al. (2007), seven studies were examined to determine if there is a relationship between menstrual cycle phases and ACL injuries in female athletes. The conclusions suggested that during the first half of the cycle (before ovulation), a female athlete is at greater risk for an ACL injury (Hewett et al., 2007). In conjunction with this finding, the level of estrogen rise summons a potential answer to the difference between male and female ACL injury rates (Hewett et al., 2007). Only Slauterbeck et al. (2002) included younger female athletes in high school in comparison to countless studies only examining collegiate/university athletes (Arendt, Agel, & Dick, 1999; Arendt, Bershadsky, & Agel, 2002; Myklebust et al., 2003; Wojtys, Huston, Boynton, Spindler, & Lindenfeld, 2002). The limited amount of research conducted creates a large controversy in understanding how the menstrual cycle relates to the different phases of maturation, which may potentially increase a risk of an ACL injury. Currently, there is no evidence to suggest gender risk factors associated with ACL injuries before adolescence occurs (Beasley & Cudik, 2003; Quatman et al., 2006). It has also been hypothesized that with the onset puberty, fluctuating female sex hormones may directly impede the balanced neuromuscular

control patterns of the lower limbs (Hewett, Myer, & Ford, 2004).

Neuromuscular control. Hewett et al. (2006) suggested that the primary cause of an ACL injury is a lack of neuromuscular control of the lower limbs during dynamic movements. Neuromuscular control may be defined as the “unconscious activation of dynamic restraints occurring in preparation for and in response to joint motion and loading for the purpose of maintaining and restoring functional joint stability” (Riemann & Lephart, 2002, p. 73). The neuromuscular control system surrounding the knee is comprised of the flexor and extensor muscles (hamstrings and quadriceps), which collectively act to protect the joint (Amis & Dawkins, 1991; Nordin & Frankel, 2012; Solomonow et al., 1987). A balance of muscular coordination and co-contraction between the flexors and extensors provide a great deal of protection for the knee joint against potentially injurious movement patterns performed in soccer games (Ford et al., 2010).

Soderman et al. (2001) conducted a longitudinal study to examine leg injuries in second and third division female Swedish soccer players. Five participants sustained an ACL injury during the longitudinal study (Soderman et al., 2001). Although the study did not specifically assess ACL injuries, it was found that injured participants had a lower hamstring/quadriceps (H/Q) ratio on the injured side than the uninjured side (Soderman et al., 2001). These females had less co-activation of the hamstring muscles compared to the quadriceps muscles (Soderman et al., 2001). Similarly, Myer et al. (2009) examined the relationship between a H/Q ratio and ACL injury risk in female soccer players and other athletes, with comparable findings. This study determined that females, who sustained an ACL injury during a full outdoor season, had decreased isolated hamstring strength compared to male athletes of the same sport (Myer et al., 2009). In addition, female athletes were observed to take longer to activate their hamstring

muscles during isokinetic testing than male athletes, which forced excessive quadriceps action (Wojtys & Huston, 1994). An increase in quadriceps activation positions the knee in a more valgus alignment, which simulates an ACL prone injury situation (Wojtys & Huston, 1994).

Wojtys and Huston (1994) examined 40 healthy and athletically active participants (26 males and 14 females) and 100 ACL-deficient participants (ACL-D) (70 men and 30 women) identified by physicians and athletic therapists. The ACL-D participants were all considered 'recovered' and subdivided into three groups depending on the amount of recovery time since their ACL injury: acute (< 6 months), semi-acute (6 – 18 months), and chronic (> 18 months). In response to a specifically designed apparatus to force anterior tibial translation, electromyographic (EMG) activity of the medial and lateral quadriceps and hamstrings were measured at 30° of knee flexion (Wojtys & Huston, 1994). The quadriceps muscle was observed to be significantly stronger in males than in females (when correcting for body weight). Additionally, EMG analysis indicated that hamstring and gastrocnemius muscles of the female ACL-D participants responded statistically significantly slower than the quadriceps. The hamstring response recruitment was presented to explain the participant's low H/Q ratios in ACL injuries. This pattern suggests minimal muscular protection of the knee ligaments (Wojtys & Huston, 1994). Decreased hamstring and gluteal muscle activity can prevent the ability to absorb ground reaction forces at the hip during landing, which increases greater risk of injury (Hewett et al., 2006). The simultaneous contraction of the knee flexors and extensors is required to compress the knee joint and assist in preventing valgus alignment, which is a biomechanically ACL injurious position (Hewett et al., 2005; Hewett, Stroupe, Nance, & Noyes, 1996). This decrease in neuromuscular control may especially increase the strain on the knee ligaments when performing a sharp deceleration, or lateral pivoting movement (Hewett et al., 2005; Olsen et al.,

2004).

Agility

Speed development is a fundamental component of training for many sports. Athletes must not only be able to accelerate rapidly in order to achieve top speed, but also change direction while doing so (Gambetta, 1996). The ability to perform frequent changes in direction at peak speed is considered a key determinant factor in sport performance of many field sports including, but not limited to rugby (Meir, Newton, Curtis, Fardell, & Butler 2001) and soccer (Reilly et al., 2000). Reilly et al. (2000) further suggested that the ability to change direction from top speed is the key predictor in identifying elite soccer players. Researchers often subjectively analyze movement in sport under the generalized term of agility. Agility may be defined by various interchangeable terms including: change of direction, speed in relation to power, and reaction to stimuli (Barrow & McGee, 1971; Chelladurai, 1976; Sheppard & Young, 2006). Barrow and McGee (1971) simply defined agility as the ability to change direction quickly and efficiently, while Chelladurai (1976) argued that agility is much more complex than just changing direction quickly and efficiently. Chelladurai (1976) further explained that agility also involves recognition of decision-making stimuli. Therefore, a more complete definition of agility is “a rapid whole-body movement with change of velocity or direction in response to a stimulus” (Sheppard & Young, 2006, p. 922).

Limb dominance. One aspect of agility that has not been adequately addressed in the literature is the influence of limb dominance on performance in agility tasks. Limb dominance is defined as an imbalance of muscle recruitment and muscular strength of the dominant limb over the non-dominant limb (Hewett et al., 1996). The dominant limb is, therefore, capable of greater dynamic control (Hewett et al., 1996). More specifically, Cortes, Greska, Kollock,

Ambegaonkar, and Onate (2013) referred to the dominant foot as the foot a person would use to kick a ball the farthest.

Gabbard and Iteya (1996) explored foot preference behaviour throughout a life span. It was collectively reported that 60% of children (3-11 years of age) were right foot dominant, 7% left foot dominant, and 33% mixed foot dominant (used both equally). It was suggested that foot dominance is less subjected to dextral environmental pressures of the world when compared to hand dominance (Gabbard & Iteva, 1996). Especially at a younger age, everyday activities that require the use of feet are not as complex or specific to one side (such as walking) (Peters, 1990). Soccer is an exception as it specifies the pronounced use of foot dominance at a younger age (Peters, 1990). During adolescence and into adulthood, motor learning skills are developed as foot dominance is defined. Adolescents/adults were identified as 75% right foot dominant, 8% left foot dominant, and only 18% mixed foot dominance (Gabbard & Iteva, 1996). With everyday life activities and the onset of puberty, it was determined that preferences of foot dominance were defined and remained the same later into life (Gabbard & Iteva, 1996).

Sayers (2000) suggested that even before a change of direction occurs in an agility task, a participant's running technique might contribute to the ability or inability to perform sprints with directional changes. Brown, Zifchock, and Hillstrom (2014) attempted to understand the effects of lower limb dominance and fatigue on running biomechanics in 20 females. Three-dimensional kinematic and kinetic data was collected as the participants performed a maximal effort sprint of 25 m. There were no significant differences observed between the dominant and non-dominant limb in running gait patterns (Brown et al., 2014). Without evidence supporting limb dominance differences in running tasks, Velotta, Weyer, Ramirez, Winstead, and Bahamonde (2011) looked to further understand the relationship between common limb dominance and the type of agility

task performed. They found that when the task was manipulative in nature (i.e., when kicking a soccer ball), participants would use the dominant leg (Velotta et al., 2011). When the task involved stabilizing tasks, such as standing on one foot, participants would prefer to use their left or non-dominant leg (Velotta et al., 2011). Previc (1991) suggested that the neurological demands of a movement or skill results in an antigravity extension control on the non-dominant side of the body that emerges before the voluntary control on the dominant side. Although the dominant leg demonstrates earlier muscular activation during dynamic activities, it is possible that it may over compensate for the non-dominant leg (Ford, Myer, Hewett, 2003). The non-dominant leg, as a result, may not be able to withstand greater knee forces during dynamic activities and, therefore, result in a greater chance of injury (Ford et al., 2003). Furthermore, Brophy, Silvers, Gonzales, and Mandelbaum (2010) suggested that female players are more likely to injure their ACL on their supporting leg (non-dominant left leg) than their dominant leg, while Faude, Junge, Kindermann, and Dvorak (2006), suggested significantly more dominant leg injuries.

Ford et al. (2003) evaluated 3D kinematic analysis on 47 female and 34 male basketball players performing a drop vertical jump (DVJ). The DVJ required the participants to drop off of a box and immediately perform a maximal vertical jump. The peak valgus knee angle throughout the task was significantly larger on the female's dominant side than the non-dominant side ($27.6 \pm 2.2^\circ$, $12.5 \pm 2.8^\circ$, respectively), which would suggest a greater potential of an ACL injury on the dominant leg. Hewett et al. (2004) also observed a significantly greater peak valgus dominant knee angle during a landing task than the non-dominant angle in post pubertal female high school students. Pre-pubertal females were also observed to perform the same pattern, however, the results were not significant. Evidently, there is uncertainty whether limb dominance is a

potential etiological factor in an ACL injury. More specifically, there is no literature to support differences in limb dominance during different pivoting tasks. The high prevalence of non-contact ACL injuries occurring during pivoting turns validates the reason to evaluate any potential limb-dominant differences.

Pivot movement patterns. A pivoting turn is used to reference the specific degree of a directional change from the foot's initial spatial alignment (Sheppard & Young, 2006). Team-sport athletes, such as soccer players, typically run with a more forward and slouched upper body (Sayers, 2000). This running technique enables the athlete to produce quick lateral forces because the centre of gravity is lower to the ground, which allow for rapid changes in direction (Sayers, 2000). In general, a change in direction from a forward movement occurs when the leg extensor muscles of the pivoting limb contract eccentrically as the foot is planted on the ground (Young, James, & Montgomery, 2002). During foot plant, the same leg extensor muscles concentrically contract and the leg flexors eccentrically contract to activate a push-off (Young et al., 2002). Therefore, a quick change in direction would be associated with a maximal stretch and shortening cycle of the leg muscles (Young et al., 2002). Minimal leg flexion as a change in angle (at the hip, knee, and ankle) and minimal ground contact time would aid in quick pivoting movements (Young et al., 2002). Interestingly, Young et al. (2002) reported that 15 male participants (18-28 years of age) were significantly slower to change their sprint direction [at 20°, 40°, and 60°] off of their non-dominant leg than their dominant leg. Participants in this study were competitively playing in a sport that requires changes of direction – soccer, basketball, football, and tennis. It was speculated that during any change in direction task, the outside, or pivoting foot, would exert more muscle influence than the inside or supporting leg. When pivoting to the left side of the body, with right leg being dominant, the right leg reactive

strength was stronger than the left supporting leg. However, the same did not hold true for the participants pivoting to the right side of the body (using the left non-dominant leg). The 13 out of 15 right-footed participants were thought to explain the discrepancies. It was proposed that limb dominance causes a superior turning performance through repetition and comfort level of the participants. Soccer participants in particular can be challenged via their opponent to change direction off their non-dominant limb. A lack of ability and efficiency to do so could result in a loss of possession or defeat, for example. No current literature has observed this finding in female soccer players. Therefore, there is a need to further understand the role of limb dominance in female soccer players of different maturational stages.

Beaulieu and Lamontagne (2009) evaluated 15 male and female university/college level elite soccer players while performing a 45° cutting movement. Three-dimensional knee and hip kinematics were compared only at IC. Initial contact was defined when the net ground reaction force was greater than 10 N and the pivoting foot was flat on the turning marker. Hip and knee flexion values were 51.9° and 18.0° for the female athletes respectively. The hip was 3.6° of external rotation and 13.9° of hip abduction. The knee was observed to be externally rotated - 2.7°.

In order to examine the relationship between pivoting at increased change in direction angles, Imwalle, Myer, Ford, and Hewett (2009) compared lower limb kinematics when changing directions at 45° and 90°. Kinetic vertical ground reaction force (VGRF) data was used to determine the phases of IC and toe-off (TO). Initial contact was defined when VGRF exceeded 10 N while TO was defined when VGRF was below 10 N (Imwalle et al., 2009). Nineteen varsity high school and college female soccer players participated in the study (17.6 ± 2.1 years, 165.6 ± 8.2 cm, 60.2 ± 5.6 kg) (Imwalle et al., 2009). During both turns, 3D video

analysis was used to collect range of motion values of the knee and hip (Imwalle et al., 2009). Kinematic values suggested that both knee and hip internal rotation angles were significantly higher with the 90° turn compared to the 45° turn (8.0° and 87.0°, respectively) (Imwalle et al., 2009). The other significant difference between the two pivot angles was a higher average of hip flexion angle during the 90° pivot ($F_{(1,37)} = 52.34$) (Imwalle et al., 2009).

The latter study demonstrated that with an increase in cut angle, hip flexion angle, and both knee and hip internal rotation angle increased (Imwalle et al., 2009). In addition, Cortes, Onate, and Van Lunen (2011) observed significant differences among participants performing a drop-jump task, a 90° cut and a 180° pivot maneuver. Nineteen Division I collegiate female soccer players participated in this study (age = 19.6 ± 0.8 years; height = 1.67 ± 0.05 m; body mass = 63.7 ± 10.1 kg). Within this study, three instants were used to evaluate kinematic parameters: IC, peak stance (PS), and peak vertical ground reaction force (PVGRF) (Cortes et al., 2011). Initial contact was defined when the VGRF exceeded 10 N after IC; PS was defined as the tallest stature throughout the turn; and PVGRF was defined as the largest kinetic value (Cortes et al., 2011). Knee valgus alignment, knee flexion, and hip flexion kinematic variables were evaluated at the three different instants (Cortes et al., 2011). The average value for all the participants at both 90° and 180° maneuvers were calculated (Cortes et al., 2011). Table 1 shows the kinematic values for only the 180° pivot maneuver.

Table 1

Kinematic Variables at Three Different Instants for the 180° Pivot Maneuver

	Knee Flexion (°)	Knee Valgus (°)	Hip Flexion (°)
IC	-24.3	-11.6	48.3
PS	-57.6	-12.2	64.9
PVGRF	-41.2	-7.6	52.7

Note. IC = Initial Contact, PS = Peak Stance, PVGRF = Peak Vertical Ground Reaction Force.

Participants performed the 180° pivot maneuver with a more erect posture and adapted to specific kinematic positions that caused an increase of load on the knee joint as compared to the other two tasks (Cortes et al., 2011). For example, participants on average performed the 180° pivot maneuver with lower knee flexion than when performing the 90° turn at maximum VGRF ($-41.2 \pm 8.8^\circ$, $-53.9 \pm 9.4^\circ$ respectively) (Cortes et al., 2011). Participants also performed the 180° pivot maneuver with a higher valgus alignment when compared to the 90° cut ($-7.6 \pm 10.1^\circ$, $-2.9 \pm 10.0^\circ$ respectively) at maximum VGRF (Cortes et al., 2011).

