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Analysis of the effect of athletes' ACL injury on hamstring strength and symmetry

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By

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Abstract

Athletes from all kinds of sports undergo intense training and prevention programs that are aimed at improving performance and preventing injuries that might set back players. Although injury prevention programs are essential for athletes, avoiding them might not always be possible.

One of the most occurring injury; for almost all sports, is related to the knee, specifically the anterior cruciate ligament injury (ACL). Studies have shown that athletes with ACL injuries have many complications that affect stability, connected muscles and overall function of the knee. These complications increase the risk of injury factor to any related limb.

The hamstring muscle is one of the largest muscles connected to the knee that can be affected easily in occurrence of ACL injury. Weakening of the muscle can affect total knee recovery as well as increase the risk of future hamstring injury.

This research paper will test the functionality of Hamstring muscle in relation to knee status. Athletes of different sports, ages and gender will undergo specific hamstring strength tests that will show how knee injury affects hamstring strength and whether they have completely recovered. Three hamstring strength tests were recorded on the isoinertial cone machine and later compared. The tests include lying leg curl (LC), straight leg pull-down (SLPD) and yo-yo flywheel front lunge (FL). Results collected include the eccentric and concentric muscle actions that can be used to compare risk factors, instability and power differences between limbs and joints.

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Table of Contents

List of figures

List of Tables

List of abbreviations

ACL – Anterior cruciate ligament

IL- injured Leg

NL- non injured leg

Reps- repetition

SS – small sample

LS- Large sample

ASI- asymmetry index

LL -Left leg

RL- Right leg

FL- front lunge

LC- lying leg curl

SLPD- straight leg pull-down

1. Introduction

Individuals with any kind of injury must undergo intense treatments to re-gain complete function and coordination of muscles or joints. These same treatments are applied to athletic players but in a more critical and intense approach as to their higher incidence of injury and re-injury probability(Putukian, 2016). Athletes are prone to many injuries when training and performing in matches thus, improvement in their overall performance and return to play physical ability is a necessity(Putukian, 2016).

ACL knee injury mainly affects young and active individuals that undergo rapid movements in different directions. This injury is more induced in the female side by up to four to six folds when compared to males from the same landing and cutting sport(Hewett, Ford, Hoogenboom, & Myer, 2010). According to Joseph et al. (2013), most sport related injuries in young athletes; almost 60 percent, are Knee injuries, and 50 percent of them are ACL related. Majority of the ACL related researches are on muscle asymmetry and their effect on the knee but not the other way around. Testing hamstring strength between injured and non-injured athletes can help in understanding whether athletes who were set back by ACL injury can still have equal muscle strength or higher muscle strength after proper rehabilitation programs.

Muscle asymmetry is when the same muscles on opposite sides of the body has different strength or power causes improper body movement and overuse from one side. It can be used to determine risk of injury or re-injury of the knee(Dervisevic & Hadzic, 2012). This imbalance can be obtained from eccentric and concentric power ratio of both the quadriceps and hamstring on both limbs where strength differences determine the severity of injury risk. Limb symmetry index (LSI) is considered a reliable injury predictor tool where asymmetry greater than 10% (<90% symmetry) in muscle strength can be predictive of future lower extremities injury, whereas, abnormal asymmetry of greater than 15% (<85%) is a high injury risk to the lower extremities(Kadija, Knežević, Milovanović, Nedeljković, & Mirkov, 2016; Kaeding & Borchers, 2014; Steidl-Müller, Hildebrandt, Müller, Fink, & Raschner, 2018). Furthermore, muscle strength asymmetry; especially in the case of hamstrings and post ACL injury , of greater than 10% contributes to high knee risk factor specifically in sports with asymmetric kinetic patterns that concentrate on one limb more than the other(Daneshjoo, Rahnama, Mokhtar, & Yusof, 2013)

The knee is a very complex joint located between two of the largest bones in the body, the tibia and the femur. It is responsible for controlling and maintaining stabilization in loading situations due to its various connections and location, which makes it highly susceptible to injury(Abulhasan & Grey, 2017).The knee if made up of 2 bone articulations the tibia-femur and the patella-femur articulation(Goldblatt & Richmond, 2003). It connects the femur to the tibia while being engulfed by the knee synovial membrane(Zantop, Petersen, & Fu, 2005) . Both articulations are responsible for holding body weight and creating a frictionless force produced by the quadriceps and femoris muscle contraction respectively(Abulhasan & Grey, 2017). As for the joints, femorotibial and patellofemoral are the two main joints that aid in movement in three different directions: sagittal, transversal and frontal. This provides the knee with movement in six different directions including extension, flexion, internal rotation, external rotation, Varus and valgus rotations(Abulhasan & Grey, 2017).

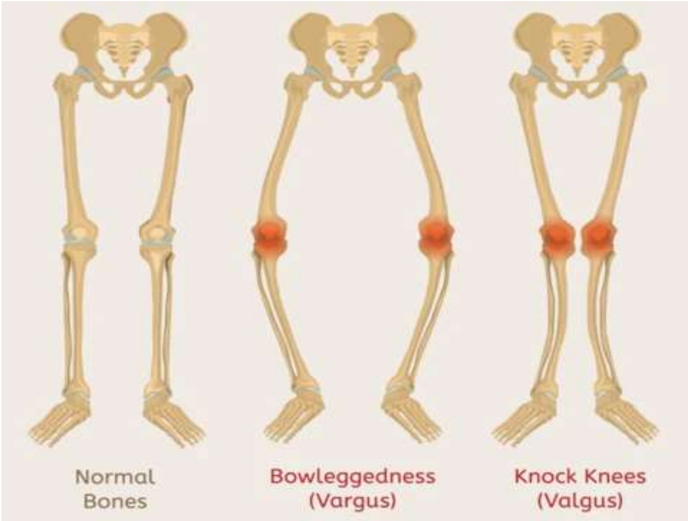

Figure 1 "Knee positions adapted from Match Fit Conditioning" ("Understanding & Preventing ACL Injuries In Football — Matchfit Conditioning," n.d.)

Ligaments are also found in the knee for stabilizing and preventing excessive rotation or the knee(Goldblatt & Richmond, 2003). Ligaments found in the knee include Anterior Cruciate Ligament (ACL), Posterior Cruciate Ligament (PCL), Menisci and Meniscofemoral Ligaments, Medial Collateral Ligaments (MCL), Medial Patellofemoral Ligament (MPL), Lateral Collateral Ligament (LCL), Popliteus and Popliteofibular Ligament(Goldblatt & Richmond, 2003). All mentioned ligaments play a role in stabilizing the knee in different directions as well as a proprioceptive aspect through their cutaneous receptors(Abulhasan & Grey, 2017).

Ligaments are fibrous tissue that are found between two bones at every joint to apply support. ACL was originally referred to as crucial ligament or the crossed ligament because of its cross like shape and importance in knee stability(Goldblatt & Richmond, 2003).The ACL stabilizes the knee by resisting anterior and rotational displacement of the knee which contributes to 85% of knee stability by enabling its flexion and rotation(Abulhasan & Grey, 2017). It is made up of two components anteromedial bundle (AMB) and the posterolateral bundle (PLB)(Duthon et al., 2006). Both bundles are not symmetrical in size and work in the opposite way. During knee flexion the AMB shortens and the PMB lengthens and vice versa happens in extension of the knee(Duthon et al., 2006). The tibia nerve connected to the ACL has 3 receptors; each with a different mechanism, have a proprioceptive function. Ruffini receptors control speed and acceleration by stretch sensitivity located on the surface of ACL(Duthon et al., 2006). Vater-Pacini receptors signal motion control located on femoral and tibial ends of ACL. Lastly the Golgi-like receptors located near the attachment of the ACL control tension(Duthon et al., 2006). Further free nerve endings connected to the ACL were found to be pain receptors as well as tissue homeostasis modulators(Abulhasan & Grey, 2017).

Athletic knee injuries can occur in multiple areas and in multiple ways(Yu & Garrett, 2007). This paper will focus on one specific injury of the knee which is the Anterior Cruciate Ligament injury. Although knee stability is affected by muscles; secondary stabilizers, it relies more on ligaments as its primary stabilizers(Abulhasan & Grey, 2017). The highest pressure applied to ligaments happens by involuntary excessive contraction of tendons from near muscles which is where ligaments interfere to apply stabilization(Abulhasan & Grey, 2017).According to Joseph et al. (2013), ACL is rated one of the highest occurring injury of up to 50% or more related to sports making it crucial to imbed into prevention programs as it is the most fragile part of the knee.

Knee ligaments can be injured by strong impact from improper landing on the ground (non-contact injury) or by external forces such as being hit by other individual (contact injury). Non-contact injuries can be caused by strength imbalance in near muscles; the hamstring and quadriceps muscles, which control knee movement and absorb impact shock(Goldblatt &

Richmond, 2003; Yu & Garrett, 2007). The hamstrings and quadriceps muscles aid in stabilization and movement of the knee, making them highly responsible for injury incident as well(Imran & O'Connor, 1998).

Injury of the ACL can occur usually with minimal to no contact in either two ways; contact and non-contact injury(Boden, Sheehan, Torg, & Hewett, 2010). Non-contact injuries mechanisms occur mainly due to intrinsic factors related to anatomy, hormones and improper body dynamics(Boden et al., 2010). It occurs when the athletes exert great forces at the knee in turn adding excessive loads on the ACL specifically(Yu & Garrett, 2007).Biomechanical factors such as knee flexion, ground reaction forces and muscle strengths are highly associated with non-contact ACL injury(Yu & Garrett, 2007).

Almost three quarters of ACL injuries are non-contact, making its mechanism critical for injury prevention programs. Females are highly associated with ACL non-contact injury due to anatomical factors giving them two to eight folds higher risk compared to men in soccer, basketball and volleyball(Boden et al., 2010; Joseph et al., 2013; Yu & Garrett, 2007).

On the other hand, contact injuries mechanism are related to physical player-player contact(Joseph et al., 2013). Studies done by Joseph et al. (2013) show that contact injuries occur at a higher rate of forty three percent when compared to non-contact and player-surface contact between high school athletes. He states that these different results are mainly related to age and sports specificity in their sample groups as opposed to other studies with professional athletes.

