Diploma thesis

Gender-specific differences in landing techniques of children and adolescents performing a drop-jump.

A test battery for the examination of children's and adolescents' knee stability.

submitted by

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Graz, December 21, 2020

Statutory declaration

I hereby formally declare that I have written the submitted thesis independently and without any outside support except for the quoted literature and other sources mentioned in the paper. I clearly marked and separately listed all of the literature and all of the other sources which I employed when producing this academic work, either literally or in content.

Graz, December 21, 2020 *Kempf Anna Sophie Maria, eh*

Acknowledgement

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Index

Glossary

ACL	Anterior cruciate ligament
CL	Cruciate Ligament
Ext.	Extension
Flex.	Flexion
IC	Initial contact
Inf.	Inferior
ISSA	Iliac spina superior anterior
Lat.	Lateral
LCA	Ligamentum cruciatum anterius
LESS	Landing error scoring system
LSI	Limb Symmetry index
M.	Musculus
Max	Maximal
MKM	Maximal Knee Moment
Med.	Medial
Min	Minimal
N	Newton
PCL	Posterior cruciate ligament
RoM	Range of Motion
Sup.	Superior

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Zusammenfassung

Einleitung: Das vordere Kreuzband ist das am häufigsten verletzte Band im Knie. Die meisten Rupturen entstehen bei kontaktlosen Sportarten. Bei Hochrisiko-Sportarten zeigen Frauen, ungeachtet ihres Alters, eine höhere Wahrscheinlichkeit für derartige Rupturen. Der typische Verletzungsmechanismus für kontaktlose LCA Verletzungen beinhaltet unter anderem ein abruptes Abbremsen und einen schnellen Richtungswechsel. Auch dynamische Valgus-Einknicke scheinen bei weiblichen Athleten häufiger vorzukommen. Daher ist das Ziel dieser Studie, durch die detaillierte kinematische Untersuchung der Landephase bilateraler Drop-jumps, die Unterschiede des Landeverhaltens männlicher und weiblicher Athleten realitätsgetreu herauszuarbeiten Da laut Studien Videos die beste Methode sind um die Biomechanik von LCA-Rupturen, minimale Knieflexion und Innenrotationen der Tibia nachzuvollziehen, wurden die Testungen mithilfe von insgesamt 16 Kameras aufgezeichnet.

Material und Methoden: Als Probanden der Studie wurden jeweils 12 gesunde, sportlich aktive männliche und weibliche Kinder und Jugendliche zwischen zehn und achtzehn Jahren ausgewählt. Diese durften in ihrer Krankengeschichte keine Knieverletzungen oder -instabilitäten in den letzten sechs Monaten aufweisen. Zur Untersuchung wurde eine Testbatterie aufgestellt, bestehend aus: Kniestabilitätsüberprüfung, Muskelkrafttestung, uni- und bilateralen drop-jumps, triple hops, cross hops und single hops, Y-Balancing und Tapping. Zudem wurden die Sprünge mit Kameras aufgezeichnet und per 3D Kinematik Analyse ausgearbeitet.

Ergebnisse: Bei der Auswertung des Landing Error Scoring System (LESS) Scores konnten keine signifikanten Unterschiede zwischen der Landetechnik von Mädchen und Jungen gefunden werden. Jedoch ließen sich signifikante Unterschiede der Leistungen von Buben und Mädchen bei single und cross hops und der Muskelkraft der Abduktoren feststellen, wobei hier die männlichen Probanden besser abschnitten. Auch die 3D Kinematik Analyse lieferte signifikante Ergebnisse: Mädchen flektieren beim Landen ihre Hüfte mehr, sowohl beim Initialkontakt als

auch beim Maximalwert, wohingegen Buben eine größere Innenrotation ihrer Knöchel beim Initialkontakt durchführen.

Diskussion: Es konnten keine signifikanten gender-spezifischen Unterschiede beim LESS Score gefunden werden. Jedoch konnten bei Buben höhere Werte bei der Kraftmessung der Abduktoren - einem Valgus protektiven Faktor - und bei Mädchen höhere Hüftflexionswinkel - ein Parameter zum Nachweis guter Landetechnik - nachgewiesen werden. Diese Ergebnisse stehen im Kontrast zu den Ergebnissen zum Landeverhalten von Erwachsenen in der Literatur und könnten den noch fehlenden Entwicklungen und Veränderungen während der Pubertät zugrunde liegen. Weitere Untersuchungen von Risikofaktoren für ACL Verletzungen bei Kindern und Jugendlichen sind notwendig, um Präventionsprogramme auszubauen und zu verbessern und somit die hohen Verletzungszahlen zu senken.