180° pivot maneuver. Greig (2009) argued that sidestep cutting (i.e., 45°, 60°, or 90°) does not represent soccer specific activities; rather a complete 180° pivot maneuver is more realistic of the tactical aspect of soccer. This opinion is similar to Bangsbo (1994) who believed that this turn was representative of the nature of competitive soccer patterns. Time motion analysis supports these opinions, as Bloomfield et al. (2007) observed soccer players perform the same number of 90° and 180° turns per match. As illustrated in Figure 3, the 180° pivot maneuver consists of five specific phases: (a) linear approach to the turn, (b) initial temporary left foot plant, (c) right foot pivot plant perpendicular to the linear approach, (d) pivot re-plant left foot, and (e) linear exit away from the turn (Greig, 2009). Initial contact can be explained by the visual aid (c) when the right (dominant) foot contacts the target area. Maximum knee flexion (MKF) can be identified between images (c) and (d) – immediately following IC and before TO of the pivoting foot. Toe-off can be identified as image (d) when the left foot re-plants, the right pivoting foot prepares for TO. The 180° pivot maneuver is performed with the right (dominant) foot. The left or non-dominant limb can also complete the turn in a similar manner.

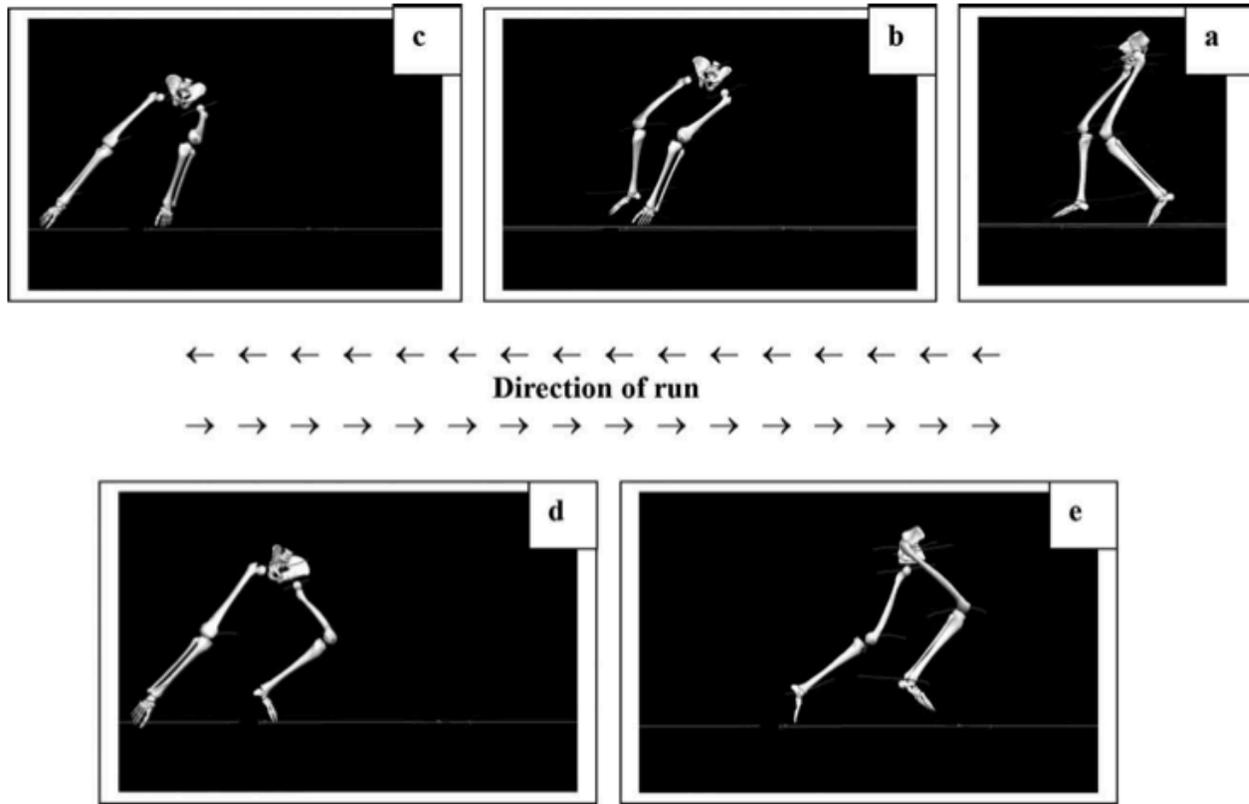


Figure 3. Visual representation of the 180° pivot maneuver: (a) linear approach, (b) pivot – left foot plant, (c) pivot – right foot plant, (d) pivot – left foot re-plant, and (e) exit. Adapted from “The Influence of Soccer-Specific Activity on the Kinematics of an Agility Sprint,” by M. Greig, 2009, *European Journal of Sport Science*, 9, p. 26. Copyright 2009 by the European College of Sport Science.

Greig (2009) investigated the influence of soccer-specific fatigue on the kinematics in a 180° pivot agility test in ten male professional soccer players (24.7 ± 4.4 years, body mass 77.1 ± 8.3 kg). This agility test was initiated from a standing start 3.5 m from the turning marker (Greig, 2009). The participants were instructed to perform a maximal effort movement towards the target area, plant their right foot (dominant, defined by the leg used to kick a soccer ball the farthest) within the area, and then pivot about this foot 180°. Additionally, the soccer players ran on the treadmill for 90 minutes in total broken up every 15-minutes in order to perform the agility test.

This protocol incorporated the most important physical aspect of soccer, sprinting, and one crucial tactical demand, pivoting. The kinematic variables, knee flexion/extension and valgus/varus alignment, were evaluated at four instants: touchdown, maximum flexion, re-plant, and take-off. These instants were grouped into a flexion phase (touchdown to MKF) and an extension phase (MKF to take-off). The way that the phases were measured was not clearly defined. Kinematic analysis only evaluated the left supporting leg and right turning leg using a nine-camera motion analysis system.

Greig (2009) found that as 90 minutes elapsed, players experienced increases knee extension and range of knee valgus alignment. Although significant findings were reported, detailed angle values at the indicated instants were not presented. Other possible relevant ranges of movements that were not evaluated were, tibia rotation, thigh rotation (femoral internal/external rotation), hip flexion/extension or hip abduction/adduction. Because greater external tibial rotation, femoral internal rotation, hip extension angle, and abnormal hip adduction/abduction angles may contribute to ACL injury (Hewett et al., 2005; Powers, 2010), such variables should be further evaluated. This study is also limited to the participants only performing the turn on their dominant right leg with their non-dominant left leg in the support position. Therefore, the understanding of kinematics during the 180° pivot maneuver using one's non-dominant limb is undetermined. Research may lead to greater awareness of the need for equal bilateral training, which would develop proper biomechanical training techniques decreasing the incidence of injury. The 180° pivot maneuver, argued as the most soccer specific turn, should be adequately performed by players of all ages on both limbs in order to succeed in the game (Peters, 1990).

Side-step cutting. Sigward et al. (2012) were the first authors to evaluate maturation

effects on knee kinematics during a 45° side-step cutting turn in female soccer players.

Participants were subdivided into four groups based on the modified Pubertal Maturation Observational Scale (PMOS): pre-pubertal, pubertal, post-pubertal, or young adult. The participants performed three different tasks on their dominant foot: 45° side-cut, 110° change in direction, or a straightforward run. A light signal was triggered 3m before foot contact on the force platform to indicate the type of task the participant had to perform. Only the data from the 45° side-cut was analyzed since it was identified that more ACL injuries occur while performing this task as compared to the other two. The pre-pubertal females showed greater knee adductor moments and GRFs when compared to the other groups. The observed characteristics suggest greater ACL injury risk than the more mature participants (Hewett et al., 2005). The results are inconsistent with the high injury rates of female soccer players' post-puberty, as there are only 10% of confirmed ACL injuries of children under the age of 14 in the United States (Shea, Pfeiffer, Wang, Curtin, & Apel, 2004). The findings were attributed to previous studies that explained children's (9-11 years of age) inept ability to turn around obstacles with high precision, suggesting adolescent awkwardness (Michel, Grobet, Dietz, & van Hedel, 2010; Vallie & McFadyen, 2005). Findings may be observed and emphasized in the current study as an increase in pivot angles parallels ACL injury risks (Imwalle et al., 2009). This study is limited to explaining maturational differences for only peak knee valgus angle, knee adductor moments, and GRFs. The latter variables do not explain other kinematics related to ACL injuries such as, knee flexion/extension, hip flexion/extension, or hip internal/external rotation. Further detailed kinematic investigation could explain the effect of limb dominance in female soccer players of three different maturational stages during a 180° pivot maneuver.

Three-Dimensional Collection/Analysis

Kinematic data is determined through quantitative video analysis procedures, which involve video motion recording and digitizing (Payton & Bartlett, 2008). Video analysis may be two-dimensional (2D) or three-dimensional (3D) depending on the performance task (Payton & Bartlett, 2008). Two-dimensional video analysis assumes the performance in only one plane of motion; any other movements outside of this plane of reconstruction are ignored and subjected to error (Payton & Bartlett, 2008). Two-dimensional analysis lacks the ability to record motion moving to and away from the camera, also known as perspective error (Richards, 2008). The 180° pivot maneuver is not confined to a single plane; rather it requires the analysis in a 3D manner. Three-dimensional video analysis enables true spatial movements of the participants to be quantified in three relative intersecting axes (Payton & Bartlett, 2008). This study follows the International Society of Biomechanics (ISB) guidelines to define the x-axis in the obvious direction of the participant's progression; the y-axis directed vertically; and the z-axis directed laterally (Payton & Bartlett, 2008).

The essential requirement for 3D analysis is to have at least two cameras simultaneously recording the participant's performance, each from a different perspective (Payton & Bartlett, 2008). Chaudhari et al. (2007) utilized two high-speed cameras to analyze three tasks: single leg horizontal hop, double leg box drop vertical, and double leg vertical jump in 3D. Participants included male ($n = 12$) and female ($n = 25$) recreational athletes with only five markers for motion analysis located on the iliac crest, greater trochanter, lateral knee joint line, lateral malleolus, and fifth metatarsal head on the same side (Chaudhari et al., 2007). The use of minimal markers and/or the type of activities tested that did not reflect regular movements of the recreational athletes, could explain no significant results. The sampling rate of the cameras is selected to improve precision. The range 50 – 100 Hz is recommended for activities such as

running, high jumping, and shot putting (Payton & Bartlett, 2008). Payton and Bartlett (2008) suggested that for moderately fast activities, the shutter speed should be within the $1/350^{\text{th}}$ – $1/750^{\text{th}}$ of a second-range to provide a non-blurred image. The cameras are zoomed out to cover only the performance sprint area in which the calibration frame encompasses, which allows for only a small margin of error. This maximizes the image size and increases accuracy during the digitizing process (Payton & Bartlett, 2008). In order to establish the relationship between 2D image co-ordinates and 3D real world co-ordinates, a rigid calibration frame with 32 reflecting sphere markers of known dimensions is recorded before data collection. The static image is then digitized for each camera's view to produce a set of 2D co-ordinates for each control point. The control points are known relative to the three orthogonal axes, which define the global co-ordinate system.

The quality of the data captured by the cameras is relative to the type of markers used to formulate the data: active (light emitted) and passive (light reflected) (Nedergaard et al., 2013). Most analysis systems use passive markers to produce the kinematic model versus an active marker system (Payton & Bartlett, 2008). An active marker system is only appropriate for minimal movements that do not involve turns such as the 180° pivot maneuver (Payton & Bartlett, 2008). Although the active marker system provides much cleaner data and emits its own light, this system requires participants to wear wires or electronic equipment hindering movements (Payton & Bartlett, 2008). Therefore, passive markers are used in this study to indicate the position and orientation of the body in 3D space. The passive markers require the reflection of visible or infrared light in order to be detected by the cameras (Payton & Bartlett, 2008). A floodlight is located adjacent to each camera to maximize visibility of the reflective markers. The positioning of the markers on the participant is essential to producing reliable

results. Skin and soft-tissue movement under the markers produces two types of error: relative and absolute. Relative error relates to the movement between two markers, while absolute error relates to the marker and the actual intended landmark (Richards, 2008). Quantifiable movement errors have been examined by attaching the markers to bone pins, however, this is very invasive and not ethical (Cappozzo, 1991). Movement error may occur as a result of pre-muscle activation or adjacent joint rotations surrounding the marker (Reinschmidt, van den Bogert, Nigg, Lundberg, & Murphy, 1997). Most skin movement artifact is attributed to movements around the thigh segment, where minimal effects are seen surrounding the shank markers (Manal, McClay, Richards, Galinat, & Stanhope, 2002). Although, Hazelwood, Hillman, Lawson, and Robb (1997) proposed that marker attachment is preferred on tight-fitting clothes rather than skin, markers are placed on exposed skin where the clothing does not cover as a result of suits available.

3D reconstruction. The most commonly used 3D reconstruction algorithm in sport biomechanics is called Direct Linear Transformation (DLT) (Payton & Bartlett, 2008). This method requires an object (calibration frame) whose real world co-ordinates are known (Payton & Bartlett, 2008). A minimum of six control points are required in the calibration frame, however, it is suggested by Payton and Bartlett (2008) that 15-20 control points should be used for accurate reconstruction. The calibration frame in the current study has 32 control points. The addition of more control points and an even distribution of them throughout the control space, increases the reconstruction accuracy (Chen, Armstrong, & Raftopoulos, 1994). The calibration frame is placed to cover the significant performance area of the 180° pivot maneuver to minimize error. This placement maximizes the image size and increases accuracy during digitizing (Payton & Bartlett, 2008). The calibration frame and its control points will be recorded

through each camera's view and then digitized to produce 2D co-ordinates. These co-ordinates are used to compute equations with 11 DLT parameters (Payton & Bartlett, 2008). Direct Linear Transformation determines a linear relationship between 2D image co-ordinates and 3D real world co-ordinates using two equations (Pourcelot, Audigié, Degueurce, Geiger, & Denoix, 2000):

Equation (1)

$$x + \delta x + \Delta x = \frac{C_1 X + C_2 Y + C_3 Z + C_4}{C_9 X + C_{10} Y + C_{11} Z + 1}$$

$$y + \delta y + \Delta y = \frac{C_5 X + C_6 Y + C_7 Z + C_8}{C_9 X + C_{10} Y + C_{11} Z + 1}$$

Where X, Y, and Z are the three space co-ordinates of a point; x, and y are the two co-ordinates of the same point of the image co-ordinate system; δx and δy are nonlinear systematic errors in the two camera's views; and Δx and Δy represent random errors, while C_{1-11} represents the 11 DLT parameters. As a result, there are more equations than unknowns. A least squares technique is used to solve the DLT parameters and calculate the 3D co-ordinates of each digitized point (Miller, Shapiro, & McLaughlin, 1980).