Figure 2 "Non-contact injuries causes" (Virgile, 2018)

Both hamstring and quadriceps muscles are located on the upper part of the leg surrounding the femur attached directly to the knee(Imran & O'Connor, 1998). This specific positioning provokes injury in case of any imbalance or deficiency between these two muscle groups strength by exceeding proper knee function and blocking the protective features the hamstring has on ACL(Coombs & Garbutt, 2002).

Figure 3 "Hamstring function in protecting ACL" (Langford, 2018)

The hamstring muscle is the muscle group found at the back part of the thigh. It consists of 3 major muscles the musculus biceps femoris, musculus semitendinosus and musculus semimembranosus(Beltran, Ghazikhanian, Padron, & Beltran, 2012). The muscles can be found in different locations around the back thigh. The bicep and semimembranosus are on the outer part of the group whereas the semitendinosus is on the deep inner part closer to the femur(Zorić, 2012).They function in stabilizing body posture, movement of lower extremities and trunk movements in relation to the thighs(Zorić, 2012).

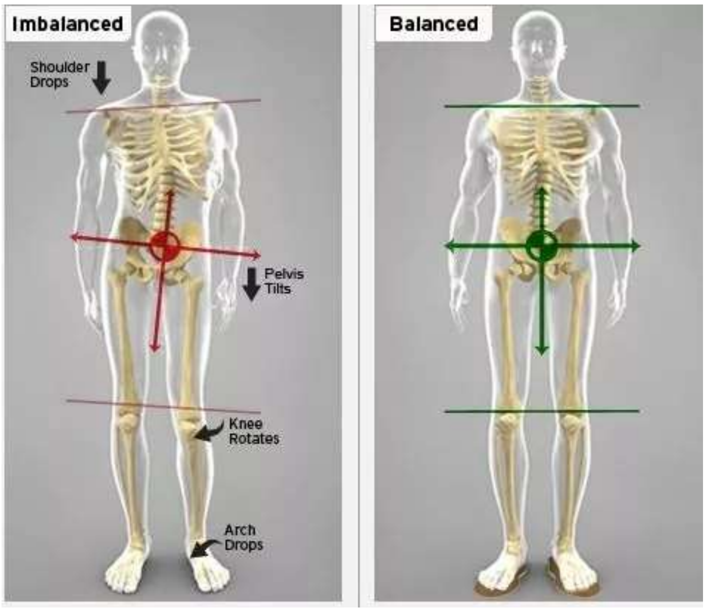

Figure 4 "Posture affected by lower muscle extremities imbalance" (Brooks, 2015)

All sport related movements such as running, jumping, sudden changes in different directions and speed are directly related to the strength of these muscles making them an essential part of proper movement(Zorić, 2012). The muscles in the hamstring are connected to different places and directions to the knee and tibia. The bicep femoris; formed of both long and short attachments, connect from different origins but later connect around the knee(Zorić, 2012). The long attachment starts at the outer ischial tuberosity and Sacro tuberous, whereas the short attachment starts at the linea aspera and supracondylar ridge of the femur(Zorić, 2012).

Both bicep muscles move downwards and laterally eventually connecting to styloid process of the fibula and lateral tibial condyle running directly into the lateral collateral ligament(Beltran et al., 2012). The dual muscle asynchrony and inability to coordinate may be the cause of biceps femoris being highest injured muscle in the hamstring complex(Sato, Nimura, Yamaguchi, & Akita, 2012). It can be related back to the anatomical configuration of the long head of the biceps that originates as a strong part of the ischial tuberosity making it vulnerable to traction forces in injury. Injuries do not occur to the semitendinosus or the semimembranosus because they are mainly muscular parts with small tendinous parts connected to the ischial tuberosity and they originate vertically in two orientations thus tolerating forces of injury respectively(Sato et al., 2012).

As for the other two muscles in the hamstring group, both semitendinosus and semimembranosus originate from the medial aspect of ischial tuberosity connecting downwards and medially(Zorić, 2012).The semimembranosus muscle arises from superolateral aspect of the ischial tuberosity making it superior and lateral to the biceps and semitendinosus. It has semimembranosus tendons ; anterior and medial to other hamstring tendons, as well as proximal and distal tendons that span the entire length of the muscle connecting it to adductor magnus tendon and the origin of long head of biceps femoris muscles(Beltran et al., 2012). The semimembranosus muscle has multiple insertions by its 5 fibrous expansions in posterior aspect of lateral condyle of the femur, the posterior joint capsule and the arcuate ligament; forming part of the oblique popliteal ligament of the knee.

It then completes down the fascia covering the popliteus muscle and posterior oblique ligaments while few fibers join the medial collateral ligament of the knee(Beltran et al., 2012). On the other hand, the semitendinosus muscle curves over the medial condyle of the tibia and passes over the medial collateral ligament of the knee which is then inserted in the upper part of the medial surface of the tibia(Beltran et al., 2012).

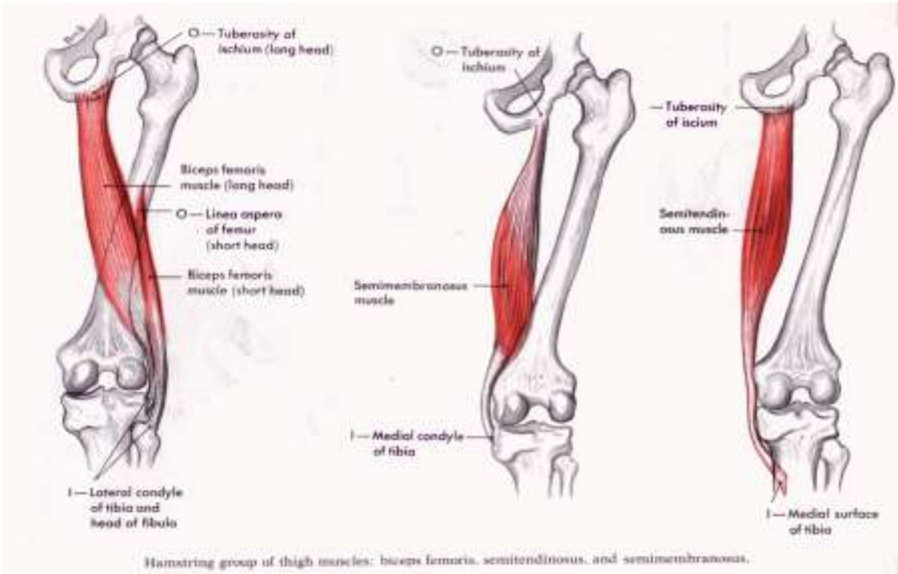

Figure 5 "Hamstring muscles" (Carr, 2014)

Nevertheless, ACL Injury can contribute to future hamstring muscle injury that is also very common in athletic sports. These two injuries are widely associated together that preventing one can decrease the possibility of injuring the other(Imran & O'Connor, 1998). Hamstring injuries can range into two groups of acute muscle strains and ruptures to chronic proximal tendinopathy(Chu & Rho, 2016). Athletes are more prone to acute hamstring strains which have high rate of reoccurrence and longer healing time. Chu and Rho (2016) found that hamstring strains make up to 15 percent and 12 percent of athletes in football and soccer respectively. This injury is associated by high speed performing sports because they occur during high speed running or excessive lengthening of the hamstrings depending on the sporting motion(Ernlund & Vieira, 2017). Acute strains are divided into two subgroups of which the first; related to the biceps femoris, occurs at the proximal muscle-tendon joint during eccentric contraction of the muscle group during the terminal swing phase in running as seen in Figure 6. It usually occurs during deceleration of the lower limbs while preparing the foot to strike(Chu & Rho, 2016).

Figure 6 "Running swing phase" (Estes, 2019)

Increased tension in the hamstring muscle is the main cause of type one acute strain. Tilting the pelvis during acceleration, shortening of the iliopsoas or imbalance between lumbar and abdominal muscles with induce pelvic anteversion puts the hamstrings at a mechanical disadvantage thus increasing its tension as seen in Figure 4. As shown in Figure 7, the bicep femoris loading during the gait cycle is between the last two steps. It represents the stretch and energy produced, which peak after the third phase going through the swing phase. This furthermore supports the fact that excessive activity in the bicep femoris occurs during the terminal phase in the running cycle.

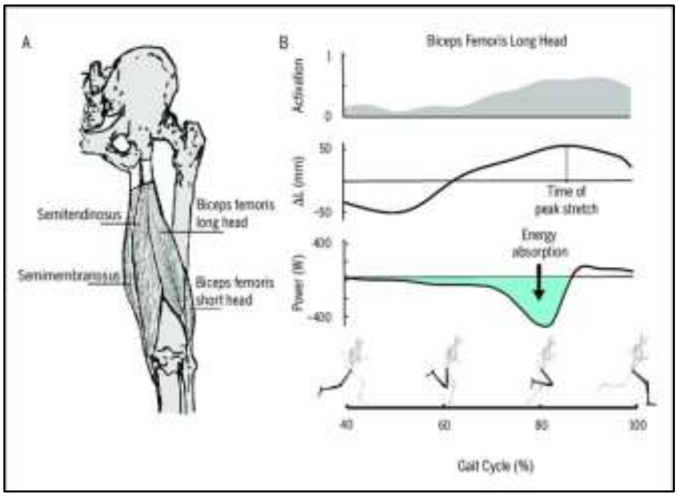

Figure 7 "Biceps femoris loading during running" (Heiderscheit, Sherry, Silder, Chummanov, & Thelen, 2010)

As for the second type of acute strain, they are more common in sports with hip flexion and knee extension movements such as dancing, high kicking and slide tackling. Recovery from this injury is longer when compared to type one acute strain because of its placement; close to the ischial tuberosity, in the proximal free tendon of the semimembranosus(Chu & Rho, 2016).Posterior hamstring tendinopathy is the other form of hamstring injury which mainly affects the semimembranosus. Its symptoms include pain on the posterior part of the high caused by mechanical overloading and repetitive stretching of the muscles. This specific injury occurs in the case of sprinters, endurance athletes and mid to long distance runners. Apart from muscles, excessive scaring of the muscle fibers cause irritation to the Sciatic nerve connected which in turn increases pain in the posterior thigh(Chu & Rho, 2016).