Abstract

Introduction: The ACL is the most injured ligament in the knee joint. Usually those, ruptures happen during non-contact sports. In high-risk sports, female athletes show greater risks for ruptures in comparison to their male counterparts. The typically performed maneuver for non-contact ACL injuries consists of an abrupt deceleration and a very fast change of direction. It seems to be more likely for female athletes to show dynamic knee valgus than for men. Therefore, this study aims to compare the kinematics of male and female young athletes during landing after a bilateral drop-jump, recorded via 16 cameras, as a representative for a realistic injury mechanism, since videos are the best way to understand the biomechanics of ACL ruptures according to the literature.

Materials and Methods: A total of 24 (12 male and 12 female) recreational athletes between the age of ten and eighteen volunteered for this study. Those must not have any history of knee injury or pain within the last six months. The trial consisted of clinical knee stability, strength testing, unilateral and bilateral drop-jumps, triple hops, cross hops and single hops, Y-Balancing and tappings.

Results: When evaluating the Landing Error Scoring System (LESS) Score, no significant gender differences in the performance of boys and girls have been discovered. However, females and males did show significant differences when performing single and triple hops and the abductor muscle forces, where boys emerged off better. Furthermore, the 3D kinematic analysis yielded significant results: females had increased hip flexion and internal rotation angles at initial contact and at max, whereas boys showed greater ankle internal rotation at initial contact.

Discussion: No gender-specific difference in the LESS Score after drop-jumps have been found, nevertheless, boys did show great abductor forces, which is known to be a valgus protective factor, whereas girls showed greater hip flexion angles, a parameter for a proper landing technique. These findings are contrary to the literature of the landing technique of adults and could be caused by the missing pubertal changes. Further in-depth investigation of ACL injury risk factors in children

and adolescent is necessary to improve and enhance prevention programs to decrease injury rates.

1 Introduction

The cruciate ligaments are a very important stabilizing factor of the knee joint. Especially the anterior cruciate ligament (ACL) secures the knee from valgus stress and external rotational forces. (1) Unfortunately, ACL injuries are the most common injury of the knee in total and particularly in young athletic adolescents, and the incidence even continues rising. (2) An ACL rupture is a crucial injury to the knee, which commonly occurs during sport activities. (3) The impact of an ACL injury can vary from patient to patient. Some experience a limitation of their sporting activity, whereas some experience a restriction of their daily life activities. (1) Although prevention programs have been elaborated and do show effects on the incident of ACL injuries, the rates of injuries are still rising. However, therapy algorithms for pediatric patients are still controversial. (4)(5)

Studies show that adult women do show a poorer landing technique in comparison to their male counterparts. (6) This study examines whether young recreational athletes already show differences in their landing too.

1.1 Relevance of the topic

For female athletes the risk of an ACL injury is four- to eight-fold greater than for their equivalently trained male counterparts. (7) 15- to 24-year-old female athletes, practicing high-risks sports have the highest individual risk to suffer a ACL injury. (2) As seen in Figure 1, the distribution of ACL injuries in the Norwegian National Knee Ligament Register shows a left shift, which results in high numbers in the young population. (8) Even more interesting: the rise in ACL injury rates in children seems to be higher than the rise in the adult population. (2) Usually ACL injuries occur after a non-contact event, such as, a fast change of direction, deceleration and landing during sports. (8)(9) It is already known that adult females do show differences in their way of landing compared to males. In general, one could say they tend to show a more ACL-harming way of landing: they land in a more erect posture and with a bigger knee valgus. (10)

Furthermore, ACL injuries are followed by a high risk of early gonarthrosis in the injured knee and subsequent knee injuries, e.g. a de novo ACL rupture or a lesion of a meniscus due to a general instability of the knee and insecurity of the patient. (11)

Those injuries do not merely cost 17,000 dollars per athlete and add up to 119 million dollars annually for only female high school basketball players in the US, but rather end the season for these athletes resulting in the loss of a possible scholarship, sports participation and lowered academic performance. (10)

Thus, ACL injuries do not seem to be just an isolated injury to the knee but also have significant consequences to the children/adolescents in educational, athletic, medical and even emotional and socioeconomic respects.