Pilot Study

A pilot study was conducted to examine the 3D kinematics of the lower body while performing a 180° pivot maneuver in three healthy female soccer players (age 18.7 ± 0.47 years, body mass 62.8 ± 5.10 kg, height 1.70 ± 0.06 m) from the Lakehead Express Soccer Club. Testing was completed in approximately 60 minutes in the C.J. Sanders Fieldhouse at Lakehead University (room SB 1025). Participants performed a maximal effort acceleration of 3.5 m from a static position, pivoted 180°, and then performed another maximal effort acceleration of 3.5 m in the same path as entry. The pivot turn was completed using the dominant and non-dominant

limbs on separate trials. Two Basler high-speed digital video cameras were used, recording at 100 Hz with a shutter speed of $1/500^{\text{th}}$ of a second. Twenty-two retro-reflective markers were used to reconstruct the performance in 3D space, and five kinematic variables were included in the analysis: knee angle, hip flexion angle, hip adduction angle, thigh rotation angle, and tibia rotation angle at three different instants (IC, MKF, and TO). It was hypothesized that: (1) the non-dominant limb would have less knee flexion, higher femoral internal rotation and tibia external rotation, a greater hip abduction angle, and a greater extension angle; and (2) at each given instant, all kinematic variables would display unfavourable ACL injury characteristics on the non-dominant limb.

Table 2 illustrates the participant's average angle values at the three different instants for both limbs. Upon entering into the marker at IC the participant's knees and the hips were observed to extend into IC while also abducting at their hips. In addition, the femur and the tibia were more internally rotated as they followed the kinematic chain (the foot turned perpendicular to the path of entry).

Table 2

Participant's average kinematic data for both non-dominant and dominant limbs at three instants: IC, MKF, and TO

		IC (°)	MKF (°)	TO (°)
Knee Angle	Non-dominant	137.7	94.1	108.9
	Dominant	141.6	127	142.9
Hip Flexion	Non-dominant	116.2	105.3	122.8
	Dominant	129.3	105.5	124.5
Hip Adduction Angle	Non-dominant	126.3	127.2	133.2
	Dominant	119.2	126.1	128.2
Thigh Rotation Angle	Non-dominant	66.4	56.8	58.1
	Dominant	58.1	57.4	58.3
Tibia Rotation Angle	Non-dominant	50.4	47.7	50.5
	Dominant	52.9	44.9	48.2

The knee and hip were then observed to flex while the hip abducted more from IC to MKF. The femur and tibia additionally externally rotated during this instant change. When moving from MKF to TO, the hip adducted and extended, the knee extended, and the thigh and tibia internally rotated. Although there was no direct cause-and-effect relationship to ACL injuries, kinematic knee and hip dominant limb patterns were considered to put the joint at risk. The dominant limb, in comparison to the non-dominant limb, exhibited more precarious ACL injury prone positions during the 180° pivot maneuver. For example, the dominant limb had greater hip and knee extension angles. This finding attested to the participant's ability to quickly perform the 180° pivot maneuver on the dominant limb as there was less hip flexion (Young et al., 2002). This finding confirmed that the lower extremity functioned as one kinetic chain as the knee and hip acted accordingly (Negrete & Brophy, 2000). Ultimately, the greater peak extension values for the dominant limb, insinuated higher loads on the knee joint suggesting ACL injury characteristics (Chappell, Creighton, Giuliani, Yu, & Garrett, 2007).

A limitation of this study was not having a timing gate system. The use of a timing gate system could have helped with the reliability within the study, as the trial with the fastest approach would have been used for data analysis. The fastest approach would have adequately represented the desired characteristics of performing the maneuver. Although there were only two high-speed digital video cameras, they allowed for optimal and adequate viewing of the performance to present valid results.

Research Problem

Changing direction is a fundamental technical and tactical component of soccer, and is related to attacking or defending opponents or other turning aspects of play (Bloomfield et al., 2007). Pivot turns, however, may produce detrimental shearing forces on the lower limbs, especially at the knee (Besier et al., 2001). As a result, knee injuries are seen in 15.8% of players from 12-19 years of age (Kibler, 1993), with female soccer players being 3-3.6 times more likely to injure their ACL when compared to males (Agel et al., 2005). Researchers have proposed multiple ACL injury etiologies for both pubertal and post-pubertal female players. For example, sex hormones dependent of the time of a female's menstrual cycle, an inadequate control of the neuromuscular system with puberty, and other anatomical changes, have been linked to higher ACL injury rates in females (Beasley & Cudik, 2003; Hewett et al., 2006; Quatman et al., 2006). To date, however, there has been no research investigating the lower extremity kinematics during pivoting turns in female soccer players at different maturational stages.

Various studies have examined the lower extremity kinematics during pivoting turns of 45°, 90°, and 180° (Cortes et al., 2011; Greig, 2009; Imwalle et al., 2009; Myer et al., 2009; Paterno et al., 2010; Young et al., 2002), however, this research has focused on completing the turns with the dominant leg. There has been no research that has made comparisons between the

dominant and non-dominant legs when performing pivoting turns. More specifically, the 180° pivot maneuver, arguably the most soccer specific change of direction movement (Cortes et al., 2011; Greig, 2009), has not been investigated previously in female soccer players of different maturational stages. As soccer demands a mastery of both limbs to shoot, pass, and change direction (Peters, 1990), it is necessary to develop a better understanding of the impact of leg dominance when performing this type of pivoting maneuver.

It is important to examine the lower extremity kinematics of a 180° pivot maneuver when completed using the dominant and non-dominant limbs in female soccer players at different maturational stages. This information may aid in the development of gender-specific training protocols for female players by helping coaches and trainers to better understand the kinematics of this movement, and how the kinematics may change as a result of physical growth and maturation. This research could also provide valuable insight into the mechanisms of knee injury seen in young female soccer players, which could minimize the frequency of future injuries.

Purpose

The purpose of this study was to evaluate the effect of leg dominance on lower limb kinematics during a 180° pivot maneuver in healthy female soccer players at three different stages of maturation: pre-pubertal, pubertal, and post-pubertal.

Hypotheses

1. There will be significant differences in the knee flexion angle between female soccer players of different maturational stages and between the dominant and non-dominant legs at different instants (IC, MKF, and TO of the pivoting leg) of a 180° pivot maneuver. Increased knee flexion will be seen in the pre-pubertal group as compared to the pubertal

and post-pubertal groups, and in the non-dominant leg as compared to the dominant leg within the post-pubertal group. Significantly greater angles will be seen at the moment of MKF as compared to the other two instants.

2. There will be significant differences in the hip flexion angle between female soccer players of different maturational stages and between dominant and non-dominant legs at different instants (IC, MKF, and TO of the pivoting leg). Greater hip angles will be seen in the pre-pubertal group over the pubertal and post-pubertal groups. The non-dominant leg will demonstrate greater hip flexion angles than the dominant leg within the post-pubertal group. Significantly greater angles will also be seen at the moment of MKF as compared to the other two instants.
3. There will be significant differences in the hip abduction angle between female soccer players of different maturational stages and between dominant and non-dominant legs at different instants (IC, MKF, and TO of the pivoting leg). Larger hip abduction angles will be seen in the post-pubertal group compared to the pubertal and pre-pubertal groups at IC. The dominant leg will also demonstrate larger hip abduction angles than the non-dominant leg at IC. At MKF and TO, the post-pubertal group and the dominant leg will show larger hip adduction angles than the less mature groups and the non-dominant leg, respectively.
4. There will be significant differences in the thigh rotation angle between female soccer players of different maturational stages and between dominant and non-dominant legs at different instants (IC, MKF, and TO of the pivoting leg). Greater internal thigh rotation angles will be seen in the post-pubertal group compared to the pubertal and pre-pubertal groups, and in the dominant leg as compared to the non-dominant leg. At IC and TO,

greater internal angles will be seen within each group on the dominant leg. At MKF, greater external rotational angles will be seen within each group on the dominant leg.

5. There will be significant differences in the shank rotation angle between female soccer players of different maturational stages and between dominant and non-dominant legs at different instants (IC, MKF, and TO of the pivoting leg). Greater external thigh rotation angles will be seen in the post-pubertal group compared to the pubertal and pre-pubertal groups, and in the dominant leg as compared to the non-dominant leg. At IC and TO, greater internal angles will be seen within each group on the dominant leg. At MKF, greater external rotational angles will be seen within each group on the dominant leg.

Method

Participants

Members of four female soccer teams from the Lakehead Express Soccer Club in Thunder Bay, Ontario, Canada were invited to participate in the study using purposive and convenience sampling (the Under 10, 12, 14, and 18 year old teams). From these teams, 27 participants volunteered to participate. The student researcher had received permission from the Lakehead Express soccer club's president to recruit participants (Appendix 9). The head coach of each team was also contacted and agreed to allow the student researcher to speak with the players and their parents/guardians. The student researcher is the head coach of the U14 girls team. Potential participants from this team were provided with a separate recruitment letter and consent form, clearly identifying that participating will not have any associated benefits and that not participating will not penalize them in any way (Appendix 5-8). Recruitment letters were handed out to all prospective parents/guardians, and asked to contact the student researcher if they were willing to participate. The modified PMOS was used to classify the participants into the three maturational groups: pre-pubertal (10.3 ± 1.1 years), pubertal (12 ± 1.4 years), or post-pubertal (14.8 ± 2.0 years) (Appendix 3) (Davies & Rose, 2000). Nine participants were recruited into each group. The modified PMOS has been shown to have strong validity for females ($r = .96$) (Davies & Rose, 2000). If the participant had one or none of the characteristics on the checklist, the participant was placed in the pre-pubertal stage; two to five characteristics placed the participant in the pubertal stage; and at least six characteristics with the growth spurt stage completed placed the participants in the last post-pubertal stage (Davies & Rose, 2000). Table 3 summarizes the descriptive characteristics of each group.

Table 3

Maturational Group Descriptive Statistics

Maturational Group	PMOS	Age	Height (cm)	Weight (kg)
Pre-Pubertal	0.4 ± 0.5	10.3 ± 1.1	144.1 ± 5.2	36.8 ± 8.4
Pubertal	4.6 ± 1.0	12.0 ± 1.4	158.7 ± 4.9	52.2 ± 11.2
Post-Pubertal	7.8 ± 0.4	14.8 ± 2.0	166.4 ± 7.8	58.3 ± 5.3

Inclusion Criteria

Participants had to be participating in the level I type sport, soccer, which involves pivoting or cutting movements (Daniel et al, 1994). Participants were further considered for this study if they answered the following question with the right or dominant foot, “If you are asked to kick the ball far up the field, which foot would you use?” This question follows Cortes et al.’s (2011) definition of the dominant right foot as the foot a person would use to kick the ball the farthest.

Exclusion Criteria

Participants were excluded if they had history of injury during the past 12 months to their ACL, lower extremities, or lower backs (Paterno et al., 2010), and/or if they had an allergy to adhesives as used in the tape for marker attachment during data collection. Participants were also excluded if they were left or mixed foot dominant.

Participants were asked to wear running shoes and tight-fitting clothing to the testing session. In addition, participants were asked to refrain from any physical activity 24 hours prior to the examination period in order to minimize the possibility of muscle fatigue (Hanson, Pahua, Blackburn, Prentice, & Hirth, 2008).

Testing Set-up

Testing involved the completion of a short maximal effort sprint coupled with a pivoting

turn. This included a 3.5 m acceleration (starting from a stationary position), immediately followed by a 180° pivot maneuver, and another 3.5 m acceleration towards and through the starting position. A complete description of the test is found in Appendix 4. The agility test's distance of 3.5 m was measured using a cloth tape measure and then marked with tape covered by orange cones. The timing gate system was set up as illustrated in Appendix 4. Pieces of tape were placed and left under all equipment on the floor in case of any disruption during time periods of data collection.

Two Basler high-speed digital video cameras were used for data acquisition. In order to complete a 3D analysis of the 180° pivot maneuver, the two video cameras (sampling at 100 Hz) were positioned to allow for optimum viewing of segmental markers (Appendix 4). The cameras were mounted on a stable tripod with a shutter speed of 1/500th of a second to minimize image blur. Furthermore, to improve digitizing accuracy the cameras were zoomed out to only include the area encompassing the calibration frame. The rigid calibration frame was recorded before data collection by each camera. A floodlight was located adjacent to each camera to amplify the brightness of the markers on the calibration frame and participants.

Testing Procedures

Testing was completed in the Sanders Building at Lakehead University (room SB 1025), and required approximately 60 minutes for each participant. The flooring in the room consisted of hard tiles; however, participants had weekly technical soccer sessions on a comparable floor surface at a local school during the winter season in order to prepare for game play. In addition, the test area was swept with a broom before each trial to maximize traction and avoid slippage.

Prior to the start of testing, participants had their parent/guardian review the Participant Recruitment Letter (Appendix 5 and 6) and read and sign the Consent Form (Appendix 7 and 8),

depending on their respective team. Next, the Par-Q+ (Appendix 1), the PMOS (Appendix 3), and half of the Sports Background Questionnaire (Appendix 2) were completed. The Sports Background Questionnaire was used to collect demographic data including: name, date of birth, number of hours played per year, foot dominance, height, and weight (Appendix 2). Standing height (cm) and body mass (lbs) were measured before the warm-up or testing began. Data of the participant's maturation group, number of characteristics, age, height, and mass are provided in Table 4. The Par-Q+ (Appendix 1), and the written consent form (Appendix 7 and 8) were used to ensure the participants' health and awareness of their entitlements. After consenting to participate, participants completed a warm-up on a stationary bike for 10 minutes and performed exercises adapted from the FIFA 11+ Warm-up Manual Part 1: Running Exercises. The FIFA 11+ manual was developed to reduce injuries in soccer players (F-MARC, 2007). In clinical research, the use of this program has been observed to reduce injuries by 30-50% (F-MARC, 2007). The participants of this study are familiar with this warm-up as it is implemented before their games and practices. The adapted exercises that were used are seen in Appendix 10.

Participants then had the 21 retro-reflective markers placed on the following anatomical locations with two-sided adhesive tape:

- Mid sternum
- Shoulder joint (left and right) (lateral aspect of the greater tubercle of the humerus)
- Elbow joint (left and right) (olecranon)
- Wrist joint (left and right) (head of the ulna)
- Lateral hip (left and right) (greater trochanter of the femur)
- Mid thigh (left and right)
- Knee joint (left and right) (lateral epicondyle of the femur)

- Mid shank (left and right) (between the knee joint and lateral ankle)
- Lateral ankle (left and right) (lateral malleolus)
- Heel (left and right) (calcaneus)
- Lateral foot near small toe (left and right) (5th metatarsal)

To remove inter-individual variability as a source of error, only the student researcher applied the 21 retro-reflective markers, each measuring approximately 2 cm in diameter. Four of the markers were mounted on 5 cm Styrofoam cones for rotational-plane measurements of the thigh and tibial segments (mid thigh (left and right) and mid tibia (left and right)). The student researcher included a 22nd marker during the digitizing process that was positioned on the participant's forehead.

After the placement of the markers, the student researcher demonstrated the 180° pivot maneuver using each limb to perform the movement. In addition, the participant completed two sub-maximal practice trials (pivoting once on their dominant and non-dominant limbs). After a 5-minute rest period, participants began the actual testing. Each participant completed four trials (pivoting twice on their dominant and non-dominant limbs). The foot used to pivot for each trial was pre-determined and then randomly assigned. The test trials were video recorded using the two Basler high-speed digital video cameras and captured on a computer. The videos allowed for the reconstruction of each participant's 3D performance using Vicon Motus motion analysis software. The student researcher initiated the four test trials using a "3-2-1-GO" command. After each trial, participants were provided with a two and a half minute rest period simulating the rest time between sprints in a 90-minute game (Mohr et al. 2003). Upon completion of the test trials, the markers were removed from the participants and they performed a light cool down on a stationary bike before leaving the testing facility. The fastest approach of the two trials for each

leg, based on the data provided by the timing system was used for data analysis. In the event that the participant slipped or markers fell off during a trial, the video was deleted and not included. Markers were reattached and a repeat trial was then completed.