According to Newton et al. (2006), many factors contribute in producing muscle imbalance depending on specific sport demands, previous injury or handedness which all in turn affect performance. Muscle imbalance is a frequently seen issue in athletes. Most athletes show higher power in dominant limbs of their bodies when compared. This is due to the fact that they rely more on the dominant limb so higher forces are applied on it making it easier for them to perform their movement easily(Newton et al., 2006). According to Newton et. al (2006), studies done on swimmers show that the total power output exerted by the dominant hand; which in this case is the right hand, was 54 percent higher than the left. This imbalance was increased even more when swimmers reached higher exhaustion.

Furthermore, another study done on female volleyball players tests contralateral limb imbalance on knee flexion and extension to determine their risk of injury. It was found that 15 percent or higher in strength differences in both limbs is associate with higher risk on injury(Newton et al., 2006). Therefore, having higher imbalance between limbs is a clear indicator of injury not only for the weaker side but also to the stronger limbs caused by the overloading from trying to overcompensate for the weaker limb deficiencies(Newton et al., 2006).

Moreover, because hamstring is an important protagonist to the ACL, it represents a potential risk factor to ACL injury or re-injury and vice versa(Newton et al., 2006). Athletes must always sustain high performance by improving muscle strength and preventing injury. In this case, jumping and sprinting are essential parts of any sports with high speed and explosive movements which is where the hamstring muscle comes in(Ardern, Pizzari, Wollin, & Webster, 2015). Lower limb injuries make up to one third of sport injuries where hamstring sprains are the most common(Ardern et al., 2015). Results of studies done by Ardern, Pizzari, Wollin and Webster (2015) show that thigh muscle strength imbalance during a pre-season puts the athlete in a 4.6 times increased risk of lower limb or hamstring strain injury.

Data collected indicate the main cause of hamstring injury is due to deficit in eccentric strength whereas concentric deficit was not accompanied with higher risks(Ardern et al., 2015). He stated that deficits in Eccentric muscle strength increases hamstring strain possibility by up to 4 times. This means that having higher eccentric muscle strength will not negatively affect the muscles on the contrary high concentric strength does(Ardern et al., 2015). Imbalance in hamstring and quadriceps strength shown by lower hamstring power will induce risk of non-contact ACL injury due to dominance of quadriceps(Ardern et al., 2015).

Apart from muscle anatomy, other intrinsic factors are involved in ACL injury mechanism. Age plays a big role in ACL injury as it reflects neuromuscular maturation and control in muscle activation during dynamic exercises(Ardern et al., 2015). Age related studies concluded that ACL injury occurs mostly for individuals over the age of 18 years. Females had highest rates of injury between late teens and early twenties whereas, males have higher risk at ages between mid and late twenties(Ardern et al., 2015).

Gender differences have been studied for a long time especially in sports. Many studies done have resulted in a higher female injury when compared to men. Many factors are associated with these findings as to why women are more prone to injuries. Female athlete's numbers have increased dramatically in the past decade as more teams are being made for them. This high increase in number is allowing more sports to be played by both genders where differences in performances can be seen and compared. According to Ireland (2002), since the increase of female participants, injuries have remained alarmingly high after the shift in gender differences. Statistics showed that women are 3.5 times more prone to ACL injury in basketball and 2.5 times more in soccer than men(Ireland, 2002). This higher risk in females can be related to joint kinesiology and mechanism. Females demonstrated higher joint laxity, smaller knee flexion angles, more internal rotation and valgus movement(Ardern et al., 2015).

These improper movements add excessive load on the knee causing injuries. Hormones have also been linked to higher injury rates in women during menstrual cycle. Both men and women have the hormone relaxin which works on elasticity of connective tissue by reducing its collagen content making it stiffer. In men, relaxin is produced at normal rates whereas it peaks in women during pregnancy or menstrual cycle at the luteal phase(Ardern et al., 2015). This confirms that women are more prone to injuries due to hormonal fluctuations. Furthermore, ACL has been found to contain relaxin receptors, causing women frequently higher injuries and susceptibility(Ardern et al., 2015).

The anatomy of the ligament in both female and males differs in thickness and strength. Zantop, Peterson and Fu(2005) stated that the intercondylar notch on the posterior part of the ligament; attached to the femur, is wider than the interior part attached to the tibia. Females were reported to have a narrower notch which can be another reason for their higher injury rate when compared to men(Zantop et al., 2005).

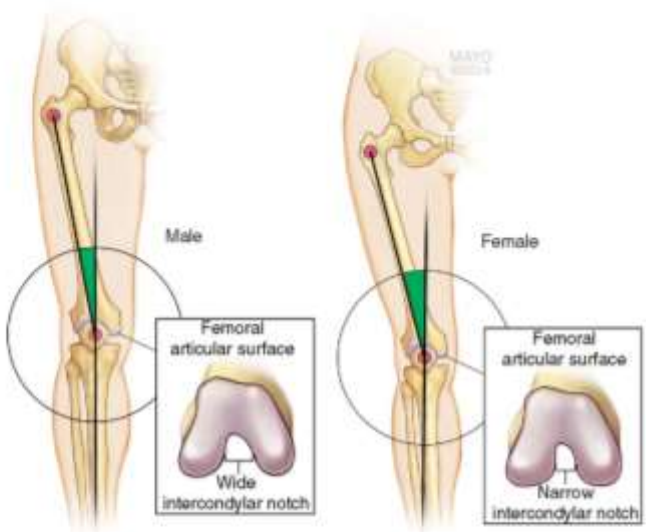

Figure 8 "Notch difference between males and females" (Wolf, Cannada, Van Heest, O'Connor, & Ladd, 2015)

Some studies compared weight and body size to knee injury caused by excessive loading. Tests conducted on 895 cadets with prior ACL injury had undergone a four-year training program followed by strength tests showed that individuals with higher BMI or relative body weight were associated with a higher risk of non-contact ACL injury(Hashemi et al., 2011; Uhorchak et al., 2003). Although having higher BMI increases ACL occurrence, healthy muscular individuals can have higher values of body mass however no risk was associated with them. Furthermore, these studies concluded that females were at higher risk of ACL injury when compared to males of the same BMI. This could be related back to the anatomy and laxity of the female knee(Ardern et al., 2015). Another potential explanation to the relation between BMI and ACL could be the level of athleticism or activity individuals have before performing the sports they were injured in due to lack of motor development needed in said sport(Uhorchak et al., 2003) .Increased body mass causes excessive loading at the tibiofemoral joint which must be resisted by the ACL; thus, the higher the body mass the lower the threshold within which the ACL can operate without injury. Higher body mass must be regarded as higher risk factor for non-contact ACL injury more so in women(Hashemi et al., 2011; Uhorchak et al., 2003).

Figure 9 "Effect of excessive weight on knee joint" (Mazzara, 2011)

Every sport has different risk of injury. Hootman, Dick and Agel (2007) stated that women in general were at higher risk of injury when compared to men. They had compared ACL incidence between 15 different sports which included men's baseball, men's basketball, women's basketball, women's field hockey, men's football, women's gymnastics, men's ice hockey, women's ice hockey, men's lacrosse, women's lacrosse, men's soccer, women's soccer, women's softball, women's volleyball, men's wrestling and finally men's spring football. According to the results obtained, injury rate of women's gymnastics and men's spring football scored the highest of 33 percent. However, men's football reported the highest ACL injury frequency compare to the others. From all the sports mentioned, three of the four highest ACL injury rates were of female sports basketball, soccer and gymnastics apart from the field football(Hootman, Dick, & Agel, 2007). Moreover, Joseph et al.(2013)

studies on ACL injury rates in different sports concluded that female soccer players scored the highest injury rate followed by men's football.

Injury occurrence can be related to athlete experience in the sport they play. Studies conducted on high school females tested the knee kinematics by measuring reaction time, muscle activation, peak moments and joint moments during deceleration phase in side-step(Sigward & Powers, 2006). the sample was made up of 15 female athletes with 8 or higher years of experience in soccer whereas the other 15 had low experience. According to the results, experienced players had higher chance of ACL injury due to the lower muscle co-contraction seen in the hamstring and quadriceps. The low experienced group all had high muscle co-contraction which can be somehow related to their higher muscle alert when performing new movements that they are not used to performing(Sigward & Powers, 2006).

Since ACL injuries are highly common in sports, many treatments and guidelines must be followed to recover injured players and have them return to play with maximal performance(Cavanaugh & Powers, 2017). Objective criteria must be regained after ACL injury prior to returning to play to minimize potential re-injury incidence(Welling, Benjaminse, Lemmink, Dingenen, & Gokeler, 2019). Complete muscle strength re-gain can be obtained after ACL reconstruction surgery starting at 6 months post operation. Training specialists must follow specific guidelines where increasing volume and intensity of training gradually is a necessity to assess the athlete's abilities by challenging them(Cavanaugh & Powers, 2017). Training progressions starts as follows, firstly quadriceps treatment is started by undergoing muscle contraction with cold compressions accompanied by external weight loads; might need the use of electro stimulators to activate the quadriceps after being dormant from ACL rupture(Cavanaugh & Powers, 2017). Secondly, athletes who are able to perform straight leg raise without assistance can move to the next phase of leg press and squats in a pain free angle motion without overloading the ACL(Welling et al., 2019). Intensity of exercises increase by changing the arc of motion in all exercises and shifting from isometric to isotonic exercises gradually(Cavanaugh & Powers, 2017). The next step happens at the 3 months marker when athletes undergo full range arc motion exercises utilizing medium to high speed movements; which is when the exercise become more complex with higher intensity. Balance and proprioceptive activities are also incorporated in this phase to regain neuromuscular control and prevent future injury as well as running and jump-landing protocols(Welling et al., 2019). Studies have concluded that athletes are able to achieve complete muscle strength re-gain at greater than 6 months after ACL reconstruction exercises; when compared to controlled non-injured groups(Cavanaugh & Powers, 2017; de Jong, van Caspel, van Haeff, & Saris, 2007; Welling et al., 2019).

Focusing on increasing both eccentric and concentric hamstring strength can be achieved by training on isoinertial flywheels and isoinertial cone machines more than traditional exercises(Hoyo et al., 2015). This is because isoinertial machines train by overloading eccentric strength and activating overall muscles thus increasing overall knee-flexor strength and maximal sprinting speed(Hoyo et al., 2015). Both machines use inertia offered by the rotating fly wheel in turn producing resistance(Tous-Fajardo, Maldonado, Quintana, Pozzo, & Tesch, 2006). It is important to mention that these equipment have high reliability as screening tools for monitoring and assessing muscle function used in sports medicine and sports training environment (da Silva et al., 2013).