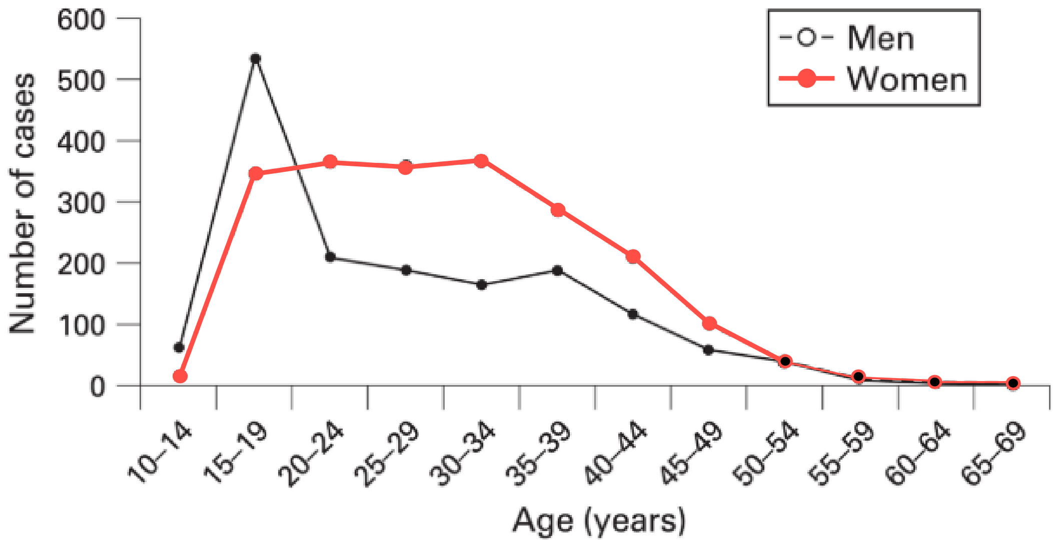

Figure 1: Distribution of ACL-injuries of the Norwegian National Knee Ligament Registry by age and sex (modified after (8)*)*

In order to decrease the number and prevent ACL injuries, prevention programs have been elaborated. Studies show that a combination of different programs achieve the best outcome. Altogether, strength training, plyometric training and technique training in combination with feedback in regard to proper form prove to be effective. The highest reduction of injury risk is achieved for female athletes under the age of 18 (72% risk reduction). Consequently, prevention-programs may show the most efficiency for ACL injury reduction during early puberty. (12)

The literature covers a great amount of studies about grown-up athletes and cadets and their landing techniques as well as their subsequent therapy and treatment of ACL injuries. (6) However, it lacks a sound number of studies of children and adolescents, which leads to a hardship and vagueness in therapy concepts for ACL injuries in younger individuals. In consequence, there is no high-quality evidence of the management of pediatric ACL injuries and especially no guidelines concerning how the treatments should manifest themselves and how they would be conducted. Apart from that, prevention and therefore avoidance of injury should be set in focus of future research, as no treatment could ever replace the persistence of the native ACL.

Hence, by examining the differences of landing after a performed drop-jump and 3D kinematic analysis of children and adolescents, the team is looking forward to being able to identify risk factors for subsequent ACL injuries and to designing further prevention-programs and trainings for athletes.

2 Theoretical part

2.1 Anatomical overview

The knee joint represents the largest synovial joint in the body. It is formed by the femur, which articulates with the tibia in the femorotibial joint and with the patella in the femoropatellar joint. All three of these bones join the same articular capsule. (13)

Due to the powerful extensor and flexor muscles' strength, a number of stabilizing factors are needed to brace those biomechanical forces. (14)

Therefore, the knee is provided with intracapsular and extracapsular ligaments: the anterior cruciate ligament, the posterior cruciate ligament, the collateral ligaments and numerous smaller ones. (13)

2.1.1 Cruciate ligaments

The cruciate ligaments are very important intracapsular structures used for the stability of the knee. As the term already implies, those two ligaments cross each other, not only in the sagittal plane but also in the frontal plane. (14)

Concerning their tibial attachment, it can be stated that the anterior cruciate ligament is fixed on the anterior intercondylar area of the tibia and the posterior ligament (PCL) can be found on the posterior intercondylar area of the tibia posterior. (14) (Figure 2)

The ACL then proceeds to the posterior inner surface of the lateral side of the intercondylar fossa on the femur condyles. The thicker PCL runs to the inner surface of the medial femur condyle. (15)

The ACL has three parts:

- Anteromedial bundle: contains the longest fibers and is most likely to be injured.
- Posterolateral bundle: is being covered by the latter.
- Intermediate bundle: lies in between the antero- and posterolateral bundle.