Upon collection of data, the two selected trials for each participant (dominant and non-dominant) were analyzed within the Vicon Motus program. The control points were manually digitized for each camera's view. The digitizing process consisted of connecting the predetermined 22 spatial model points.

Three-dimensional reconstruction of the positional data was accomplished using the Direct Linear Transformation technique. The time-dependent coordinate data were filtered using a Butterworth digital filter in order to minimize the small random errors that may have occurred during the digitizing process. The cutoff frequency was determined using the Jackson Knee Method (Jackson, 1979), and ranged from 4 to 8 Hz.

Digitizing Precision and Accuracy Assessment

Precision is, “the extent to which a measurement procedure gives the same results each time it is repeated under identical conditions” (Miller-Keane & O-Toole, 2005, [def. 2]).

Therefore, in the current study, precision defines the ability to repeatedly measure data points from the same two digitized trials. In order to assess the precision of the digitizer, one trial was digitized a second time. The root mean square error (E_{RMS}) was used to quantify precision at the left ankle, left knee, left hip, left mid thigh, left mid tibia, and the right hip, for the x , y , and z planes via Equation 2.

Equation (2)

$$E_{RMS} = \sqrt{\sum (\chi_i - \chi_{ii})^2 / N}$$

Where N is equal to the total amount of frames, χ_i is the first digitized data point, χ_{ii} is the

second digitized data point. Table 4 provides the calculated E_{RMS} of each marker at the x , y , and z reference planes. The small values produced, reflected high precision.

Table 4

Precision of digitizing the left ankle, left knee, left hip, right hip, left mid thigh, and left mid shank in the x , y , and z planes using the E_{RMS} equation (mm).

Marker	Right Hip			Left Hip			Left Knee		
Plane	x	y	z	x	y	z	x	y	z
E_{RMS}	0.028	0.028	0.018	0.014	0.006	0.001	0.005	0.003	0.005

Marker	Left Ankle			Left Mid Thigh			Left Mid Shank		
Plane	x	y	z	x	y	z	x	y	z
E_{RMS}	0.005	0.004	0.005	0.002	0.002	0.002	0.003	0.007	0.003

Accuracy refers to the differences between the measured values and the true standard values (Wilson et al., 1999). During 3D reconstruction, the calibration process may be used to determine the digitizing accuracy (Wilson et al., 1999). The Vicon Motus program calculated the overall error of the two camera views for the digitized control points. The mean square error for the x , y , and z planes were 0.0041, 0.0032, and 0.0066 mm, respectively. Based on these results, both high digitizing precision and accuracy were seen through the low error measurement values.

Dependent variables. The dependent variables for this study were kinematic variables that describe various positions seen during the completion of the 180° pivot maneuver, and included knee flexion/extension angle, hip flexion angle, hip adduction/abduction angle, thigh rotation angle, and shank rotation angle. These angles were measured at three distinct instants, IC, MKF, and TO, which were identified during the digitizing process. Initial contact was defined as the instant when the participant's foot contacted the ground. Maximum knee flexion was selected at the moment when the participant's knee had the greatest angle of flexion. Toe-off was identified as the first instant where the participant's foot left the ground.

Knee flexion angle was established with the knee joint as the vertex and the two vector arms represented by the distance from the lateral malleolus of the ankle and from the lateral aspect of the greater trochanter of the femur. A change in angle between the vector arms represented the change in knee flexion. A larger angle represented a more extended knee position and a smaller angle represented a flexed knee position at the time of interest.

The hip flexion angle was defined as the angle between the two vector arms of the right (left) shoulder and the right (left) knee. The hip angle described the position of hip flexion/extension the participant. The larger the hip angle, the more the hip was extended. Conversely, a smaller angle signified a more flexed position of the hip.

The hip adduction/abduction angle was defined as the angle between the left (right) hip and the right (left) knee with the right (left) hip at the vertex. This variable measured how much the leg moved inward towards the medial axis (adduction) and away from the midline axis (abduction) of the body in the frontal plane. A larger angle corresponded with a more abducted hip position while a smaller angle accounted for an adducted hip position.

Thigh rotation angle was defined as the angle from the right (left) hip to the right (left) mid thigh to the reference YZ plane. This angle indirectly measured the femur's internal/external rotation value. A smaller angle indicated external rotation, while a larger angle corresponded to internal rotation of the hip.

Shank rotation angle was defined as the angle between the right (left) knee and the YZ plane with the vertex at the right (left) mid shank. This segment to reference plane angle represented internal/external rotation of the tibia. As in the thigh rotation angle, a change to a smaller angle indicated external rotation, while a larger angle corresponded with internal rotation.

The contact time, or the total amount of time it took participants to complete the maneuver, was included as another dependent variable. It was measured as the total time (in seconds) from IC to TO of the pivoting leg.

Independent variables. Three independent variables were used in this study: maturation stage, limb dominance, and instants. Maturation stage was used to divide the population into three subgroups: pre-pubertal, pubertal, and post-pubertal, based on the PMOS. Limb dominance was predetermined based on the Cortes et al. (2013) dominant limb identification, and used to manipulate the limb with which the participants will complete the 180° pivot maneuver. The non-dominant limb represented the left foot while the dominant limb represented the right foot.

Statistical Analysis

Statistical analyses were completed using SPSS Statistics 19.0 for Windows. Descriptive statistics (mean and standard deviation) were calculated for the dominant and non-dominant limbs, across maturation levels (pre-pubertal, pubertal, post-pubertal), and at each instant (IC, MKF, and TO). 2 (leg dominance) x 3 (maturation stage) x 3 (instants) factorial ANOVAs were used to assess the interaction effects for each of the dependent variables. Significant main effects for each independent variable were further analyzed with Bonferroni adjusted pairwise comparisons. Statistical significance was set at $p < 0.05$.

Results

Knee Flexion Angle

Table 5 presents the mean and standard deviation knee flexion angles for the three maturational groups between their dominant and non-dominant leg at the three different instants IC, MKF, and TO during the 180° pivot maneuver.

Table 5

Descriptive Statistics for Knee Flexion Angle

Maturation	IC		MKF		TO	
	D (°)	ND (°)	D (°)	ND (°)	D (°)	ND (°)
Pre-Pubertal	142.3 ± 6.7	146.9 ± 5.9	122.0 ± 10.0	120.2 ± 9.9	147.3 ± 11.5	140.4 ± 12.8
Pubertal	144.8 ± 7.8	145.3 ± 6.7	121.2 ± 6.1	124.5 ± 7.3	143.0 ± 5.3	140.7 ± 6.0
Post-Pubertal	144.4 ± 8.2	144.7 ± 8.6	118.4 ± 6.4	121.4 ± 6.5	139.1 ± 11.6	140.3 ± 8.5

Note. Values are presented as mean ± SD; IC = Initial Contact; MKF = Maximum Knee Flexion; TO = Toe-off; D = Dominant; ND = Non-dominant.

Interaction Effects

There were no statistically significant interactions among the 2x3x3 knee flexion comparisons, however, practically important trends in the data were observed. The dominant leg produced greater knee flexion angles at all instants and within each maturation group except for three combinations: pre-pubertal at MKF and TO, and pubertal at TO. When isolating for the dominant leg at TO, the difference between the pre-pubertal group's greater knee extension angle and the post-pubertal group's angle, approached significance ($p = .08$). The post-pubertal group had the greatest knee flexion angles amongst all maturation groups at MKF and TO with the dominant leg and also at IC and TO with the non-dominant leg. At IC with the dominant leg and MKF on the non-dominant leg, the pre-pubertal group had the greatest knee flexion angles.

Main Effects

A significant main effect was seen between instants ($F(2,72) = 84.323, p < .05$). Post-

hoc analysis revealed that MKF ($M = 121.3^\circ$, $SD = 2.0$) produced a greater knee flexion angle than IC ($M = 144.7^\circ$, $SD = 1.5$), and TO ($M = 141.8^\circ$, $SD = 3.0$) ($p < .05$). Therefore, participants had a more extended knee at IC and flexed their knee as they moved into MKF. From MKF, participants pivoted and extended at their knee into TO.

There were no significant main effects in the knee flexion angle among maturational groups ($F(2,72) = .578$, $p = .563$) or for leg dominance ($F(1,72) = .048$, $p = .827$).

Hip Flexion Angle

Table 6 presents the group's mean and standard deviation hip flexion angles for the three groups between their dominant and non-dominant leg at the three different instants.

Table 6

Descriptive Statistics for Hip Flexion Angle

Maturation	IC		MKF		TO	
	D($^\circ$)	ND($^\circ$)	D($^\circ$)	ND($^\circ$)	D($^\circ$)	ND($^\circ$)
Pre-Pubertal	133.0 \pm 13.5	133.5 \pm 9.8	111.2 \pm 22.4	111.9 \pm 12.2	135.7 \pm 15.7	130.5 \pm 10.4
Pubertal	133.0 \pm 14.6	127.2 \pm 18.2	112.6 \pm 24.9	107.1 \pm 28.0	137.4 \pm 13.2	126.5 \pm 22.0
Post-Pubertal	141.6 \pm 10.9	132.6 \pm 10.6	119.3 \pm 11.9	114.6 \pm 5.9	133.4 \pm 12.8	135.8 \pm 4.9

Note. Values are presented as mean \pm SD; IC = Initial Contact; MKF = Maximum Knee Flexion; TO = Toe-off; D = Dominant; ND = Non-dominant.

Interaction Effects

There were no significant interaction effects reported, however, there were noteworthy patterns in the data. The pre-pubertal group showed minimal hip flexion differences between legs at IC and MKF. There was, however, a notable 5° greater hip flexion angle difference with the non-dominant leg as compared to the dominant leg at TO. Within the pubertal group, the non-dominant leg had a greater hip flexion angle than the dominant leg at each instant, although mean differences were not statistically significant. Within the post-pubertal group, the non-dominant leg had greater hip flexion than the dominant leg at IC ($M = 132.6^\circ$, $SD = 10.6$; $M =$

135.9°, SD = 13.2, respectively) and MKF (M = 114.6°, SD = 5.9; M = 119.3°, SD = 11.9, respectively), but not at TO (M = 135.8°, SD = 4.9; M = 133.4°, SD = 12.8, respectively); mean differences were not significant.

When isolating for the non-dominant leg, the pubertal group had the greatest hip flexion angle at each instant compared to the other two groups. In addition, the post-pubertal group had the smallest hip flexion angle at MKF and TO (when performing with their non-dominant leg). In regards to the dominant leg, the pre-pubertal group had the greatest hip flexion angle at IC and MKF, with the post-pubertal group having the smallest angle. Interestingly, at TO, the post-pubertal group had the greatest hip flexion angle value.

Main Effects

Significant differences were seen for hip flexion angles among the instants ($F(2,72) = 122.303, p < .05$). Participants had a greater hip flexion angle at MKF (M = 112.8°, SD = 4.0) as compared to IC (M = 133.5°, SD = 4.6) and TO (M = 133.2°, SD = 4.1).

Although there was no main effect between leg dominance ($F(1,48) = 1.138, p = .29$), the non-dominant leg (M = 124.4°, SD = 10.5) did show more hip flexion than the dominant leg (M = 128.6°, SD = 11.2). There was also no significant main effect among the three maturational groups ($F(2,48) = .696, p = .504$). The pubertal group (M = 124.0°, SD = 11.8) had greater hip flexion than the post-pubertal group (M = 129.5°, SD = 10.4), but the difference was not statistically significant ($p = .438$). The pre-pubertal group (M = 126.0°, SD = 11.3) had a mean hip flexion value that was in between the two groups. There was no significant difference observed between IC and TO ($p = 1.0$).

Hip Adduction/Abduction Angle

Table 7 presents the mean and standard deviation hip abduction angles for the three

groups between their dominant and non-dominant leg at the three different instants.

Table 7

Descriptive Statistics for Hip Adduction/Abduction Angle

Maturation	IC		MKF		TO	
	D(°)	ND(°)	D(°)	ND(°)	D(°)	ND(°)
Pre-Pubertal	103.7 ± 6.5	107.5 ± 4.3	102.0 ± 8.6	104.3 ± 4.8	106.1 ± 8.5	109.5 ± 3.8
Pubertal	106.1 ± 5.0	106.4 ± 7.8	103.5 ± 3.4	104.6 ± 6.9	105.9 ± 5.7	108.0 ± 7.4
Post-Pubertal	107.6 ± 4.1	106.7 ± 7.2	104.3 ± 4.1	104.7 ± 7.4	107.7 ± 4.7	112.4 ± 4.7

Note. Values are presented as mean ± SD; IC = Initial Contact; MKF = Maximum Knee Flexion; TO = Toe-off; D = Dominant; ND = Non-dominant.

Interaction Effects

There were no overall significant differences between maturation, instant, and leg dominance, although there were some noteworthy trends. The dominant hip adduction angle was greater than the non-dominant angle within each group and at each instant except in the post-pubertal group at IC. The post-pubertal group had the greatest hip abduction angle with the dominant leg at IC as compared to the less mature groups, which supported the hypothesis. Also in support of the hypothesis, the dominant leg showed larger hip adduction angles than the non-dominant leg at TO within each group.

Main Effects

There was a significant main effect among instants ($F(2, 47) = 20.740, p < .05$). Post-hoc analysis revealed a significantly smaller hip abduction angle at MKF ($M = 103.9^\circ, SD = 1.0$) than at IC ($M = 106.3^\circ, SD = 1.4$) and TO ($M = 108.3^\circ, SD = 2.4$).

There was no main effect among the maturational groups ($F(2, 48) = .559, p = .576$) or between leg dominance ($F(1, 48) = 1.804, p = .185$). However, it was practically important to note that the post-pubertal group ($M = 107.2^\circ, SD = 2.9$) had greater hip abduction than the pre-pubertal ($M = 105.5^\circ, SD = 2.7$) and the pubertal group ($M = 105.7^\circ, SD = 1.5$). Participants'

dominant leg ($M = 105.2^\circ$, $SD = 1.9$) had a greater hip adduction angle than the non-dominant leg ($M = 107.1^\circ$, $SD = 2.6$) but mean differences were not significant ($F(1,48) = 1.804$, $p = .185$).

Thigh Rotation Angle

Table 8 presents the mean and standard deviation thigh rotation angles for the three groups between their dominant and non-dominant leg at the three different instants.

Table 8

Descriptive Statistics for Thigh Rotation Angle

Maturation	IC		MKF		TO	
	D($^\circ$)	ND($^\circ$)	D($^\circ$)	ND($^\circ$)	D($^\circ$)	ND($^\circ$)
Pre-Pubertal	41.9 \pm 4.3	45.8 \pm 3.7	35.1 \pm 8.0	37.5 \pm 8.7	39.1 \pm 6.4	41.8 \pm 4.9
Pubertal	40.4 \pm 5.8	42.4 \pm 5.5	40.4 \pm 5.8	38.5 \pm 6.3	36.4 \pm 6.5	40.6 \pm 3.8
Post-Pubertal	42.8 \pm 5.5	43.2 \pm 5.3	31.6 \pm 5.2	33.6 \pm 8.5	37.8 \pm 6.5	40.3 \pm 5.0

Note. Values are presented as mean \pm SD; IC = Initial Contact; MKF = Maximum Knee Flexion; TO = Toe-off; D = Dominant; ND = Non-dominant.

Interaction Effects

There were no overall significant interaction effects between maturation, instant, and leg dominance, although there were some noteworthy trends. The non-dominant leg generally had a greater internal rotation angle than the dominant leg within each group at each instant.