The aim of this research is to analyze the hamstring strength asymmetry of athletes with prior Anterior Cruciate Ligament injury and athletes with no prior ACL injury. This study is designed to assess the hypothesis that athletes with prior ACL injury will have higher hamstring strength asymmetries in injured legs when compared to uninjured legs. Furthermore, injured legs will have weaker hamstring (power) when compared to control (non-injured leg). Due to the high occurrence of ACL injury in athletes, it will always be an ongoing topic to tackle. The knee is a fundamental and compound part of the body that causes many curiosities as to its high injury rate and importance in body movement.

2. Methodology

This chapter of the thesis will demonstrate the methods and tools used to test hamstring strength and collect data of athletes. Testing hamstring strength in relation to previous ACL injury will be conducted using isoinertial cone and yo-yo flywheel machines. Because ACL injuries can affect hamstring performance, the full recovery of hamstring muscle will be tested on whether athletes with ACL injuries are able to regain full muscle strength or have imbalance compared to non-injured athletes. Data to be collected will measure maximum power produced on isoinertial cone and yo-yo flywheel machines while performing Hamstring directed movement. Both eccentric and concentric hamstring power will be analyzed to visualize the differences between each leg for each athlete, as well as evaluate the risk of a future injury or re-injury, depending on the results. Data to be analyzed will include concentric hamstring strength, eccentric hamstring strength, hamstring muscle power difference in both legs, and injury percentage in relation to muscle imbalance in both limbs.

The sample used in this study was made of large sample (LS) of 13 athletes chosen based on previous ACL injury only as shown in Table 2. The samples were not specific to any gender, age or sport but rather only specific to high performing athletes. Athletes included in this sample are of different ages and genders as mentioned before. Detailed background information of only 8 of the 13 injured athletes were obtained using surveys due to external limitations. Thus, comparisons of limited information will be done on the 8 athletes that information is available for; whereas, the other comparisons will be done on all 13. All athletes included in this paper completed ACL physiotherapy rehabilitation followed by a strength training program. The data collected were taken after 6 months from the start of strength training whether it was completed of not.

Table 1 Smaller sample characteristics

Athlete characteristics

	Females (n=4)	Males (n=4)	total (n=8)
Age	18.00	18.50	18.25
Height (cm)	170.00	178.50	174.25
Weight (Kg)	60.25	72.25	66.25
BMI (KG/M^2)	20.86	22.45	21.66
Contact injury	2	1	1.50
Non-contact injury	2	3	2.50
RL/LL dominant	4/0	3/1	7/1
RL/LL injured	2/2	2/2	4/4
Pre-ACL injury	1	0	1.50
Post ACL injury	2	2	2.00

Data represented in the following Figure 17, Figure 18 and Figure 19 show details of every player in the different test performed. Numbers in these tables indicate number of every athlete with power results in Watts of eccentric and concentric hamstring muscles for both legs during performance of the three tests. As seen in the tables, results were coded depending on risk of injury possibility in case of strength asymmetry shown between hamstring muscles in same and different legs. Formulas applied for calculating difference were as follows:

$$100 - \left(\frac{Larger\ contraction\ value - Smaller\ contraction\ value}{Larger\ contraction\ value} \times 100\right)$$

Values in the equation can be either eccentric or concentric depending on which value presented is higher. All data used in this research paper was collected by expert trainers who conducted them on athletes in a high-performance center. Tests were also performed identically by performing movements that use only hamstrings muscle group including lying leg curl (LC) , straight leg pull-down (SLPD) and yo-yo flywheel front lunge (FL).

Table 2 Large sample characteristics

Number	Age	Sex	weight (Kg)	Height (Cm)	BMI
1	15	M	55	170	19.03
2	18	M	72	180	22.22
3	24	F	64	170	22.15
4	25	M	97	186	28.04
5	18	F	53	173	17.71
6	16	F	57	163	21.45
7	26	M	65	179	20.29
8	16	M	65	178	20.52
9	19	M	63	179	19.66
10	14	F	67	174	22.13
11	23	M	76	182	22.94
12	26	M	70	180	21.60
13	26	M	55	165	20.20

Figure 10 "Yo-yo flywheel" (Global Performance, 2017)

Figure 11 "isoinertial cone" (Global Performance, 2017)

Figure 12 "Smart coach lite power encoder" (Global Performance, 2017)

Equipment used for obtaining the data include isoinertial cone, yo-yo flywheel, Smart Coach application version 3.1.8.0 (Smart Coach Europe ab, Barcelona, Spain) and Smart Coach strength measuring tool. Prior to each test, athletes had to warm up using either the bicycle or treadmill for 5 minutes. After the warm up they would perform muscle activation exercises using vibratory machines on hamstrings, calves, quadriceps, hip flexors and glutes. These steps are essential to completely activate all muscles in the lower limbs thus preventing any room for error. After these steps, the expert informs the athlete on how to perform the proper movement and what rules they should follow. Variables controlled in the tests included specific movements done by the athletes, weights used on the machines, test trials and repetitions used. The weight used on the machines was a fixed 1-kilogram weight on both the yo-yo flywheel and isoinertial cone machine for standardized results and maximum strength production. Each expert will allow every athlete to perform 3 familiarization trials for every test to ensure proper application and technique. After the trials, the trainer informs the athlete to pull with maximum force on the limb attached to the isoinertial cone/yo-yo flywheel machine as fast as they can for 10 repetitions (reps) depending on the movement being conducted. The expert then uses approximately 10 properly performed consecutive repetitions and disregards any false or trial pulls done by the athlete; thus, concluding the test. Each test will be done on both limbs to compare the results between for the same athlete him/herself and others at the same time.

For the isoinertial cone tests, athletes were connected by a rope clipped to a strap on one ankle while the other leg is fixed to the ground. Core activation was emphasized during these tests to fixate the unattached leg to the ground and prevent interference with results as shown in Figure 13 & Figure 14.

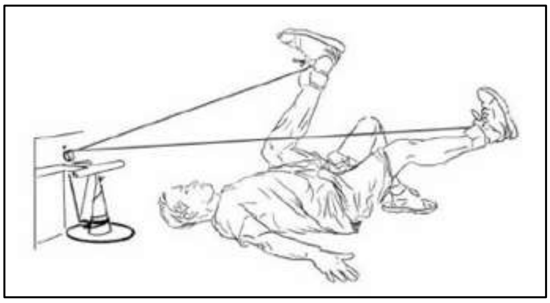

Figure 13 "Straight leg pull down on isoinertial cone machine" (Tous-Fajardo, Gonzalo-Skok, Luis Arjol-Serrano, & Tesch, 2016)

Figure 14 Lying leg curl on isoinertial cone machine" (VirtualFitnessAus, 2011)

As for the yo-yo flywheel tests (Figure 15), the front lunges were conducted with athletes connected by a cable clipped to a vest; worn on the upper body. The leg being tested was up on the machine whereas the other was on the ground acting as a hinge. All the machines were connected to “Smart Coach strength measuring tool” encoder which when pulled, measures concentric and eccentric forces displayed as power values on the computer screen on Smart Coach application version 3.1.8.0 (Smart Coach Europe ab, Barcelona, Spain).

Figure 15 "Front lunge on yo-yo flywheel" (NeuroExcellence, 2018)

Data will be analyzed by comparing hamstring muscle power in Watts. Comparison between hamstring eccentric and concentric power will be calculated in percentages where differences under 10 percent will be considered as safe zone with no risk of injury. Differences between 10-15 percent and greater than 15 percent will be considered low risk and high-risk indicators of future injury respectively. These numbers have been chosen based on Kaeding and Borchers’ (2014) conclusion of predictive injury occurrence in muscle strength and muscle asymmetry. Results obtained will focus mainly on the hamstrings muscles. Therefore, any deficiencies present reflect solely on the muscles involved and their values when compared to other variables. Variables to be equated were taken from a small sample group (SS) of 8 who were able to complete a detailed characteristics survey questionnaire which includes body mass index (BMI), sex, age, sport type to ACL injury as shown in Appendix.

Furthermore, comparison between cause of ACL injury occurrence and type of ACL injury (contact or non-contact) will be explored. The effect of ACL injury on hamstring strength will be analyzed by associating previous ACL injury and hamstrings power. Comparisons will be made on the basis of the non-injured legs being the control data and the injured legs as the experimental data.

3. Data Analysis

In the following section, data will be presented in a form of values and figures that will show overall results of athletes used in this study. Athletes background will be presented in tables to show overall general information or in forms of numerical averages such as age or BMI. Limb asymmetry data will be statistically analyzed by using two-sample t-test for obtaining significant difference (p-value) between injured versus non-injured leg peak power. The same T-test will be applied for both limbs concentric: eccentric percent asymmetry to see which group has higher asymmetry present. Each test conducted using different movement will have separate individualized results and two tailed T-tests since each of them represents a different movement thus different power and mechanism.

4. Results

Results of both LS and SS will be presented here depending on the data being compared. The following Figure 16 represents ACL injury depending on gender from the LS.

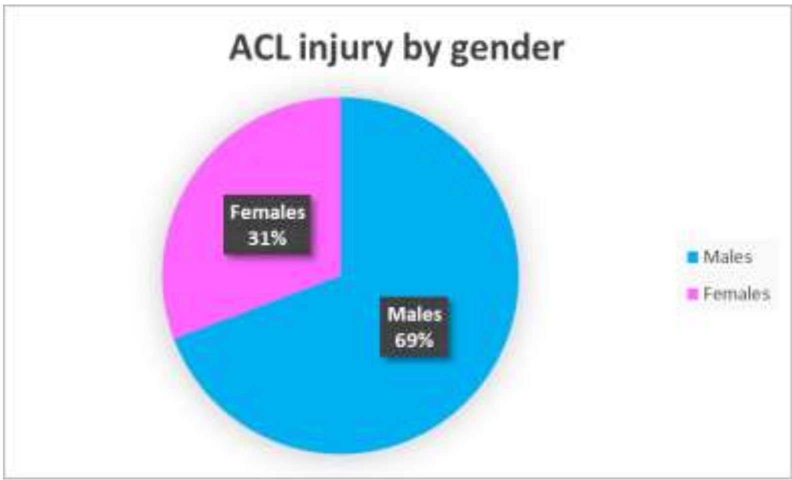

Figure 16 ACL injury according to gender in LS

Color coding was applied to show whether differences put athletes in any risk or injury. Every horizontal line in Figure 17, Figure 18 and Figure 19 represent a single player with their peak hamstring power divided by the test performed. Cells colored blue were associated with no risk of injury with numbers below 10% in concentric and eccentric differences. Cells colored yellow were associated with low risk of injury where differences between concentric and eccentric power were higher than 10%. Cells in green reflect high risk of injury where differences are higher than 15%. As for the red cells they represent differences of higher than 20 percent which put athletes at a very high risk of injury due to massive muscle strength imbalance.