Those bundles are torqued around each other.

Moreover, the PCL also consists of three parts:

- Anteromedial bundle: inserts anteriorly into the tibia and medially into the femur.
- Posterolateral bundle: inserts into the very back of the tibia and externally into the femur.
- Posterior meniscofemoral ligament: reaches from the posterior horn of the lateral meniscus to the lateral facies of the femur. (16)

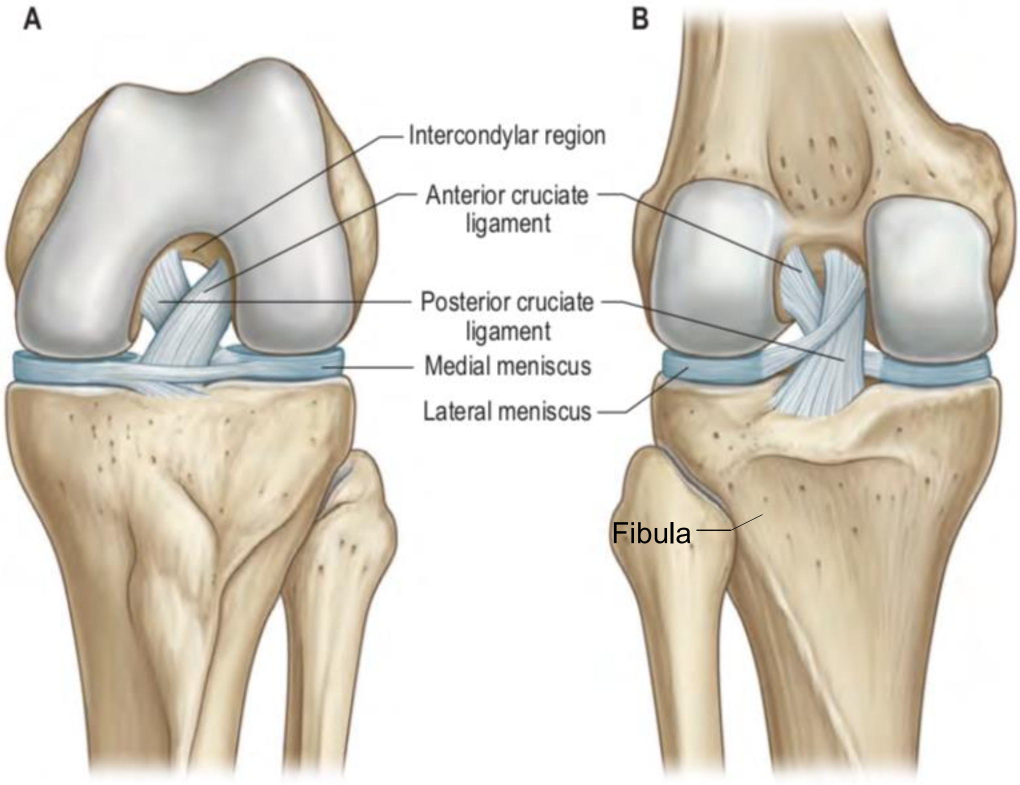

*Figure 2: The left knee joint. **A**, Anterior aspect in full flexion. **B**, Posterior aspect in extension. (modified after* (14)*)*

2.1.2 Menisci

Those c-shaped discs, made out of fibrocartilage, are situated in between the femoral and tibial articular surface. Due to the fact that they slide along the tibial plateau, they are called *transportable articular socket*. The medial meniscus is more demilune-shaped and is in contact with the rear part of the tibial collateral ligament. The lateral meniscus is nearly o-shaped and smaller than the latter one. Fixed by short tense ligaments, ending between the anterior and posterior horn of the menisci, they still have room to move. (Figure 3) By flexing the knee, the menisci get shifted to the back by the condyles. They do not only compensate incongruences of the joint surfaces, but also enlarge the pressure zone. (15)