Main Effects

There was a significant main effect for mean change between instants ($F(2,47) = 56.357$, $p < .05$). Post-hoc analysis revealed that each instant significantly differed from one another. From IC ($M = 42.7^\circ$, $SD = 1.8$) to MKF ($M = 34.7^\circ$, $SD = 3.3$) participants externally rotated, and then internally rotated from MKF to TO ($M = 39.3^\circ$, $SD = 2.0$).

The mean difference between leg dominance approached statistical significance as the non-dominant leg ($M = 40.4^\circ$, $SD = 3.6$) had a significant greater internal rotation than the

dominant leg ($M = 37.5^\circ$, $SD = 3.6$) ($F(1,72) = 15.473$, $p = .053$). Although there were no significant differences between maturation groups ($F(2,48) = .732$, $p = .486$), the pre-pubertal ($M = 40.2^\circ$, $SD = 3.8$) group's thigh had greater internal rotation than both the pubertal ($M = 38.4^\circ$, $SD = 2.1$; $p = .980$) and post-pubertal ($M = 38.2^\circ$, $SD = 4.8$; $p = .835$) groups.

Shank Rotation Angle

Table 9 presents the mean and standard deviation shank rotation angles for the three groups between their dominant and non-dominant leg at the three different instants.

Table 9

Descriptive Statistics for Shank Rotation Angle

Maturation	IC		MKF		TO	
	D($^\circ$)	ND($^\circ$)	D($^\circ$)	ND($^\circ$)	D($^\circ$)	ND($^\circ$)
Pre-Pubertal	48.3 \pm 5.0	51.3 \pm 6.8	39.4 \pm 7.4	42.5 \pm 9.9	47.1 \pm 6.9	48.2 \pm 8.6
Pubertal	50.7 \pm 4.1	47.6 \pm 6.0	40.7 \pm 8.1	36.1 \pm 8.8	46.6 \pm 6.8	41.7 \pm 10.3
Post-Pubertal	50.1 \pm 4.4	51.8 \pm 5.1	42.3 \pm 6.3	45.0 \pm 6.8	48.3 \pm 5.1	52.0 \pm 7.8

Note. Values are presented as mean \pm SD; IC = Initial Contact; MKF = Maximum Knee Flexion; TO = Toe-off; D = Dominant; ND = Non-dominant.

Interaction Effects

There were two significant interaction effects observed between the post-pubertal and the pubertal groups with respect to shank rotation angle. The post-pubertal group's had a greater shank internal rotation angle with the non-dominant leg at both MKF ($F(2,48) = 3.052$, $p < .05$) and TO ($F(2,48) = 3.669$, $p < .05$).

There were no significant interactions within the maturational groups when comparing leg dominance at any of the three instants. Notably, the pre-pubertal and post-pubertal group's non-dominant leg had greater internal rotation than the dominant leg at each instant, where the opposite occurred within the pubertal group.

Main Effects

A significant main effect was observed among instants ($F(2,47) = 80.221, p < .05$). Post-hoc analysis revealed significant mean differences among all instants, and there was a greater internal rotation angle at IC ($M = 50.0^\circ, SD = 1.7$) than both MKF ($M = 41.0^\circ, SD = 3.0$) and TO ($M = 47.1^\circ, SD = 3.3$). Participants externally rotated their shank from IC to MKF; then internally rotated from MKF to TO to a larger internal rotation angle than seen at IC. The thigh also showed this rotational pattern.

There was no main effect among the maturational groups ($F(2,48) = 2.082, p = .14$), however, the pubertal group ($M = 43.9^\circ, SD = 5.3$) was noticeably more externally rotated than the post-pubertal group ($M = 48.3^\circ, SD = 3.9$). The pre-pubertal group's thigh rotation mean value was in between the other two maturational groups ($M = 46.2^\circ, SD = 4.4$). There was no significant difference between leg dominance ($F(1,48) = .009, p = .927$).

Contact Time

Table 10 presents the mean and standard deviation for contact time among the three groups and between their dominant and non-dominant leg.

Table 10

Descriptive Statistics for Contact Time

Maturation	Dominant Leg (seconds)	Non-Dominant Leg (seconds)
Pre-pubertal	0.31 ± 0.10	0.32 ± 0.06
Pubertal	0.31 ± 0.09	0.31 ± 0.09
Post-Pubertal	0.37 ± 0.12	0.34 ± 0.12

Interaction Effects

There were no significant interaction effects observed between leg dominance and maturational groups, although there was a noteworthy trend. The pre-pubertal group's dominant leg ($M = 0.31, SD = 0.99$) had a notably shorter contact time as compared to the post-pubertal

group's dominant leg ($M = 0.37$, $SD = 0.12$), ($p = .241$).

Main Effects

There were no main effects among maturational groups ($F(2,24) = .604$, $p = .555$) or between leg dominance ($F(1,24) = .411$, $p = .528$).

Discussion

The purpose of this study was to determine the effects of maturation and leg dominance on kinematic values during a 180° pivot maneuver among healthy female soccer players. Although the pre-pubertal group had greater thigh internal rotation angles, which are ACL kinematic characteristics known to increase the risk on an ACL injury; it is the post-pubertal group's kinematic combinations on the dominant leg that would place them at the greatest risk for an ACL injury. They had the smallest hip flexion angles, the largest hip abduction angles at IC, and a potentially injurious knee flexion/extension pattern. In addition, the post-pubertal group was observed to take the longest time (in seconds) during the maneuver on their dominant leg than any other group's dominant or non-dominant leg, which could be explained by the greater ranges of motion needed to decelerate.

Knee Flexion Angle

The knee kinematics were similar to those described by Greig (2009) and Cortes et al. (2011). From IC to MKF, participants exhibited a movement into knee flexion (flexion phase), whereas from MKF to TO, participants extended at their knee to push-off. Young et al., (2002) stated that in order to produce a fast change of direction, it is desirable to perform smaller flexion angles at the knee and at the hip.

It was hypothesized that the pre-pubertal group would have larger peak knee flexion angles than the pubertal and post-pubertal groups. The results did not support this hypothesis, as there were no significant differences among the maturational groups ($p = 1.00$). When considering that the majority of ACL injuries in the United States are seen in female soccer players between 14-18 years of age (Shea et al., 2004), the post-pubertal group (14.8 ± 2.0 years) in the current study is relatively young. This result is similar, however, to the findings of Russel,

Croce, Swartz, and Decoster (2007), where there were no significant differences in knee flexion angles between recreational females of different maturational stages during two different landing maneuvers.

Within the pre-pubertal group, participants showed greater peak knee flexion angles with the non-dominant leg as compared to the dominant leg. Although it has been suggested that children do not specify foot dominance at a young age, playing soccer may enhance an earlier foot dominance selection (Gabbard & Iteva, 1996; Peters, 1990). Moreover, Velotta et al. (2011) explained that soccer players were more inclined to use their non-dominant leg for stabilizing tasks and their dominant leg for kicking, which would inevitably demand different muscle activation between limbs (Brophy, Backus Pansy, Lyman, & Williams, 2007).

The post-pubertal group had the largest peak knee flexion angle at MKF and TO on the dominant leg. Accordingly, the post-pubertal group's dominant leg had the longest contact time throughout the maneuver, although differences were not statistically significant. This finding may suggest a need to slow their momentum down over a longer period of time because they are, on average, heavier than the less mature groups. In addition, the post-pubertal group showed the greatest MKF angle during the pivot maneuver. Longer contact times with larger knee joint ranges of motion would reduce the magnitude of the ground reaction forces seen after contact, which could help reduce the potential for injury. These results are similar to those of Decker, Torry, Wyland, Sterett, and Steadman (2003) in which nine recreational female athletes (26.4 ± 4.5 years) performed vertical drop-landings off a 60 cm box. Decker et al. (2003) noted that the females landed with a more erect posture at IC, subsequently resulting in greater knee ranges of motion throughout the rest of the landing phase to transfer absorbed energy. The more erect posture at IC was explained through the lack of hip musculature activation, which resulted in

higher GRFs on the knee (and the ankle). Although upper body kinematics were not examined in the current study, it is possible that a similar strategy was adopted in the post-pubertal group. The post-pubertal group had the greatest hip flexion angles at MKF and TO but not at IC, which could be caused by a delay in hip flexion imposing greater reliance and higher GRFs on the knee at initial ground contact. This can be further supported by female's energy absorption distribution of 40%, 41%, and 19% to the ankle plantarflexor and knee and hip extensor muscles, respectively during a landing activity (Devita & Skelly, 1992). Moreover, Mclean, Lipfert and van den Bogert (2004) also observed greater knee and hip flexion angles during the plant and turn phase of a 30-40° sidestep cut in 8 female participants (21.4 ± 3.2 years of age). Larger flexion angles occurred as a result of having to avoid a simulated defender. Larger angles suggest the need to rapidly decelerate after IC in order to generate enough energy to evade an opponent. Perhaps the results could have been significant in the current study if a simulated defender was used.

These results support the concept of the delayed onset of a balanced muscular coordination and co-contraction between the flexor and extensor muscles surrounding the knee in more mature females (Wojtys & Huston, 1994). This disadvantageous quadriceps-dominant technique places more stress on the various structures of the knee to withhold greater amounts of force (Hewett et al., 2006). The delayed flexion suggests a lack of hamstring and gluteal muscle activity, which may prevent forces from being absorbed at the hip (Hewett et al., 2006).

Interestingly, on the non-dominant leg, the post-pubertal group had the largest knee flexion angles at IC and TO, suggesting a better pivoting strategy than the other two less mature groups.

Decreased knee flexion angle (0-30° flexion, 17-50 ms after IC) has been found to be a

position that is associated with ACL injury (Krosshaug et al., 2007); however, it is unclear as to when an ACL injury would occur within in the current study. At IC, the post-pubertal and pubertal groups had average peak knee flexion angles of 35.6° and 35.2° , respectively which are relatively close to the suggested dangerous range. Coaches should carefully watch and correct players' small knee extension angles, suggesting a more flexed position during the warm-up exercises.

Hip Flexion Angle

As the participants contacted the marker to initiate the maneuver, they had less hip flexion with the pivoting leg. With the forward momentum of the trunk, they moved into greater hip flexion as they reached the position of peak knee flexion at MKF. From MKF into TO, participants moved into a position of less hip flexion. This finding explains that the lower extremity functions as one kinetic chain as the knee and hip move synergistically (Negrete & Brophy, 2000). Hip flexion angles on the dominant leg at IC are similar to the hip angle of 131.7° observed by Cortes et al. (2011). Although the participants in the Cortes et al. study (2011) were division I collegiate female soccer players, the participants in this current study all showed a similar angle, independent of the maturation group.

The smaller peak hip flexion angles observed in the dominant limb within each group may result in higher loads being placed on the knee joint, which is a characteristic of a position that could potentially cause an ACL injury (Chappell et al., 2007). More specifically, this result suggests that the post-pubertal group would have to compensate in another way, potentially absorbing more force at the knee. With a larger hip extension angle, the center of gravity (COG) moves behind and away from the body resulting in an increase in quadriceps contraction (Shimokochi & Shultz, 2008).

Although the pre-pubertal group was hypothesized to have the largest hip flexion angles as compared to the more mature groups, the pubertal group was found to demonstrate larger mean flexion angles. Michel et al. (2010) explained that children were not able to perform higher precision locomotor tasks as effectively as more mature individuals. This suggested that they would be unable to perform the 180° pivot maneuver with greater flexion angles (Michel et al., 2010). The post-pubertal group did demonstrate greater peak hip extension angles as hypothesized, although results were not statistically significant. Yu et al. (2005) evaluated female soccer players between the ages of 11-16 during a stop-jump task and observed significant decreases in both knee and hip flexion angles at both IC and MKF as the age of the participants increased. Although similar increases in hip extension angles with maturation were observed in the current study, statistical differences may be specific to the task demand.

A lack of experience pivoting in games/practices could help explain why there were no significant differences between leg dominance within the pre-pubertal group at IC and MKF. At TO, however, the non-dominant leg had a 5° larger hip flexion angle, which may be linked to the other two more mature groups. As a quick change in direction is associated with shortening concentric and eccentric movement (Young et al, 2002), the pre-pubertal group's dominant leg would have performed the maneuver faster than the non-dominant leg. The effective reliance on the dominant leg during practices and game play could explain these findings. Moreover, the continuation of reliance on the dominant leg over time and the learned and compensatory movement strategies could explain kinematic patterns by the more mature groups that could potentially lead to an ACL injury.

The pubertal group, who have not yet been completely affected by pubertal maturation and have established the ability to perform motor skills (Issacs, 1976), had the largest hip flexion

angles at each instant on the non-dominant leg, which did not support the original hypothesis. The hypothesis was supported, however, on the dominant leg where the pre-pubertal group had the largest peak hip flexion angles over the two more mature groups. Just as the dominant leg within the knee flexion variable showed a more at risk ACL injury characteristic, the same movement pattern was demonstrated here. It is possible that the pubertal group did not demonstrate the largest peak hip flexion angles with the dominant leg because they were starting to exhibit the effects of maturation (Yu et al., 2005). Although the pubertal group is not entirely affected by maturation, the tendency to overcompensate on the dominant side may start to alter kinematic limb differences as performed by the post-pubertal group. Furthermore, these results could be the building block towards the significantly more dominant leg ACL injuries in female players (Faude et al., 2006).

The post-pubertal group had the largest hip extension angle at IC on the dominant leg as compared to the other two less mature groups. Decker et al. (2003) noted that an increase in peak hip extension angle at IC was directly related to a more erect posture. As the previously mentioned, this would result in more energy absorbed by the knee as compared to the hip. As observed in the current study on the dominant leg, the post-pubertal females had the largest knee flexion angles at both MKF and TO, and the least amount of hip flexion at MKF. Perhaps by the time participants are completing the maneuver and approaching TO, females finally start to recruit and activate the appropriate hip musculature. As a result of this proposed timing delay and movement strategy used and the failed neuromuscular control over the knee flexors and extensors, an ACL tear may have already happened (ACL injuries occur 17-50 milliseconds (ms) after IC). Although no literature to date has provided an at risk range for hip flexion angle during an ACL injury, the post-pubertal group's dominant leg would appear to be considered to be at

greater risk.

Hip Adduction/Abduction Angle

Participants initiated the maneuver by abducting their pivoting leg at the hip to reach for the marker at IC. When moving from IC to MKF, the forward momentum of the body propelled the torso closer to the pivoting leg, decreasing the hip abduction angle. As the participants started to extend the pivoting leg after MKF, the non-pivoting leg led the body in the opposite direction creating a larger hip abduction angle at TO.

Abnormal frontal plane kinematics have the potential to affect an increase in ACL injury risk (Hollman et al., 2009; Powers, 2010; Sigward & Powers, 2007). It was hypothesized that the post-pubertal group would demonstrate the largest peak hip abduction angles at IC. Although the results were not statistically significant, the post-pubertal group did show the largest peak hip abduction angles at IC when isolating for the dominant leg, suggesting a greater risk for a potential ACL injury. Considering that most non-contact ACL injuries occur within the first 17-50 ms after IC (Krosshaug et al., 2007), the hip position in the post-pubertal group at IC would suggest an increased potential for injury to the ACL (as compared to the less mature groups).