ATHLETE	INJURED LEG CONCENTRIC (Watts)	INJURED LEG ECCENTRIC (Watts)	NON-INJURED LEG CONCENTRIC (Watts)	NON-INJURED LEG ECCENTRIC (Watts)	INJURED LEG C/E DIFF. (%)	UNINJURED LEG C/E DIFF. (%)	DIFFERENCE BETWEEN LEGS IN CONCENTRIC (%)	DIFFERENCE BETWEEN LEGS IN ECCENTRIC (%)
	YO-YO FRONT LUNGE POWER (Watts)							
1	277	248	321	273	10.42	15.14	13.67	8.87
2	105	82	176	154	21.43	12.37	40.47	46.62
3	208	150	224	172	27.76	23.19	7.18	12.71
4	644	495	463	345	23.14	25.55	28.10	30.35
5	224	199	326	292	11.19	10.46	31.22	31.77
6	169	134	204	171	20.74	16.19	17.06	21.56
7	278	246	400	375	11.46	6.21	30.59	34.47
8	190	164	234	192	13.71	17.76	18.51	14.50

Figure 17 Concentric: Eccentric hamstring asymmetry comparison between injured and non-injured leg during yo-yo flywheel front lunge test

ATHLETE	INJURED LEG CONCENTRIC (Watts)	INJURED LEG ECCENTRIC (Watts)	NON-INJURED LEG CONCENTRIC (Watts)	NON-INJURED LEG ECCENTRIC (Watts)	INJURED LEG C/E DIFF. (%)	UN-INJURED LEG C/E DIFF. (%)	DIFFERENCE BETWEEN LEGS IN CONCENTRIC (%)	DIFFERENCE BETWEEN LEGS IN ECCENTRIC (%)
	STRAIGHT LEG PULL-DOWN POWER (Watts)							
1	74	57	60	60	23.00	-1.08	19.07	5.88
2	74	63	68	52	15.36	22.72	8.21	16.20
3	68	57	65	58	15.61	10.94	3.82	1.48
4	77	66	76	73	14.44	4.37	1.18	9.46
5	61	57	69	68	6.73	1.25	11.68	16.59
6	56	56	59	53	-0.14	9.17	5.05	4.47
7	81	71	88	75	12.65	15.05	8.68	6.11
8	68	60	64	58	10.89	9.05	5.87	3.93

Figure 18 Concentric: Eccentric hamstring asymmetry comparison between injured and non-injured leg during isoinertial cone straight leg pull-down test

ATHLETE	INJURED LEG CONCENTRIC (Watts)	INJURED LEG ECCENTRIC (Watts)	NON-INJURED LEG CONCENTRIC (Watts)	NON-INJURED LEG ECCENTRIC (Watts)	INJURED LEG C/E DIFF. (%)	UN-INJURED LEG C/E DIFF. (%)	DIFFERENCE BETWEEN LEGS IN CONCENTRIC (%)	DIFFERENCE BETWEEN LEGS IN ECCENTRIC (%)
	LYING LEG CURL POWER (Watts)							
1	28	26	37	32	8.17	13.41	24.04	19.45
2	37	35	39	39	5.14	0.97	6.10	10.06
3	33	27	44	44	18.65	0.38	25.94	39.52
4	35	32	49	47	9.94	4.73	28.46	32.37
5	46	35	46	38	24.51	17.16	0.54	8.37
6	17	15	20	18	15.02	9.10	15.88	21.36
7	33	25	54	50	25.85	8.26	39.05	50.74
8	34	23	39	30	31.03	24.82	13.73	20.86

Figure 19 Concentric: Eccentric hamstring asymmetry comparison between injured and non-injured leg during isoinertial cone lying leg curl test

In the following part of the analysis, hamstring asymmetries are represented in a graph form depending on the test applied on the SS made up of 8 athletes. Figure 20 represents hamstring asymmetries in both injured and non-injured leg of each player performing the front lunge on the yo-yo flywheel. The same variables are seen in Figure 21 in the SLPD test and Figure 22 the LC test. All three graphs contain horizontal lines which represent the risk of injury ranges related to percent difference in strength. These green, yellow and red lines represent percent asymmetry of 10, 15 and 20 percent respectively. The vertical grey and blue lines represent the peak power asymmetry in injured and non-injured leg respectfully.

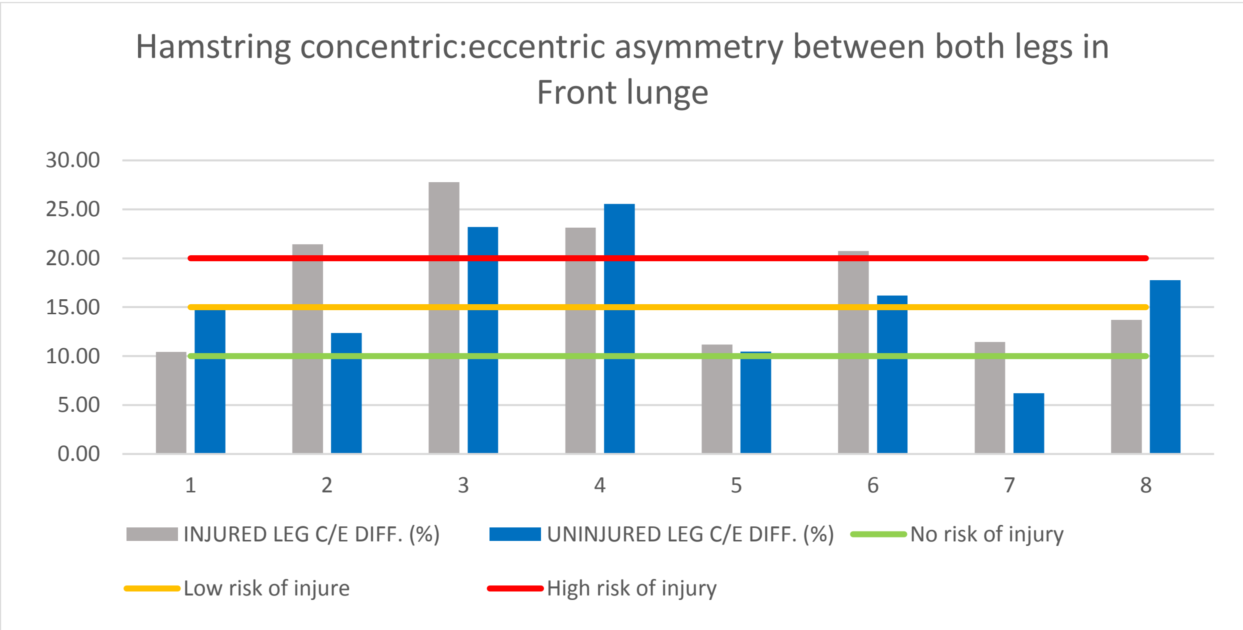

Figure 20 Hamstring asymmetry in front lunge test between injured and non-injured legs

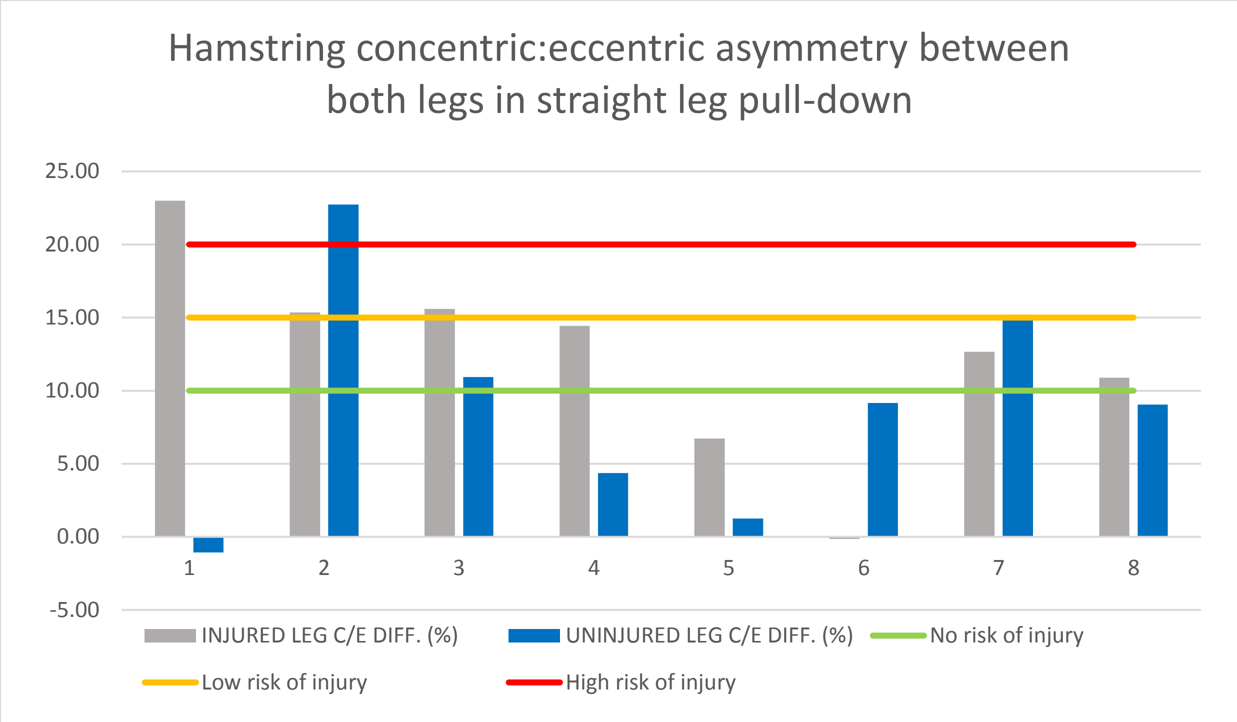

Figure 21 Hamstring asymmetry between in injured and non-injured leg in straight leg pull-down