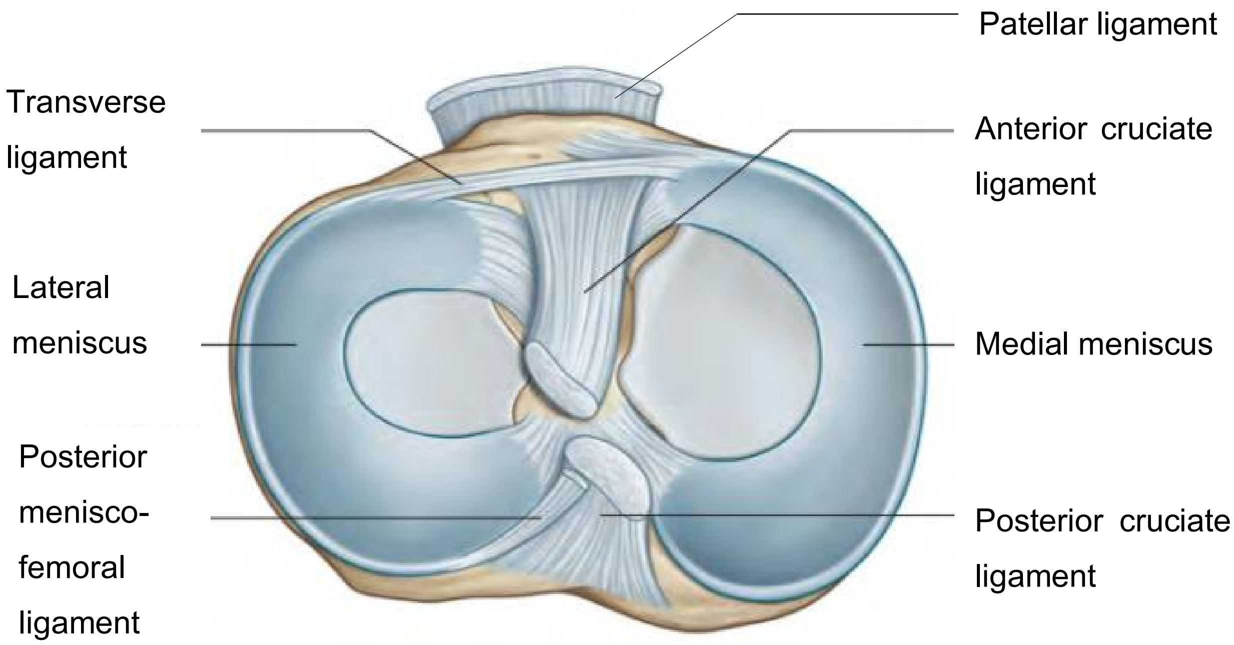

Figure 3: Menisci of the knee (modified after (14)*)*

2.1.3 Collateral ligaments

Originating from the medial femoral epicondyle the tibial collateral ligament pulls broadly to the front and inserts distally the tibial plateau and tibial tuberosity at the medial tibial facies. The fibular collateral ligament reaches from the lateral femoral epicondyle to the head of the fibula.
The fibular collateral ligament and the tibial collateral ligament provide support for the knee joint in the frontal plane, thus, they are working against the medial and lateral forces and are stabilizing the knee during extension. (15)
The physiological valgus of the knee, due to the slight medial tilt of the distal end of the femur, does not only result in vertical but also in transversal forces onto the knee joint. The second increases the knee's tendency to a valgus posture. The medial ligaments work against these transversal forces. (16)

2.1.4 Capsule and other ligaments

Horizontal forces are counteracted by the posterior capsule and ligaments, even allowing amuscular stand when in hyperextension. The collateral ligaments, to be precise, the PCL, the tendons of the gastrocnemius muscle, the arcuate popliteal ligament and the oblique popliteal ligament form the back of the stabilizing posterior joint capsule and its ligaments. (16)

Gender differences: The knee joint is physiologically in a valgus position due to the fact that the femur is not in an absolute vertical alignment with the tibial bone. Taking in account that females do have a wider pelvis, this valgus position increases even more for the female gender. (16)

2.1.5 Malalignments

In comparison to the physiological anatomy of the knee joint, the malalignments display atypical alignments of the knee joint.
Among other malalignments, especially two pathological knee positions can be found in the majority of patients:

- Genu varum: The femur and the tibial bone enclose an exterior angle >180° leading to a deviation of the mechanical axis of the leg (medial intercondylar eminentia and intercondylar fossa) medial of the knee joint center > 10 mm.
- Genu valgum: In this case the diaphyseal axial angle is smaller than 160° and it comes to a shift of the mechanical axis of the leg to the lateral side of the knee joint center > 10 mm.