Moreover, when the foot is firmly contacted with the ground (MKF), larger hip adduction angles have been shown to increase the potential of injuring the ACL (Hollman et al., 2009; Powers, 2010). In addition, Imwalle et al. (2009) found that hip adduction at peak kinetic force (approximately at MKF) was the only significant predictor of knee valgus alignment ($r = .49$) in 19 varsity high school and college female soccer players (17.6 ± 2.1 years) during 90° and 40° cutting maneuvers. Knee abduction was observed to increase when hip adduction angles also increased; thus, suggesting that larger hip adduction angles in post-pubertal females increased the risk of an ACL injury (Imwalle et al., 2009). In the current study, there were no statistically

significant or notable interaction effects at MKF. Perhaps this is because of the homogeneous group of soccer players recruited. Participants of this study, regularly perform drills and exercises from the FIFA 11+ Warm-up Manual, which has been shown to decrease the risk of injury to the lower extremity. It is plausible that all the participants learned to perform dynamic movements in a similar manner, minimizing any differences between leg dominance and the varying effects of maturation.

Although not statistically significant, the dominant leg had larger hip adduction angles at TO, which supported the hypothesis. Therefore, the dominant leg would have a greater potential risk for an ACL injury as compared to the non-dominant leg because larger hip adduction angles after MKF has been shown to increase the risk (Hollman et al., 2009; Powers, 2010). This finding further supports the idea that female players are more likely to injure their dominant leg (Faude et al., 2006).

Increasing hip abduction strength has been reported as a method to prevent ACL injuries (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004). Brent, Myer, Ford, Paterno, and Hewett (2013) directly measured hip abductor strength on a Biodex System 3 Pro isokinetic dynamometer in adolescent soccer and basketball players over three years. The relationship between isokinetic measures and hip abductor strength has not been investigated, however, it has been shown that hip abductor strength plays a key role in controlling valgus knee alignment (Neumann, 2010). Brent et al. (2013) stated that isokinetic hip abductor measures could be related to functional activities, as the testing velocity would represent similar speeds during cutting tasks. Female soccer players have demonstrated increased hip abductor strength with maturation; however, the results were not as noteworthy as their male counterparts. Similarly, it is possible that the post-pubertal soccer players in the current study may not have increased their

hip abductor strength as a consequence of maturation. This could be inferred because they showed the largest hip abduction angles at IC, which could potentially suggest a lack of control over the hip resulting in greater valgus alignment at the knee (Hollman et al., 2009; Neumann, 2010; Powers, 2010).

Thigh and Shank Rotation Angles

Imwalle et al. (2009) stated that peak internal and external rotation of the hip was not a significant predictor of knee valgus alignment as compared to hip adduction. Minimal changes may only be detected for femoral and tibial internal rotation. The hip and knee can perform large ranges of movements during flexion/extension, while internal/external rotations at these joints in reference to the YZ plane have limited range.

Participants externally rotated their thigh and shank from IC to MKF. In conjunction with the previous findings, as the knee and hip flexed and the hip abducted from IC to MKF, the femur and tibia externally rotated. From MKF to TO as the knee and hip started to extend and the hip adducted, the femur and tibia internally rotated. This rotational movement was consistent between both limbs. The consistent rotational pattern between the shank and the upper thigh is hypothesized to decrease stress and strain on the ACL reducing the risk of rupture (Hewett et al., 2005). An incongruent rotational combination, however, places the ACL at a higher risk of injury (Hewett et al., 2005). For example, external rotation of the tibia (shank) coupled with internal hip rotation (femur) would create a greater risk for ACL injury.

Increased hip internal rotation and external tibial rotation are known contributors to ACL loading that could lead to ACL rupture (Hewett et al., 2005; Kristianslund et al., 2014). Interestingly, the non-dominant hip had the largest peak internal rotation angles compared to the dominant leg within each group and at each instant, which is inconsistent with the previous

kinematic variables and hypothesis of the current study (Hewett et al., 2005). Considering there was no significant difference between leg dominance when comparing shank rotation angle, the position of the non-dominant leg may suggest a greater likelihood of sustaining an ACL injury.

Interestingly, there was a significant difference between the peak shank internal rotation angle of the post-pubertal group and that of the pubertal group's non-dominant leg at MKF and TO, with a larger angle seen in the post-pubertal group. The post-pubertal group was able to properly perform the maneuver with more control (with respect to the shank) over the pubertal group. During the adolescent period, the tibia and the femur grow rapidly (PHV), which may disrupt balancing abilities. Considering PHV occurs in North American females around 11.8 years of age, and that the pubertal group in the current study were 12 ± 1.4 years of age, the lack of control over lower extremity rotations could be explained by these motor performance disruptions (Payne & Isaacs, 2008; Tanner & Davies, 1989). Although not statistically significant, the post-pubertal and pubertal group's dominant leg had greater peak tibial external rotation than the non-dominant leg.

Although the results were not statistically significant, the hypothesis was not supported as the pre-pubertal group had greater peak thigh internal rotation angles than the more mature groups. In terms of shank rotation, the pubertal group had the largest peak mean external rotation angles. No specific group would be at a greater potential risk for an ACL injury (with respect to internal/external thigh and shank rotation values) because two different groups obtained the largest peak internal and peak external rotation values. If one group had obtained both the largest peak internal thigh and external shank rotation values, this counteractive combination would suggest a great potential for injury. Similar to the larger rotational movements in the pre-pubertal group, Sigward et al. (2012) found that pre-pubertal female soccer players (10.1 ± 0.3 years of

age) performed sidestep cuts at 45° and 110° with greater impact forces on the shank that would increase knee valgus alignment as compared to more mature counterparts. Although Sigward et al. (2012) did not directly evaluate internal rotation angles, general inferences can be drawn that pre-pubertal female soccer players have not fully developed locomotor skills to enable them to mechanically perform complex movements such as the 180° pivot maneuver. The difference between the current study and that of Sigward et al. (2012) is that participants in the latter study were subjected to a simulated defender. The presence of this defender may have magnified the difficulty with which pre-pubertal children perform an agility task (Sigward et al., 2012). Moreover, when controlling for velocity, the pre-pubertal group still exhibited a pattern that posed a greater risk for injury (Sigward et al., 2012). Conversely, other studies evaluating the effects of maturation of lower extremity kinematics have suggested that more mature athletes perform agility tasks with movement patterns producing greater frontal loads potentially contributing to a situation for an ACL injury (Ford et al., 2006; Yu et al., 2005).

Practical Application of the Results

All players within the Lakehead Express Soccer Club perform components of the FIFA 11+ Manual during warm-ups. The head coaches are responsible for ensuring that the players perform the running/cutting exercises correctly, with “posture and good body control, including straight leg alignment, knee-over-toe position and soft landings” (F-MARC, 2007, p.6). These exercises focus on “core strength, neuromuscular control and balance, eccentric training of the hamstrings, plyometric and agility” (F-MARC, 2007, p.8). For example, the exercise “Circling Partner”, consists of shuffling sideways at 90° to and completely around a given partner. This movement, when performed properly, focuses on both knee and hip flexion while being light on one’s toes preventing valgus alignment. Although the local club implements the FIFA 11+ injury

prevention warm-up, it is unclear whether the coaches properly recognize and instruct/alter any observed mechanical problems. Therefore, the club should educate and mandate coaches to closely watch for and make corrections to technique, which may be potentially injurious when observed.

The ability to change direction quickly is an essential key component in the game of soccer in order to succeed, especially at a faster game play (Reilly et al., 2000). As a result, minimal hip and knee flexion may help achieve this quick movement. Consequently, the less hip flexion observed with the post-pubertal group may contribute to an ACL injury (Hewett et al., 2005). Correct mechanical movements should be slowed down for all athletes during training to enforce a greater hip flexion angle during these movements.

The fact that all participants are from the same club and regularly perform the same warm-up exercises could possibly explain the lack of significant maturational differences. If the FIFA 11+ manual is instructed properly at the youngest age, the risk of future injuries may be reduced. Proper technique should be constantly evaluated so that the surrounding muscles over time become accustomed to unpredictable movements in game and/or practice situations; especially during a match when fatigue has been shown to increase valgus alignment (Greig, 2009).

Myer, Ford, Brent, and Hewett (2007) observed knee kinematics and kinetics in high-risk (larger knee abduction values) and low-risk female soccer and basketball players during a drop vertical jump. Participants were tested before and after a neuromuscular training program. The high-risk female athletes showed significant reductions in knee abduction profiles, whereas the low-risk group did not show significant reductions. Thus, this suggests the importance of identifying the high-risk female athletes and subjecting them to a neuromuscular training

program to aid in the reduction of ACL injuries. If pre-pubertal players were identified as high-risk athletes, improper performance techniques would be attributed to a lack of technical skill/knowledge, as they would not be affected by maturation. On the other hand, if pubertal and post-pubertal players were identified as high-risk, their improper techniques could be associated with maturational effects. Neuromuscular training should be incorporated into training regimes for all players. Focus should be directed towards IC during different dynamic activities based on the findings of more at risk kinematic positions demonstrated by the post-pubertal group in the current study. Standard screening measuring knee joint stability should be incorporated prior to the start of season and throughout defined intervals. Individual evaluations can be conducted during the FIFA 11+ warm-up exercises by practitioners or educated coaches to ensure proper technique is achieved and also to identify high-risk athletes. Identifying these at risk athletes and coaching proper mechanics during dynamic activities could aid in decreasing the 3-3.6 times greater ACL injury risk that exists between genders (Agel et al., 2005). Although there is a greater risk for females to injure their ACL, it may also be suggested that the same intervention should be carried out in male athletes. This would allow youth to continue staying active and healthy while avoiding the long-term damaging effects of a knee injury including the subsequent development of osteoarthritis (Lohmander et al., 2004; Mykle & Bahr, 2005).

Conclusion

The results of this study suggest that post-pubertal females pivoting with their dominant leg, perform kinematic patterns that may lead to a greater risk for an ACL injury during a 180° pivot maneuver as compared to less mature players on the non-dominant leg. Upon entering into the maneuver at IC, the knee and the hip extend for contact while abducting at the hip. In addition, the femur and the tibia are more internally rotated as they follow the kinematic chain with the foot turning perpendicular to the path of entry. The knee and hip then flex while the hip decreases the hip abduction angle more from IC to MKF. The femur and tibia externally rotate during this instant change. When moving from MKF to TO, the knee and hip start to extend, the hip abducts, while the thigh and shank internally rotate.

Although the pre-pubertal group had greater thigh internal rotation angles, the post-pubertal group's overall characteristics placed them at greater risk for an ACL injury. In addition, the dominant leg had larger knee extension angles and reduced hip flexion angles than the non-dominant leg, which are kinematics known to increase the possibility of ACL injury. Considering that rotational movements at the thigh and shank were observed not to be key predictors of an ACL injury (Imwalle et al., 2009), the dominant leg would be at greater risk than the non-dominant leg.

Future Research

Repeating the current study using a longitudinal design may account for individual differences, which is not understood through the cross-sectional designs utilized in the research completed to date. Future research should also examine the kinematic with kinetic variables along with GRF to determine if there are in fact greater forces and joint moments produced with the greater speed. Perhaps a backward stepwise linear regression could be used to investigate the

associations between the independent variables of the current study and peak knee abduction moments, as it is the greatest known kinematic variable that may lead to an ACL injury (Hewett et al., 2005).

Delimitations

This study was delimited to the female soccer players on the U10, U14, and U18 teams within the Lakehead Express Soccer Club. The participants were subdivided into only three maturational stages based on the modified PMOS: pre-pubertal, pubertal, and post-pubertal (Sigward et al., 2012). Additionally, the study only observed right-foot dominant players in order to relate findings to the current literature (Cortes et al., 2011; Greig, 2009). The movement analyzed is delimited to the 180° pivot maneuver, which is the most soccer related maneuver when compared to smaller turn angles such as the 45° or 90° turn (Cortes et al., 2011; Greig, 2009). The variables of interest were delimited to the knee and hip kinematics (knee flexion/extension, hip flexion/extension, hip adduction/abduction, thigh internal/external rotation, and tibial internal/external rotation).

Assumptions

Instructions were explicitly provided via script and data collection procedures were undertaken in an identical format for each participant. It was assumed that the participants performed the 180° pivot maneuver as described in testing the protocol at maximal effort and as demonstrated by the student researcher. It was also assumed that the instruments used in this study were reliable and valid for the population being tested. For example, as previously noted, the PMOS has been shown to be highly valid to differentiate females through the pubertal stages ($r = .96$ for females) (Davies & Rose, 2000). The video analysis system was verified through high precision and accuracy of the directed study. Participants performed similar movement

patterns on a gym floor at the training site in which weekly practices were completed (similar to the flooring used in this testing). Therefore, with the descriptive and explicit instructions, visual demonstrations, practice trials, and exclusion criteria, the participants were anticipated to perform one maneuver sufficiently for data analysis.

Limitations

One limitation of this study is that there were only two high-speed Basler digital video cameras used to collect data in comparison to an eight or nine camera system set-up (Imwalle et al., 2009; Greig, 2009; Cortes, Onate, & Van Lunen, 2011). More than two cameras allow for marker positions to be easily reconstructed, whereas a two-camera system may not easily show all markers. When the reflective markers were not seen in a frame of time, the researcher was required to extrapolate the position. The placement of cameras followed the proposed method by Martin and Pongrantz (1974) that compels the optical axes of the two cameras to be orthogonally aligned and intersecting.

The study was limited to analyzing only one trial for each participant's dominant and non-dominant limb. In addition, another limitation of the current study was that testing was conducted in a controlled laboratory and without the use of a simulated defender. Mclean et al. (2004) observed increased knee angles with the anticipation of evading the opponent while Besier et al. (2001) observed significant increased peak valgus and internal/external knee moments with an unknown anticipation factor. The current values may not be directly affected, but they may be underestimated as compared to movements that occur during regular game situations. Marker application and reapplication may have also contributed to decreased reliability. These errors were, however, reduced by a single marker applicator, the student researcher. Although the created kinematic model requires a high degree of subjective

assessment, this method is associated with lower reliability (Kadaba et al., 1989).

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Appendix 1

Physical Activity Readiness Questionnaire (Par-Q+)

PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

Regular physical activity is fun and healthy, and more people should become more physically active every day of the week. Being more physically active is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

SECTION 1 - GENERAL HEALTH

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.		YES	NO
1.	Has your doctor ever said that you have a heart condition OR high blood pressure?	<input type="checkbox"/>	<input type="checkbox"/>
2.	Do you feel pain in your chest at rest, during your daily activities of living, OR when you do physical activity?	<input type="checkbox"/>	<input type="checkbox"/>
3.	Do you lose balance because of dizziness OR have you lost consciousness in the last 12 months? Please answer NO if your dizziness was associated with over-breathing (including during vigorous exercise).	<input type="checkbox"/>	<input type="checkbox"/>
4.	Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)?	<input type="checkbox"/>	<input type="checkbox"/>
5.	Are you currently taking prescribed medications for a chronic medical condition?	<input type="checkbox"/>	<input type="checkbox"/>
6.	Do you have a bone or joint problem that could be made worse by becoming more physically active? Please answer NO if you had a joint problem in the past, but it does not limit your current ability to be physically active. For example, knee, ankle, shoulder or other.	<input type="checkbox"/>	<input type="checkbox"/>
7.	Has your doctor ever said that you should only do medically supervised physical activity?	<input type="checkbox"/>	<input type="checkbox"/>

If you answered NO to all of the questions above, you are cleared for physical activity.



Go to Section 3 to sign the form. You do not need to complete Section 2.

- › Start becoming much more physically active – start slowly and build up gradually.
- › Follow the Canadian Physical Activity Guidelines for your age (www.csep.ca/guidelines).
- › You may take part in a health and fitness appraisal.
- › If you have any further questions, contact a qualified exercise professional such as a CSEP Certified Exercise Physiologist® (CSEP-CEP) or CSEP Certified Personal Trainer® (CSEP-CPT).
- › If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.