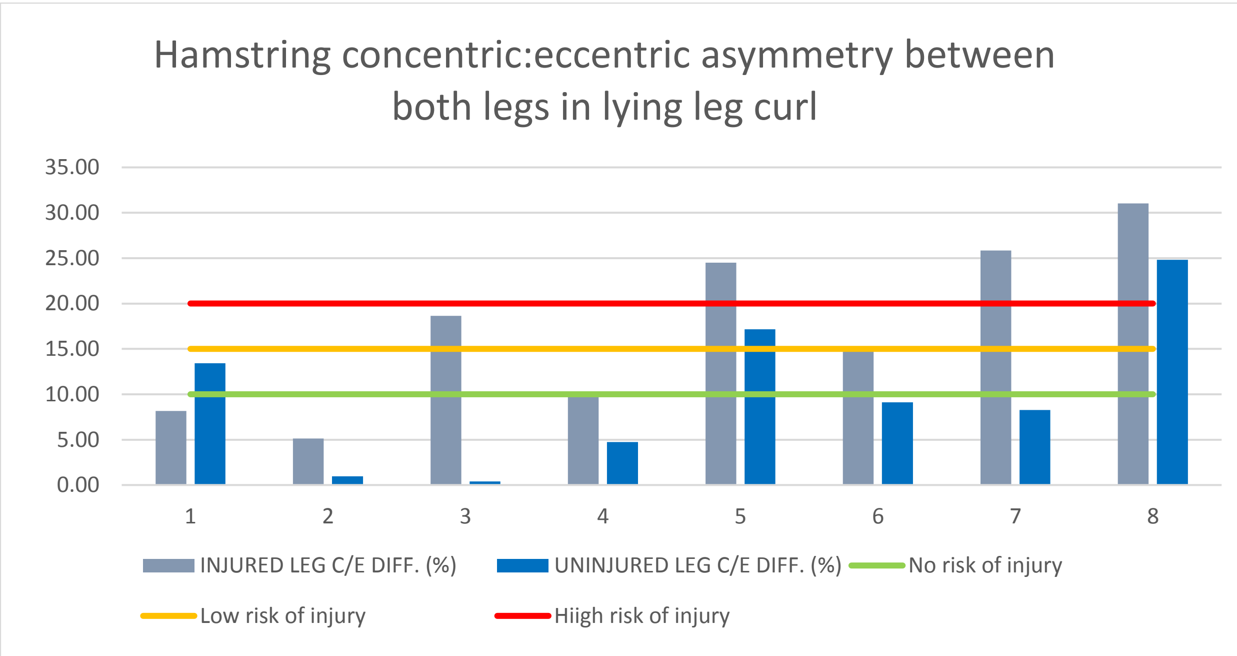

Figure 22 Leg curl concentric: eccentric hamstring asymmetry difference between injured and non-injured legs

When talking about asymmetries of hamstring muscles, it can be compared by total power or eccentric to concentric power imbalances. Figure 23 shows the average hamstring asymmetry as percent imbalance during concentric and eccentric contractions done on both groups. More detailed comparison of the bilateral total hamstring power differences was shown in Figure 24 between the different tests performed. The same Figure 24 shows the number of athletes with higher injured leg hamstring power in the last row.

	Front lunge hamstring imbalance (%)	Straight leg pull-down hamstring imbalance (%)	Lying leg curl hamstring imbalance (%)
Injured leg average	15.21	14.50	19.30
Non-injured leg average	19.75	10.13	15.28

Figure 23 Average hamstring asymmetries in different movements

	Front lunge		straight leg pull-down		Leg curl	
	Injured leg power (Kg)	Non-injured leg power (Kg)	Injured leg power (Kg)	Non-injured leg power (Kg)	Injured leg power (Kg)	Non-injured leg power (Kg)
1	525.58	593.67	130.57	120.05	54	69.15
2	187.32	330.61	136.58	120.37	72.02	78.34
3	357.39	395.28	125.48	123.74	59.5	88.43
4	1139.18	807.97	142.79	148.76	66.75	95.86
5	422.85	617.13	117.74	137.1	80.71	83.63
6	303.28	374.94	111.72	112.19	31.65	38.83
7	523.88	775.74	151.34	163.61	57.59	104.04
8	354.47	425.54	127.86	121.52	57.55	69.16
Athletes with Higher injured leg power	1		4		0	

Figure 24 Bilateral total hamstring power

In the following part, the p-values were obtained for each test using the two tailed t-test. The results were grouped depending on the test performed by athletes separated by injured versus non-injured leg. Each row in Figure 25 and Figure 26 represent a different test for the peak power and power asymmetry respectively. Each test will have a separate p-value seen under the column titled "P".

Paired Samples T-Test

			statistic	df	p
Injured Leg FL	Un-Injured Leg FL	Student's t	-1.0214	7.00	0.341
Injured Leg SLPD	Un-Injured Leg SLPD	Student's t	-0.0976	7.00	0.925
Injured Leg LC	Un-Injured Leg LC	Student's t	-3.4746	7.00	0.010

Figure 25 Differences between total hamstring peak power in both legs during different tests

Paired Samples T-Test

			statistic	df	p
Injured leg asymmetry FL	Un-Injured leg asymmetry FL	Student's t	0.917	7.00	0.389
Injured leg asymmetry SLPD	Un-Injured leg asymmetry SLPD	Student's t	0.900	7.00	0.398
Injured leg asymmetry LC	Un-Injured leg asymmetry LC	Student's t	2.780	7.00	0.027

Figure 26 Differences between hamstring concentric: eccentric peak power asymmetry in both legs during different tests

If we dive in to understand which of the p-values showed significant differences i.e. LC. The following Figure 27 and Figure 28 show the detailed mean and median of each LC t-test done for every individual leg regarding the peak power and asymmetry differences respectively.

Paired Samples T-Test

			statistic	df	p
Injured Leg LC	Un-Injured Leg LC	Student's t	-3.47	7.00	0.010

Descriptives

	N	Mean	Median	SD	SE
Injured Leg LC	8	60.0	58.5	14.5	5.12
Un-Injured Leg LC	8	78.4	81.0	20.1	7.10

Figure 27 Descriptives of LC hamstring peak power for both legs

Paired Samples T-Test

			statistic	df	p
Injured leg asymmetry LC	Un-Injured leg asymmetry LC	Student's t	2.78	7.00	0.027

Descriptives

	N	Mean	Median	SD	SE
Injured leg asymmetry LC	8	17.29	16.84	9.30	3.29
Un-Injured leg asymmetry LC	8	9.85	8.68	8.35	2.95

Figure 28 Descriptives of LC hamstring asymmetry for both legs

Each athlete had the injury occur at different times in the training season. The following Figure 29 represents the time of injury according to the data collected from the survey completed by 8 athletes.

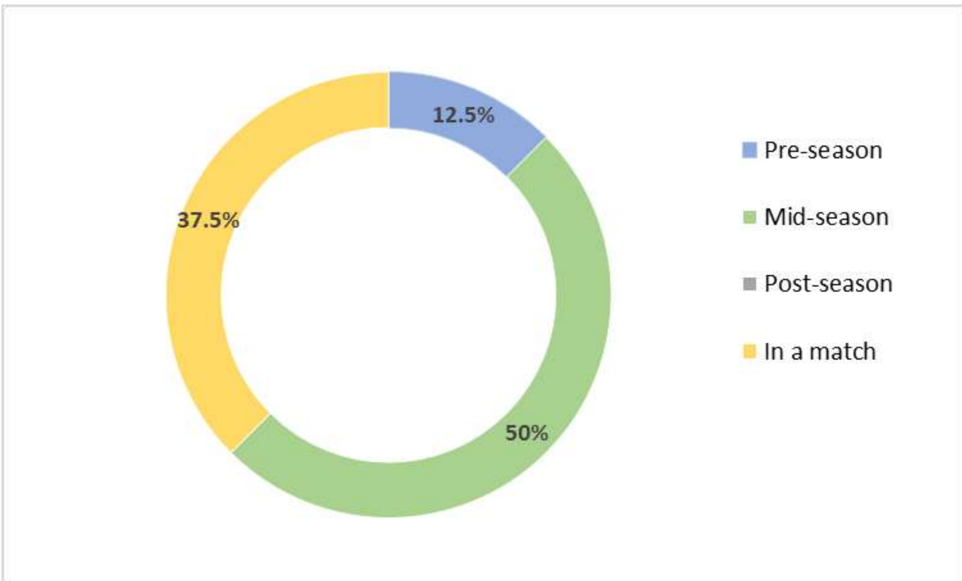

Figure 29 ACL injury occurrence in training season

The following Figure 30, represents the injury occurrence grouped depending on sport played. Each of the bars in the graph represent total number of injuries, female injuries and male injuries in grey, red and blue respectively.

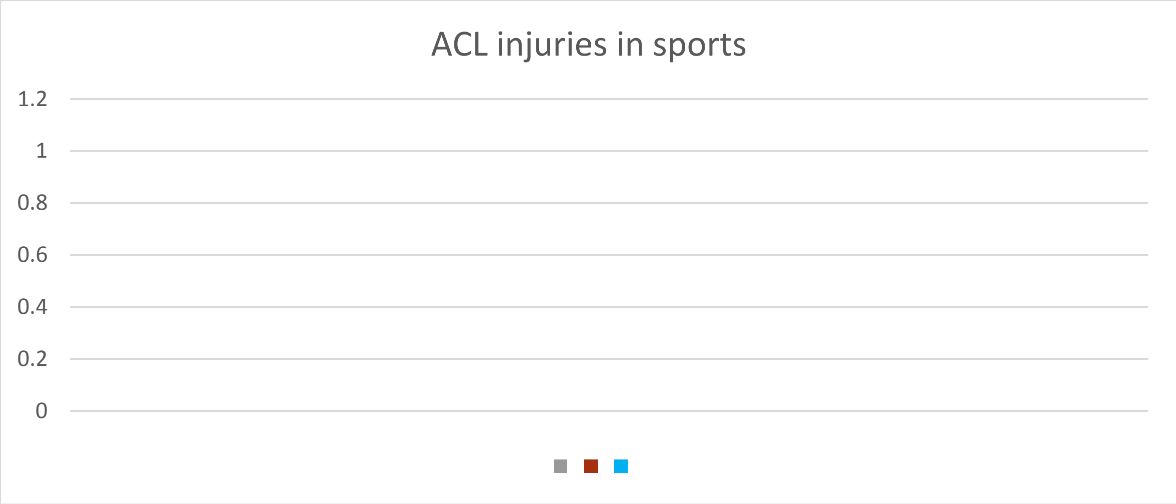

Figure 30 "ACL injury in different sports based on gender"

Figure 31 shows the range of ages of injury in the SS of each of the genders collected from the 8 athletes who completed the survey.