For diagnosing these malalignments, a strictly anterior-posterior x-ray of the legs is needed. (16)

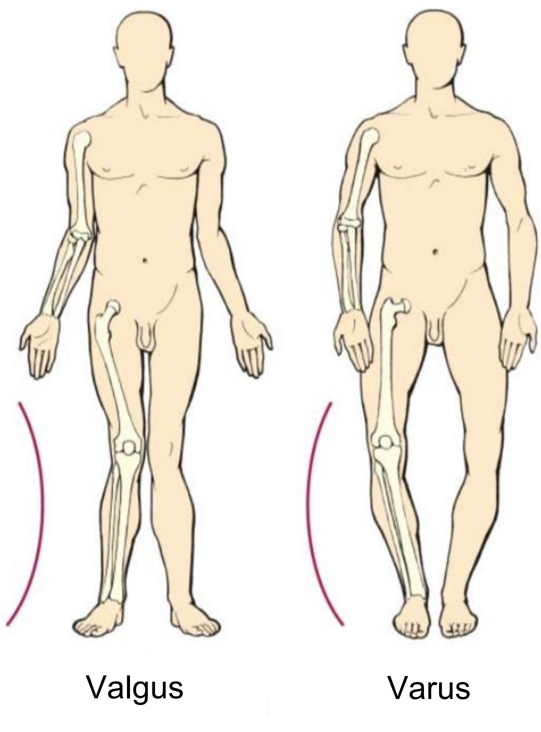

Figure 4: Knee malalignments modified after (17)*)*

2.2 Functional anatomy

2.2.1 Movements

2.2.1.1 Extension/Flexion

These termini are defined by the relation of the calf to the gluteal muscle. An extension is performed when the calves diverge from the gluteal muscles. In comparison, a flexion is performed when calves and gluteal muscles approach. Having an insight into this ginglymoid joint, one can observe the femur's condyles rolling and sliding over the tibial plateau during these movements. (16)

Extension represents the neutral position of the knee joint when the femur and the tibia add up to a straight line in sagittal plane. From this position, an additional passive extension of 5 to 10° is possible, whereas active hyperextension is barely possible.

Flexion is depending on the hip joint's position. If the latter is being flexed, the knee joint can be flexed actively to up to 140°. In contrast, if the hip joint is in an extended position, only a 120° of knee flexion is achievable due to the active insufficiency of the ischiocrural muscles. (18) Passively, it is possible to flex the knee at an angle of 160°. (16)