If you answered YES to one or more of the questions above, please GO TO SECTION 2.



Delay becoming more active if:

- › You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better
- › You are pregnant – talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- › Your health changes – please answer the questions on Section 2 of this document and/or talk to your doctor or qualified exercise professional (CSEP-CEP or CSEP-CPT) before continuing with any physical activity programme.

SECTION 2 - CHRONIC MEDICAL CONDITIONS

Please read the questions below carefully and answer each one honestly: check YES or NO.		YES	NO
1.	Do you have Arthritis, Osteoporosis, or Back Problems?	<input type="checkbox"/> If yes, answer questions 1a-1c	<input type="checkbox"/> If no, go to question 2
1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	<input type="checkbox"/>	<input type="checkbox"/>
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	<input type="checkbox"/>	<input type="checkbox"/>
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	<input type="checkbox"/>	<input type="checkbox"/>
2.	Do you have Cancer of any kind?	<input type="checkbox"/> If yes, answer questions 2a-2b	<input type="checkbox"/> If no, go to question 3
2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and neck?	<input type="checkbox"/>	<input type="checkbox"/>
2b.	Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?	<input type="checkbox"/>	<input type="checkbox"/>
3.	Do you have Heart Disease or Cardiovascular Disease? This includes Coronary Artery Disease, High Blood Pressure, Heart Failure, Diagnosed Abnormality of Heart Rhythm	<input type="checkbox"/> If yes, answer questions 3a-3e	<input type="checkbox"/> If no, go to question 4
3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	<input type="checkbox"/>	<input type="checkbox"/>
3b.	Do you have an irregular heart beat that requires medical management? (e.g. atrial fibrillation, premature ventricular contraction)	<input type="checkbox"/>	<input type="checkbox"/>
3c.	Do you have chronic heart failure?	<input type="checkbox"/>	<input type="checkbox"/>
3d.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer YES if you do not know your resting blood pressure)	<input type="checkbox"/>	<input type="checkbox"/>
3e.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	<input type="checkbox"/>	<input type="checkbox"/>
4.	Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes	<input type="checkbox"/> If yes, answer questions 4a-4c	<input type="checkbox"/> If no, go to question 5
4a.	Is your blood sugar often above 13.0 mmol/L? (Answer YES if you are not sure)	<input type="checkbox"/>	<input type="checkbox"/>
4b.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, and the sensation in your toes and feet?	<input type="checkbox"/>	<input type="checkbox"/>
4c.	Do you have other metabolic conditions (such as thyroid disorders, pregnancy-related diabetes, chronic kidney disease, liver problems)?	<input type="checkbox"/>	<input type="checkbox"/>
5.	Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome)	<input type="checkbox"/> If yes, answer questions 5a-5b	<input type="checkbox"/> If no, go to question 6
5a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	<input type="checkbox"/>	<input type="checkbox"/>
5b.	Do you also have back problems affecting nerves or muscles?	<input type="checkbox"/>	<input type="checkbox"/>

Please read the questions below carefully and answer each one honestly: check YES or NO.		YES	NO
6.	Do you have a Respiratory Disease? This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure	<input type="checkbox"/> If yes, answer questions 6a-6d	<input type="checkbox"/> If no, go to question 7
	6a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	<input type="checkbox"/>	<input type="checkbox"/>
	6b. Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	<input type="checkbox"/>	<input type="checkbox"/>
	6c. If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	<input type="checkbox"/>	<input type="checkbox"/>
	6d. Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	<input type="checkbox"/>	<input type="checkbox"/>
7.	Do you have a Spinal Cord Injury? This includes Tetraplegia and Paraplegia	<input type="checkbox"/> If yes, answer questions 7a-7c	<input type="checkbox"/> If no, go to question 8
	7a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	<input type="checkbox"/>	<input type="checkbox"/>
	7b. Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	<input type="checkbox"/>	<input type="checkbox"/>
	7c. Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	<input type="checkbox"/>	<input type="checkbox"/>
8.	Have you had a Stroke? This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event	<input type="checkbox"/> If yes, answer questions 8a-c	<input type="checkbox"/> If no, go to question 9
	8a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	<input type="checkbox"/>	<input type="checkbox"/>
	8b. Do you have any impairment in walking or mobility?	<input type="checkbox"/>	<input type="checkbox"/>
	8c. Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	<input type="checkbox"/>	<input type="checkbox"/>
9.	Do you have any other medical condition not listed above or do you live with two chronic conditions?	<input type="checkbox"/> If yes, answer questions 9a-c	<input type="checkbox"/> If no, read the advice on page 4
	9a. Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months OR have you had a diagnosed concussion within the last 12 months?	<input type="checkbox"/>	<input type="checkbox"/>
	9b. Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	<input type="checkbox"/>	<input type="checkbox"/>
	9c. Do you currently live with two chronic conditions?	<input type="checkbox"/>	<input type="checkbox"/>

Please proceed to Page 4 for recommendations for your current medical condition and sign this document.

PAR-Q+



If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active:

- › It is advised that you consult a qualified exercise professional (e.g., a CSEP-CEP or CSEP-CPT) to help you develop a safe and effective physical activity plan to meet your health needs.
- › You are encouraged to start slowly and build up gradually – 20-60 min. of low- to moderate-intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- › As you progress, you should aim to accumulate 150 minutes or more of moderate-intensity physical activity per week.
- › If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.



If you answered YES to one or more of the follow-up questions about your medical condition:

- › You should seek further information from a licensed health care professional before becoming more physically active or engaging in a fitness appraisal and/or visit a or qualified exercise professional (CSEP-CEP) for further information.



Delay becoming more active if:

- › You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better
- › You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- › Your health changes - please talk to your doctor or qualified exercise professional (CSEP-CEP) before continuing with any physical activity programme.

SECTION 3 - DECLARATION

- › You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- › The Canadian Society for Exercise Physiology, the PAR-Q+ Collaboration, and their agents assume no liability for persons who undertake physical activity. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.
- › If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.
- › Please read and sign the declaration below:

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that they maintain the privacy of the information and do not misuse or wrongfully disclose such information.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

For more information, please contact:
Canadian Society for Exercise Physiology
www.csep.ca

KEY REFERENCES

1. Jamnik VJ, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the effectiveness of clearance for physical activity participation; background and overall process. APNM 36(S1):S3-S13, 2011.
2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or BC Ministry of Health Services.

Appendix 2

Sports Background Questionnaire

Sports Background Questionnaire

Name: _____

Birth Date: _____ (MM/DD/YYYY)

Total number of hours played per year: _____

Foot dominance: _____

Please leave the following three spaces blank:

Height: _____ (cm)

Leg Length: _____ (cm)

Weight: _____ (kg)

Appendix 3

Pubertal Maturation Observation Scale (PMOS)

Female Pubertal Maturation Observational Scale form

Female Characteristic Checklist

- _____ The adolescent has grown 3 to 3.5 inches in the past 6 months or is past this growth spurt.
- _____ The adolescent has begun breast development.
- _____ The adolescent has begun menarche.
- _____ The adolescent has evidence of darker underarm hair or shaves.
- _____ The adolescent has evidence of darker hair on her legs or shaves.
- _____ The adolescent's calves are becoming defined.
- _____ The adolescent has evidence of acne.
- _____ There was evidence of sweating after physical activities.

KEY: + characteristic is present _ characteristic is absent

SCORING CRITERIA FOR FEMALES

STAGES NUMBER OF “+” Prepuberty 1 or less Pubertal 2 - 5 Postpubertal at least 6; growth spurt completed

Appendix 4

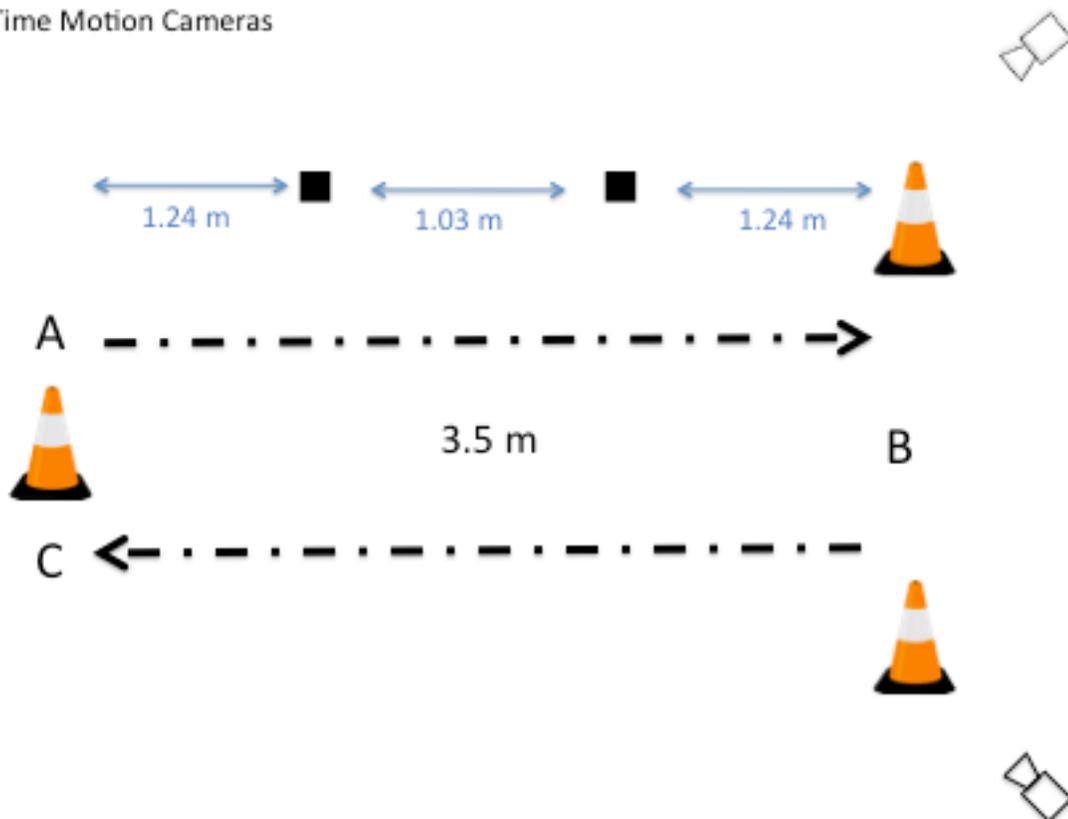
180° Pivot Maneuver Test

180° Pivot Maneuver Test

The 180° Pivot Maneuver Test will be setup based on the test used by Greig (2009). The researcher will initiate the test with the participant starting in a staggered two-point stance with feet shoulder width apart beside cone A. The participant will perform a maximal effort movement to a distance of 3.5 m from cone A to cone B. Upon reaching cone B, the participant will perform a 180° pivot maneuver with either their dominant or non-dominant foot. The foot that will be used to pivot will be randomly assigned and told to the participant before each trial. Leaving cone B, the participants will follow the same direction path as entry with a maximal effort sprint towards cone C. The total distance to travel is 7.0 m, however, the participants will be allowed to pass cone C to decelerate and come to a stop. Trials will be disqualified and repeated if the participant: steps over the pivoting marker, pivots with the wrong foot, or falls at any point. All trials will be video recorded using 2 high-speed cameras. One trial will be used for data analysis from both pivot variations. The faster of the two trials will be used. The other trials will be kept but not analyzed.

■ Wireless Timing System

□ Time Motion Cameras



Appendix 5

Recruitment Form Re: U10, U12, and U18 Players

Dear prospective participant's parent or guardian,

Your daughter is invited to participate in the following research project entitled, "The Effect of Limb Dominance on Lower Limb Kinematics During a 180° Pivot Maneuver in Healthy Female Soccer Players at Three Different Stages of Physical Maturation". This project will be conducted by Vanessa Smykalski, a graduate student in the School of Kinesiology at Lakehead University, supervised by Dr. Derek Kivi. Your daughter is being asked to volunteer because she is a healthy female athlete who is a member of the Lakehead Express soccer club on either the Under-10, Under-12, or Under-18 teams. Furthermore, your daughter will be asked to participate if she responds to the question "If you are asked to kick the ball far up the field, which foot would you use?" by indicating that she would use her right foot.

The purpose of this study is to evaluate the effect of leg dominance on lower limb movements during a maximal effort acceleration coupled with a 180° pivot maneuver. Prior to participation in this study, you and your daughter will both sign the attached consent form, and then you will assist your daughter in completing the Physical Activity Readiness Questionnaire (Par-Q+), the Pubertal Maturation Observation Scale (PMOS), and Sports Background Questionnaire. The Par-Q+ will be used to ensure the participants are healthy and aware of their entitlements. The Sports Background Questionnaire will be used to collect demographic data including: name, date of birth, number of hours played per year, foot dominance, height, leg length, and mass. The PMOS will then be used to identify your daughter's maturational stage: pre-pubertal, pubertal, or post-pubertal. This Scale categorization is based on the following characteristics: menarche and breast development, increased perspiration with physical activity, body hair, acne, muscle development, and growth spurt.

She will be asked to attend one testing session, which will take place in C.J. Sanders Fieldhouse at Lakehead University. She will be asked to refrain from any physical activity 24 hours prior to the examination time in order to minimize the possibility of muscle fatigue. The session will require approximately 60 minutes of her time.

After the consent form is signed and the Par-Q+ and Sports Background questionnaire are completed, the student researcher will measure her height, leg length, and weight. She will then complete a warm-up on a stationary bike for 10 minutes followed by exercises adapted from the FIFA 11+ Warm-up Manual Part 1: Running Exercises. These exercises are the same as those used in your daughter's current warm-ups with the club team. The following exercises will be included and adapted to only two cones 6 m apart:

- Running Straight Ahead – Jog to the cone and back two times.
- Running Hip Out – Jog towards the cone, stop and lift your right knee level to your hip, and rotate it to the right side and back down in one continuous movement. Turn to face the start cone and repeat the same exercise. The same movements will be performed in the same manner with the left leg.
- Running Hip In – Jog towards the cone, stop and lift your right knee to the side level to your hip, and rotate it in and back down in one continuous movement. Turn to face the start cone and repeat the same exercise. The same movements will be performed in the same manner with the left leg.
- Running Circling Pattern – Jog towards the cone, shuffle 3 steps to the left at 90°, shuffle an entire circle (keeping hips facing forward), and then back to the cone. Participant's arms will be beside their body for balance purposes. Turn around complete

the previous same steps to the start cone but shuffle to the right at 90° instead. Repeat this sequence twice.

After the warm-up is completed, she will have 21 retro-reflective markers placed on her body using two-sided adhesive tape in the following specific locations:

- Mid sternum
- Shoulder joint (left and right)
- Elbow joint (left and right)
- Wrist joint (left and right)
- Lateral hip (left and right)
- Mid thigh (left and right)
- Knee joint (left and right)
- Mid shank (left and right)
- Lateral ankle (left and right)
- Heel (left and right)
- Lateral foot near small toe (left and right)

The markers will be used to track her movement to assist with the analysis.

Following the placement of the markers, the agility test will be demonstrated for completing the pivoting maneuver on both dominant and non-dominant legs. She will be allowed one sub-maximal practice trial using each leg to complete the 180° pivot maneuver and allowed to ask any further questions for clarification. After completion of the practice trials, she will be given adequate rest of 5 minutes before the actual testing begins. The test trials will be initiated from a starting marker with a maximal effort sprint of 3.5 m. At the end of this distance, she will perform a 180° pivot maneuver with either her dominant or non-dominant leg and then sprint back as fast as she can past the starting marker. For each trial, the foot that she will pivot with will be randomly assigned. She will complete four trials: pivoting twice on both legs, with a rest period of 3 minutes between trials. These trials will be video recorded and timed using a wireless timing system. Only the fastest trial for each limb will be used for data analysis. The session will conclude with a 10 minute cool-down period of easy biking.