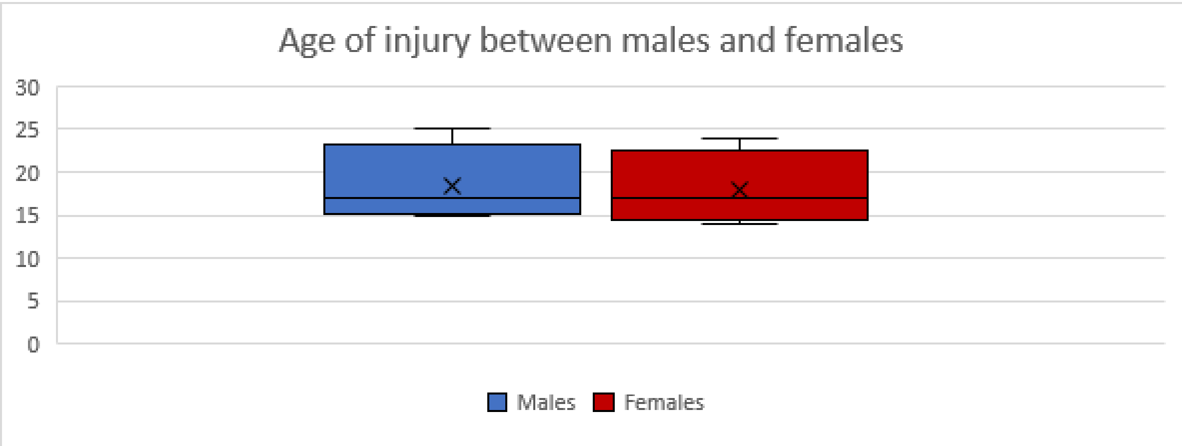

Figure 31 "Age of injury"

Figure 32 represents the years of experience that every athlete had up until they had the ACL injury in the SS. Figure 33 represents the duration of strength training completed after the rehabilitation done by physiotherapists in the SS.

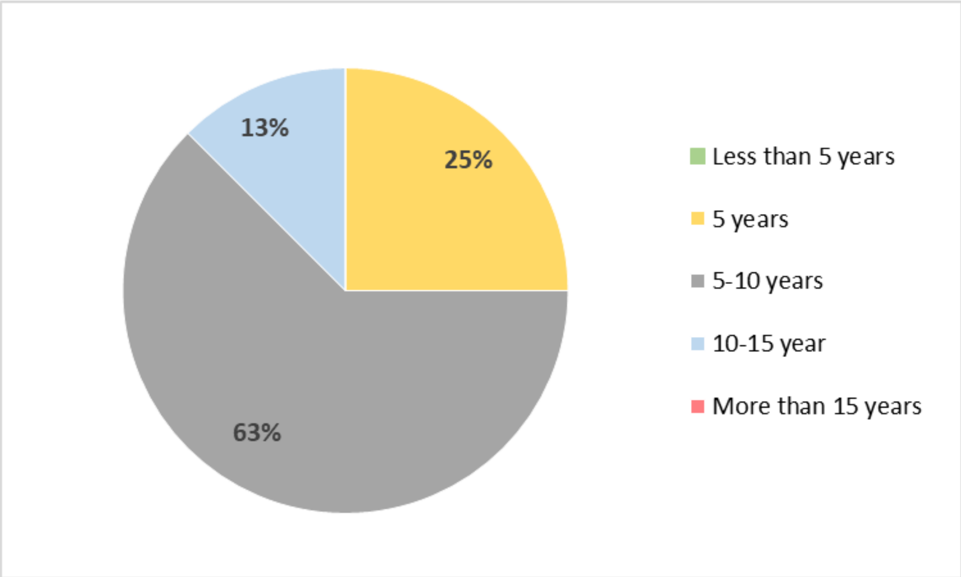

Figure 32 Years of experience in the small sample

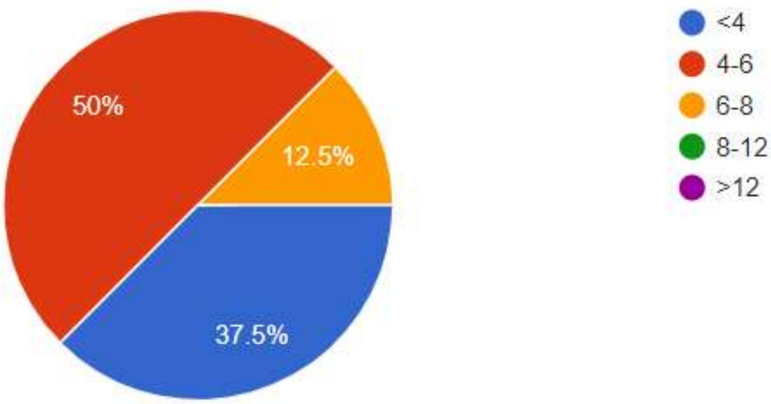

Figure 33 Strength training duration (months) post ACL injury and physiotherapy

5. Discussion

As seen by previously mentioned authors, ACL and hamstrings are related in a quite synchronized manner where one has a high effect on the other. Each test used in this paper had different results and overall interpretation that contribute to different conclusions. Thus, each test will be broken down separately for proper analysis

Firstly, the front lunge test results in Figure 20, show that 5 of the injured players were at a high risk of re-injury in the previously injured leg due to larger differences in concentric and eccentric peak powers. Whereas, the other 3 athletes had higher risk in the non-injured leg. Variances can be seen clearly in the graph where many athletes had results over the yellow line (>15% difference), some can be seen in the low risk (between 10-15% difference) range and only one leg from two different athletes had no risk (less than 10% difference). Some athletes have very high differences between both legs as seen in athlete number 2 with around 10 percent higher value. Athlete number 2 has the right leg in the high-risk zone and the left in the low risk. The larger gap in muscle asymmetry can lead to higher risk of injury to the more symmetrical muscle due to overcompensation and loading applied during performance(Newton et al., 2006).

The second test, SLPD results were very different with high variances in each player. Many of the results for this test were low risk (blue coded in Figure 21) thus stating that there are no large imbalances as opposed to other tests performed. Some of the asymmetry were seen as negative numbers that have higher eccentric power than concentric as shown in Figure 21. These numbers put players in a safe zone where results did not reflect any risk on injury. Some of the players had very high variances in results as well where one leg had more eccentric strength and the other had higher imbalances such as athlete 1. Athlete number one had higher eccentric power in the hamstring of the non-injured leg than the concentric power which resulted in a negative imbalance number; a bar under 0, thus no risk of injury but rather beneficial for the muscle(Ardern et al., 2015). The injured leg however, is in a high-risk zone of 23% intra-leg imbalance in the hamstring muscle putting the total inter-leg hamstring difference at around 24 percent. This shows that athletes can have intra-leg power symmetry but not inter-leg power symmetry thus increasing risk of injury due to high differences between them. Apart from this athlete, the majority of the athletes showed up in the no injury zone such as athletes 5 and 6 for both intra- and inter- leg powers. Athlete 2 showed high risk of injury in both legs with high imbalances between hamstring muscles of over 15 percent in every intra-leg strength whereas the inter-leg strength difference was less than 10%.

The third and last test; lying leg curl, had high differences in values for each player; however, numbers were scattered rather than being around the same zone as seen in the straight leg pull-down test in Figure 22. Some of the athletes have shown to have both legs in the same safe zone such as athletes 2 and 4. Other athletes showed high difference such as athletes 3 and 7 where their non-injured leg was under the green line which has no risk of injury, whereas the injured leg is in the high risk zone of over 15 percent imbalance in eccentric and concentric contraction of the hamstring muscle. Two of the athletes had both inter and intra leg imbalance over the high-risk threshold above 15 percent such as athletes 5 and 8.

Statistical analysis of the test results was conducted based on their t-test p-values which has to be <0.05 to have significant differences. According to the results of asymmetry, the FL and SLPD tests, both had no significant differences between both legs with p-values 0.341 and 0.925 respectively; shown in Figure 25. In the case of the peak power t-test results, both FL and SLPD as well had no significant differences with values of 0.389 and 0.398 respectively (Figure 26). Although the SLPD test had the highest number of athletes who had higher injured leg power than the non-injured (Figure 24), values of the T-test when comparing both peak power and asymmetry had no significant difference between either group but rather were the highest. Nevertheless, FL also had only one athlete who had higher hamstring power in their injured leg (Figure 26)

On the contrary, the last test of LC had some opposing results to the previous tests where both the peak power and the asymmetry (Figure 25 and Figure 26) p-values were associated with high significance of <0.05. On further inspection, the results of the p-value clearly show that this high significant difference was due to overall weaker injured limb and not the non-injured limb which can be seen in the higher mean asymmetry and lower mean peak power(Figure 27 and Figure 28). None of the athletes had higher peak power in the injured leg in this test when compared to control group and other test results. Overall, we can safely say that 2 of the 3 tests (66.6%) do not support the hypothesis that ACL injured limb has overall higher asymmetry and weaker hamstring muscle. On the contrary, the leg curl test supports the hypothesis seen in the significant differences of weaker hamstring muscle in the injured limb.

Majority of the Athletes had more symmetrical non-injured leg when performing both SLPD and LC using the isoinertial cone machine according to the higher values by 4.37% and 4.02% respectfully in the injured group. On the other hand, while performing the front lunge using the yo-yo flywheel, the injured leg was more symmetrical when compared to the control non-injured leg by 4.54%. Having said that, risk of injury can also be related to total muscle power (Watts) between different limbs. Figure 24 presents total hamstring power in Watts; obtained by adding the concentric and eccentric power of said leg, between the injured limb and non-injured limb. In the LC test, all athletes had weaker hamstring when compared to non-injured leg. As for the other tests, the FL performed on yo-yo flywheel only had one athlete with stronger hamstring power in their injured leg than the control leg. The SLPD scored the highest number of 4 athletes; 50%, with stronger hamstring in injured leg as opposed to other tests with lower numbers.