During the testing, potential risks of participating in this study include, but are not limited to, injuries such as muscle strains and/or ligament sprains. Since all of the movements involved in the testing are performed on a regular basis during training and/or competitive play, and the fact that she will complete a warm-up and have sub-maximal practice trials before the testing begins, the risk of injury is minimal. In addition, Miss Smykalski is certified in CPR-C and Standard First Aid. A potential benefit from participating in this study is that she will learn about how her specific leg dominance plays a role while pivoting 180°.

Participation in this study is voluntary; both you and your daughter have the right to withdraw at any time and the right to decline answering any questions. Participating in this study will not give her any associated benefits to her team nor will she be penalized if she does not want to participate or drops out at any time. All of your daughter's recorded personal information will be strictly confidential where only the researchers, Miss Smykalski and Dr. Kivi will have access. Data will be stored securely in Dr. Kivi's office in Lakehead University for a period of 5 years as per Lakehead University policy.

The final research project will be presented to the faculty and graduate students of Lakehead University. The project will be published in a scientific journal and may also be presented at a conference. During this process no identifiable characteristics will be used.

The results of this study will be available upon request following the completion of the study. If you have any questions regarding your daughter's participation, please contact Vanessa or Dr. Kivi. This research has been approved by the Lakehead University Research Ethics Board. If you have any inquiries related to the ethics of the research and would like to speak to someone

outside of the research team, please contact Sue Wright at the Research Ethics Board at 807-343-8233 or swright@lakeheadu.ca.

Thank you,

Vanessa Smykalski, MSc (c), BSc HK
Phone: 807-632-7705
Email: vlsmykal@lakeheadu.ca

Derek Kivi, PhD
Phone: 807-343-8645
Email: dkivi@lakeheadu.ca

Appendix 6

Recruitment Letter Re: U14 Players

Dear prospective participant's parent or guardian,

Your daughter is invited to participate in the following research project entitled, "The Effect of Limb Dominance on Lower Limb Kinematics During a 180° Pivot Maneuver in Healthy Female Soccer Players at Three Different Stages of Physical Maturation". This project will be conducted by Vanessa Smykalski, a graduate student in the School of Kinesiology at Lakehead University, supervised by Dr. Derek Kivi. Your daughter is being asked to volunteer because she is a healthy female athlete who is a member of the Lakehead Express soccer club Under-14 team.

Furthermore, your daughter will be asked to participate if she responds to the question "If you are asked to kick the ball far up the field, which foot would you use?" by indicating that she would use her right foot.

The purpose of this study is to evaluate the effect of leg dominance on lower limb movements during a maximal effort acceleration coupled with a 180° pivot maneuver. Prior to participation in this study, you and your daughter will both sign the attached consent form, and then you will assist your daughter in completing the Physical Activity Readiness Questionnaire (Par-Q+), the Pubertal Maturation Observation Scale (PMOS), and Sports Background Questionnaire. The Par-Q+ will be used to ensure the participants are healthy and aware of their entitlements. The Sports Background Questionnaire will be used to collect demographic data including: name, date of birth, number of hours played per year, foot dominance, height, leg length, and mass. The PMOS will then be used to identify your daughter's maturational stage: pre-pubertal, pubertal, or post-pubertal. This Scale categorization is based on the following characteristics: menarche and breast development, increased perspiration with physical activity, body hair, acne, muscle development, and growth spurt.

She will be asked to attend one testing session, which will take place in C.J. Sanders Fieldhouse at Lakehead University. She will be asked to refrain from any physical activity 24 hours prior to the examination time in order to minimize the possibility of muscle fatigue. The session will require approximately 60 minutes of her time.

After the consent form is signed and the Par-Q+ and Sports Background questionnaire are completed, the student researcher will measure her height, leg length, and weight. She will then complete a warm-up on a stationary bike for 10 minutes followed by exercises adapted from the FIFA 11+ Warm-up Manual Part 1: Running Exercises. These exercises are the same as those used in your daughter's current warm-ups with the club team. The following exercises will be included and adapted to only two cones 6 m apart:

- Running Straight Ahead – Jog to the cone and back two times.
- Running Hip Out – Jog towards the cone, stop and lift your right knee level to your hip, and rotate it to the right side and back down in one continuous movement. Turn to face the start cone and repeat the same exercise. The same movements will be performed in the same manner with the left leg.
- Running Hip In – Jog towards the cone, stop and lift your right knee to the side level to your hip, and rotate it in and back down in one continuous movement. Turn to face the start cone and repeat the same exercise. The same movements will be performed in the same manner with the left leg.
- Running Circling Pattern – Jog towards the cone, shuffle 3 steps to the left at 90°, shuffle an entire circle (keeping hips facing forward), and then back to the cone. Participant's arms will be beside their body for balance purposes. Turn around complete

the previous same steps to the start cone but shuffle to the right at 90° instead. Repeat this sequence twice.

After the warm-up is completed, she will have 21 retro-reflective markers placed on her body using two-sided adhesive tape in the following specific locations:

- Mid sternum
- Shoulder joint (left and right)
- Elbow joint (left and right)
- Wrist joint (left and right)
- Lateral hip (left and right)
- Mid thigh (left and right)
- Knee joint (left and right)
- Mid shank (left and right)
- Lateral ankle (left and right)
- Heel (left and right)
- Lateral foot near small toe (left and right)

The markers will be used to track her movement to assist with the analysis.

Following the placement of the markers, the agility test will be demonstrated for completing the pivoting maneuver on both dominant and non-dominant legs. She will be allowed one sub-maximal practice trial using each leg to complete the 180° pivot maneuver and allowed to ask any further questions for clarification. After completion of the practice trials, she will be given adequate rest of 5 minutes before the actual testing begins. The test trials will be initiated from a starting marker with a maximal effort sprint of 3.5 m. At the end of this distance, she will perform a 180° pivot maneuver with either her dominant or non-dominant leg and then sprint back as fast as she can past the starting marker. For each trial, the foot that she will pivot with will be randomly assigned. She will complete four trials: pivoting twice on both legs, with a rest period of 3 minutes between trials. These trials will be video recorded and timed using a wireless timing system. Only the fastest trial for each limb will be used for data analysis. The session will conclude with a 10 minute cool-down period of easy biking.

During the testing, potential risks of participating in this study include, but are not limited to, injuries such as muscle strains and/or ligament sprains. Since all of the movements involved in the testing are performed on a regular basis during training and/or competitive play, and the fact that she will complete a warm-up and have sub-maximal practice trials before the testing begins, the risk of injury is minimal. In addition, Miss Smykalski is certified in CPR-C and Standard First Aid. A potential benefit from participating in this study is that she will learn about how her specific leg dominance plays a role while pivoting 180°.

Participation in this study is voluntary; both you and your daughter have the right to withdraw at any time and the right to decline answering any questions. If you give your daughter permission to participate in this study which is being completed by her head coach, she will not receive any benefits such as extra playing time, nor will she be penalized in any way if she does not want to participate or decides to drop out at any time. All of your daughter's recorded personal information will be strictly confidential where only the researchers, Miss Smykalski and Dr. Kivi will have access. Data will be stored securely in Dr. Kivi's office in Lakehead University for a period of 5 years as per Lakehead University policy.

The final research project will be presented to the faculty and graduate students of Lakehead University. The project will be published in a scientific journal and may also be presented at a conference. During this process no identifiable characteristics will be used.

The results of this study will be available upon request following the completion of the study. If you have any questions regarding your daughter's participation, please contact Vanessa or Dr. Kivi. This research has been approved by the Lakehead University Research Ethics Board. If you

have any inquiries related to the ethics of the research and would like to speak to someone outside of the research team, please contact Sue Wright at the Research Ethics Board at 807-343-8283 or swright@lakeheadu.ca.

Thank you,

Vanessa Smykalski, MSc (c), BSc HK
Phone: 807-632-7705
Email: vlsmyskal@lakeheadu.ca

Derek Kivi, PhD
Phone: 807-343-8645
Email: dkivi@lakeheadu.ca

Appendix 7

Consent Form Re: U10, U12, and U18 Players

Consent Form

I _____ (PLEASE PRINT), agree to allow my

daughter, _____ (PLEASE PRINT), to participate in the study entitled “The Effect of Limb Dominance on Lower Limb Kinematics During a 180° Pivot Maneuver in Healthy Female Soccer Players at Three Different Stages of Physical Maturation.” This study is being conducted by Miss Vanessa Smykalski under the supervision of Dr. Derek Kivi.

I have read and understood the participant recruitment letter, and I understand that I will complete for my daughter a Physical Activity Readiness Questionnaire (Par-Q+), a Pubertal Maturation Observation Scale (PMOS), and a Sports Background Questionnaire prior to her participation.

I understand that my daughter and I will attend a single testing session during which data will be collected. I understand that she is not to participate in any physical activity 24 hours prior to testing to prevent possible muscle fatigue. I will fill out my daughter’s age, sport type, and hours played per year on the given questionnaire. She will complete a biking warm-up including dynamics exercises before the testing, along with a cool down following the testing. I am aware that the student researcher will measure my daughter’s height, leg length, and weight. I understand that she will receive the placement of 21 reflective markers. I am comfortable allowing the student researcher to place these reflective markers on the previously identified anatomical landmarks. I understand that she will have one practice trial pivoting on her dominant and non-dominant foot, as well as four recorded test trials (two on both her dominant and non-dominant feet). All trials will be video recorded for analysis. I give explicit consent for these recordings.

I understand that my daughter’s participation in this study is voluntary, and that she may withdraw or I may withdraw her at any time and for any apparent reason. I understand that all of her information will remain anonymous and confidential, and will be securely stored in Dr. Kivi’s office at Lakehead University for a period of 5 years after the completion of the study. No identifiable characteristics will be used in the final report or in the presentation of the results.

I understand that the potential risks in this study are similar to those that my daughter would experience during soccer training and games including, but not limited to muscles strains and/or ligament sprains. I accept these risks by allowing my daughter to participate in this study. By participating in this study, my daughter will learn about how her specific leg dominance plays a role while pivoting 180°.

I understand that I will be provided with a copy of my daughter’s results at the completion of the study, if requested.

Signature of Participant

Date

Signature of Parent/Legal Guardian

Date

If you wish to receive a copy of your results upon completion of the study, please provide an email address so you can be contacted:

Appendix 8

Consent Form Re: U14 Players

Consent Form

I _____ (PLEASE PRINT), agree to allow my

daughter, _____ (PLEASE PRINT), to participate in the study entitled “The Effect of Limb Dominance on Lower Limb Kinematics During a 180° Pivot Maneuver in Healthy Female Soccer Players at Three Different Stages of Physical Maturation.” This study is being conducted by Miss Vanessa Smykalski under the supervision of Dr. Derek Kivi.

I have read and understood the participant recruitment letter, and I understand that I will complete, for my daughter, a Physical Activity Readiness Questionnaire (Par-Q+), a Pubertal Maturation Observation Scale (PMOS), and a Sports Background Questionnaire prior to her participation.

I understand that my daughter and I will attend a single testing session during which data will be collected. I understand that she is not to participate in any physical activity 24 hours prior to testing to prevent possible muscle fatigue. I will fill out my daughter’s age, sport type, and hours played per year on the given questionnaire. She will complete a biking warm-up including dynamics exercises before the testing, along with a cool down following the testing. I am aware that the student researcher will measure my daughter’s height, leg length, and weight. I understand that she will receive the placement of 21 reflective markers. I am comfortable allowing the student researcher to place these reflective markers on the previously identified anatomical landmarks. I understand that she will have one practice trial pivoting on her dominant and non-dominant foot, as well as four recorded test trials (two on both her dominant and non-dominant feet). All trials will be video recorded for analysis. I give explicit consent for these recordings.

I understand that my daughter’s participation in this study is voluntary, and that she may withdraw or I may withdraw her at any time and for any apparent reason. I understand that all of her information will remain anonymous and confidential, and will be securely stored in Dr. Kivi’s office at Lakehead University for a period of 5 years after the completion of the study. No identifiable characteristics will be used in the final report or in the presentation of the results.

I understand that the student researcher is my daughter’s head coach and that in participating, my daughter will not be provided with any associated benefits by participating. Also, I understand that my daughter can choose not to participate without being penalized in any way.

I understand that the potential risks in this study are similar to those that my daughter would experience during soccer training and games including, but not limited to muscles strains and/or ligament sprains. I accept these risks by allowing my daughter to participate in this study. By participating in this study, my daughter will learn about how her specific leg dominance plays a role while pivoting 180°.

I understand that I will be provided with a copy of my daughter’s results at the completion of the study, if requested.

Signature of Participant

Date

Signature of Parent/Legal Guardian

Date

If you wish to receive a copy of your results upon completion of the study, please provide an email address so you can be contacted:

Appendix 9

Letter from the President of Lakehead Express Soccer Club

To Whom It May Concern,

My name is Amy Rubino-Start, and I am the club president of Lakehead Express Soccer Club. I give Vanessa Smykalski, a Master's of Science student and her supervisor, Dr. Derek Kivi in the School of Kinesiology at Lakehead University, permission to recruit players from the under 10, 12, 14, and 18 year old female soccer teams to participate in Vanessa's thesis research project entitled, "The Effect of Leg Dominance on Lower Limb Kinematics During a 180° Pivot Turn in Healthy Female Soccer Players at Three Different Stages of Physical Maturation."

I have be reassured that players will not receive any associated benefits including extra playing time, and they will not be penalized for not wanting to participate. The club continues to support this research project and the valuable insight into potential knee injury prevention in young female soccer players.

Thank you,

arubinoStart July 4/15

Amy Rubino-Start
Club President of Lakehead Express Soccer Club
Phone: 807-627-0102
Email: arubino@shaw.ca

Appendix 10

Adapted Warm-up Exercises

Adapted Warm-up Exercises

1. Running Straight Ahead – Jog to the cone and back two times.
2. Running Hip Out – Jog towards the cone, stop and lift your right knee level to your hip and rotate it to the right side and back down in one continuous movement. Turn to face the start cone and repeat the same exercise. The same movements will be performed in the same manner with the left leg.
3. Running Hip In – Jog towards the cone, stop and lift your right knee to the side level to your hip and rotate it in and back down in one continuous movement. Turn to face the start cone and repeat the same exercise. The same movements will be performed in the same manner with the left leg twice.
4. Running Circling Pattern– Jog towards the cone, shuffle 3 steps left at 90°, shuffle an entire circle (keeping hips facing forward), and then back to the cone. Arm movement will be in motion with opposite leg. Turn around complete the previous same steps to the start cone but shuffle to the right at 90° instead. This whole sequence will then be repeated twice.

Appendix 11

Tri Council Ethics Tutorial Certificates

Certificate of Completion

This document certifies that

Vanessa Smykalski

*has completed the Tri-Council Policy Statement:
Ethical Conduct for Research Involving Humans
Course on Research Ethics (TCPS 2: CORE)*

Date of Issue: 10 April, 2014

Certificate of Completion

This document certifies that

Derek Kivi

*has completed the Tri-Council Policy Statement:
Ethical Conduct for Research Involving Humans
Course on Research Ethics (TCPS 2: CORE)*

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