As previously mentioned, BMI can have somewhat an effect on ACL and future injuries due to excessive load on the knees, thus disrupting its normal function. In the SS athletes had normal BMI in the range of 19 to 24.55 as shown in Table 1 with an average of 21.66 KG/m^2. More males had non-contact form of injury as opposed to the lower number of the females in the SS. In this sample there were equal number of females with contact ACL and non-contact ACL injuries whereas males had one contact and 3 non-contact out of all 4 in the SS. All four females stated having more dominance in their right leg (RL) than in their left leg (LL) whereas men had 3 RL dominance and 1 LL dominance. As for the injures, 2 of the females had injuries in the dominant leg whereas the other 2 in their non-dominant leg. 3 of the males had injuries in their dominant leg where as one had the injury in their non dominant leg. In the same table, it is clear that post- ACL injuries can occur to up-to 50% of the athletes in both genders as 2 of each of the 4 athletes from every gender had post ACL injury.

Figure 31 represents the average age of injury according to gender. The average age of females and males were both in teenage years of 18 and 19 years respectively. Ardern et al. (2015) also stated that ACL injuries mostly occur over the age of 18 where majority of female injuries recorded were the highest between late teens and early twenties; whereas, males were between mid and late twenties. Females age range was between 15 and 22 whereas males age range was between 15 and 25, putting both genders at higher risk of injury in teenage and adulthood. Both average gender ages were over the threshold of 18 years which can be used as a reason for injury.

In both LS and SS, gender did not play a role in injury occurrence. This can be seen in the results of the number of injured athletes in the LS where females had a surprisingly lower number of 4 out of the total 13 making up 31% of sample injury. On the other hand, the number of males in this sample were 9 out of 13 making up 69% of sample injury as seen in Figure 16. Ardern et al.(2015), Ireland(2002) and Zantop et al.(2005) all dove deep into the reasons why females are at higher ACL injury risk whether it was due to anatomy, hormones or overall techniques with a unanimous conclusion of higher injury occurrence in females by 3.5 folds. This conclusion does not apply to this sample since the majority of the LS were males (69%) and the SS had equal number for either gender.

Furthermore, females in the SS had shown an overall less number of non-contact injuries of 2/8 whereas males had 3/8, as well as less number of dominant leg injuries as opposed to males. Newton et al.(2006), Boden et al.(2010) and Yu & Garrett (2007) stated that ACL mostly occurs in a non-contact manner in females and more in the dominant limb since they rely on it for better performance and higher power, which is less seen in males.

This experiment provides a new insight into the relationship between ACL injury and sports played. According to Figure 30, majority of the injuries reported in this sample were from football, basketball and one heptathlon athlete. Football has been the sport with highest reported ACL injuries followed by female basketball and gymnastics, which is seen in this sample(Hootman et al., 2007; Joseph et al., 2013). According to the data, football sport had a total of 7 ACL injuries, basketball has 5 injuries and 1 athlete from heptathlon represented in the “other” column. Overall, males have shown higher injury rate when compared to females in both basketball and football respectively. Males have scored a number of 3 and 6 injuries in basketball and football respectively. On the other hand, females injured were 2,1 and 1 in basketball, football and other (heptathlon) respectively. As for the average age in which athletes had the injuries depending on gender. Furthermore, majority of the females in this sample played basketball whereas the majority of males played football. These results clearly support the claim stating that male football and female basketball athletes are two sports highly associated with ACL injury.

As expected, injuries were quite prevalent in this sample for post ACL injury even after completion of rehabilitation and strength training needed for complete return of knee function. The results make up 50% of the sample of having multiple lower limb injuries some of which include re-injury of the ACL. This cause of high post ACL injury can be linked to the duration of strength training and recovery of each athlete which usually is over 6 months for complete knee strength regain and function(Cavanaugh & Powers, 2017; de Jong et al., 2007;

Welling et al., 2019). Half of the athletes in this sample completed 4 to 6 months strength training however, only 37.5% of them trained for less than 4 months which is quite far from the minimum time needed.

Due to the lack of available data, the results cannot confirm whether athletes who had not completed over 6 months of training can be somehow used as a post ACL precursor due to deficiencies in knee functions. Apart from the training duration, the part in which athletes are in the training season can also affect injuries in the lower limbs specifically in the pre-season(Ardern et al., 2015). The results do not fit this theory since the majority of the ACL injuries in this sample occurred in mid-season phase whereas the minority occurred in the pre-season phase.

Years of experience would be something that some might interpret as a lower injury rate for the athlete because they know how to move and what to do which is not true. This sample had a high percentage of athletes who had been playing professionally for over 10 years whereas only 25% of them had between 5 to 10 years of experience; still considered high. As mentioned previously, athletes with higher years of experience are at higher risk of getting injured due to their accustomed muscle contractions which usually decrease as the experience increases(Sigward & Powers, 2006).

6. Conclusion and Future Works

ACL is one of the complex ligaments at risk in many sports due to the various factors that contribute in its injury mechanism which might have a weakening effect on the hamstring muscles. Athletes used in this sample did not have any relation to some of the primary injury factors such as gender or BMI but rather to the years of experience, age and sport played. Injuries recorded were higher in male athletes where the majority were in a non-contact mechanism. On the other hand, females were lower in number and their injury mechanism was equal between contact and non-contact.

All injuries recorded were made up of basketball and football players; with the exception of one heptathlon athlete, 75% of which who had over 10 years of experience. Each of the tests conducted contributed to the hypothesis which stated, "ACL injured limb has weaker hamstring muscles when compared to non-injured limb". Both FL and SLPD tests dispute the hypothesis where both results had no significant differences in peak power and power asymmetry. Having this low difference between both groups also implies that the hamstring muscle is able to function as normally as the non-injured leg without deficiencies. On the other hand, LC supported the hypothesis with significantly more asymmetrical and weaker hamstring muscles. Results Interpretation can be set as 66.6% hypothesis dispute and 33.3% support.

Some of the restrictions of this research include:

- The inability to collect a large sample because of the COVID-19 pandemic circumstances,
- Inability to contact all the athletes for the survey questionnaire,
- Lack of documented injuries data,
- And limited research duration.

The effect of ACL injuries on the hamstrings' overall performance must be studied deeper due to their relation and close connections. Future studies can incorporate higher sample size and more hamstring related movements to compare individual and grouped test results for clearer answers. Better comparisons can be made based on gender, BMI, and age of athletes using a larger sample size.

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Appendix

Información de antecedentes del atleta

* Required

1. Nombre (permanecerá anónimo) *

2. ¿Qué tipo de deporte juegas? *

   Mark only one oval.

   - Football
   - Basketball
   - Tennis
   - Heptathlon
   - Volleyball
   - Hockey
   - Swimming
   - Maraton
   - Otro

3. si has elegido Otro, por favor especificas.

4. En que posicion juegas? *

5. ¿Cuánto tiempo llevas jugando este deporte? *

Mark only one oval.

- ⬭ 5 años
- ⬭ 5-10 años
- ⬭ 10-15 años
- ⬭ mas de 15 años
- ⬭ menos de 5 años

6. ¿Tienes alguna lesión en las extremidades inferiores? *

Mark only one oval.

- ⬭ si
- ⬭ no

7. Si respondiste a la pregunta anterior "Sí", Que fue la lesion/es?

____
____
____
____
____

8. Has recuperado completamente del lesion? eres capaz de realizar correctamente? *

Mark only one oval.

- ⬭ No
- ⬭ Si, completamente
- ⬭ Si, pero no tan fuerte como antes

9. ¿Cuantos años tenías cuando te lesionaste?

____

10. ¿Cuándo durante la temporada ocurrió la lesión?

Mark only one oval.

- Pre-temporada
- Temporada media
- post temporada
- en un partido

11. ¿Cuántas veces a la semana y horas estaba entrenando antes de la lesión or si no tienes? *

Mark only one oval.

- 2 dias- 1 hora de cada sesion
- 2 dias - 2 horas de cada sesion
- 3 dias - 1 hora de cada sesion
- 3 dias - 2 horas de cada sesios
- 4 dias - 1 hora de cada sesion
- 4 dias - 2 horas de cada sesion
- 5 dias - 1 hora de cada sesion
- 5 dias - 2 horas de cada sesion
- 6 dias - 1 hora de cada sesion
- 6 dias 2 horas de cada sesion
- toda la semana - 1 hora de cada sesion
- toda la semana 2 horas de cada sesion
- otro

12. Si has elegido "otro", por favor especifica.

____
____
____
____
____

Atletas con LCA

Si no tienes la lesion de LCA previa, puedes parar la encuesta aquí.

13. Si tu lesion fue Ligamento cruzado anterior (LCA) responde las siguientes preguntas, Cuál fue la causa de la lesión?

Mark only one oval.

- ◯ contacto - Fue causado por otros jugadores que te golpearon
- ◯ non-contacto - fue causado por un movimiento incorrecto (por ti mismo)

14. ¿Cuánto tiempo tardaste en volver a jugar? Tiempo de recuperacion?

Mark only one oval.

- ◯ 6 meses
- ◯ 6-12 meses
- ◯ 12-18 meses
- ◯ mas de 18 meses
- ◯ Menos de 6 meses

15. ¿Cuánto duró su fase de recuperación de fisioterapia?

Mark only one oval.

- 3 meses
- 4 meses
- 5 meses
- 6 meses
- >6 meses

16. ¿Durante cuánto tiempo (meses) entrenó después de la fase de fisioterapia para realizar ejercicios de fuerza antes de volver a jugar?

Mark only one oval.

- <4
- 4-6
- 6-8
- 8-12
- >12

17. ¿Tienes alguna lesión previa? (antes de su lesión de LCA) ¿Y que era?

____

18. ¿Qué pierna es tu pierna dominante?

Mark only one oval.

- Derecha
- Izquierda

19. ¿Qué pierna resultó lesionada?

Mark only one oval.

- ( ) Derecha
- ( ) Izquierda

20. ¿Has tenido alguna otra lesión después de ACL? volver a lesiónar o otras lesiones en las extremidades inferiores? Que fue?

21. ¿Crees que has recuperado la función completa de la rodilla y la fuerza en comparación con su estado anterior?

Mark only one oval.

- ( ) No
- ( ) Si
- ( ) Si pero mas debil que antes