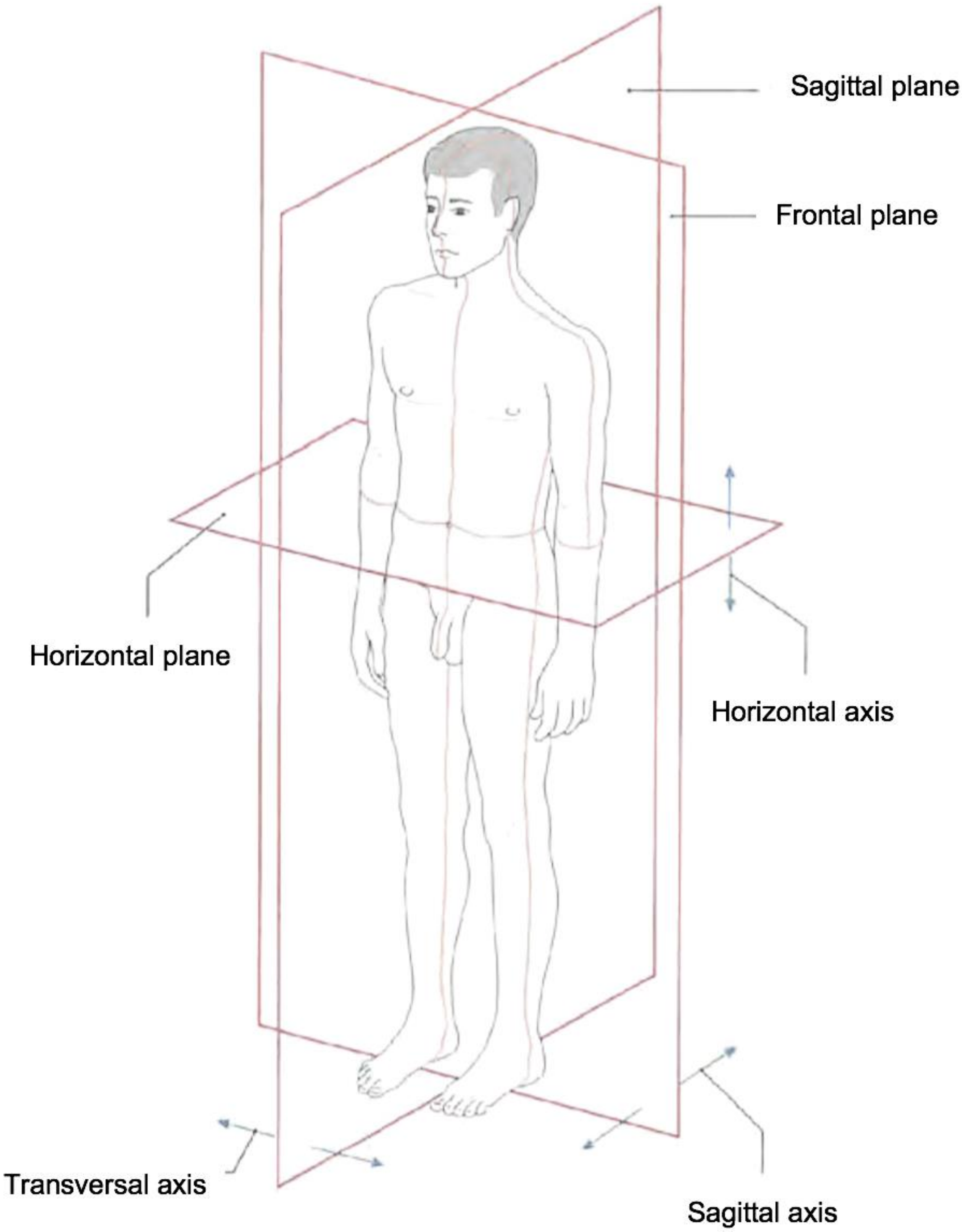

Figure 5: Planes and axes on the body (modified after: (21))

2.2.1.2 Rotation

An active rotation of the knee joint is only possible in a flexed position owing to the stabilizing components of the cruciate and collateral ligaments.

In flexion, an external rotation of the lower leg reaches up to 30°. In contrast, an internal rotation is limited to 10° by the cruciate ligaments torqueing around each other. (16)

Furthermore, an external rotation of 5 to 10° occurs after extending the leg. It is an obligatory mechanism to relax the cruciate ligaments in the extended position and to tense the medial and lateral collateral ligaments. (18) This so-called *screw-home-movement* is a *locking* mechanism that provides stability to the extended knee. (14)

2.2.2 Functional anatomy of the cruciate ligaments

The cruciate ligaments strengthen the knee joint particularly in the sagittal, frontal and even in the horizontal plane.

2.2.2.1 Stabilization in sagittal plane

Especially in an antero-posterior movement, the cruciate ligaments provide stabilizing factors for the knee joint, thus, no shearing of the femur and tibia against each other in sagittal direction is possible. In extension as well as in a 30° flexion both CLs are tensed equally. With flexion, the distal part of the femur is tilted, the PCL is moved into a more erect position, meanwhile the ACL is nearly in a horizontal position. (16)

At 90° and 120° flexion, the ACL's intermediate and posterolateral bundles are relaxed, just the anteromedial bundles are slightly tensed. In contrast, the PCL is mainly tightened in the inflected joint. At extension or hyperextension, all bundles of the ACL are tensed and the PCL is mainly relaxed except for its posterior bundles. While hyperextending, the intercondylar fossa moves caudally onto the ACL and tightens it like a bowstring. By doing so, the ACL is one of the main structures inhibiting hyperextension. To be precise, in every position at least one part of both cruciate ligaments is tensed respectively. For simplification and better understanding, it is assumed that the PCL tightens during flexion and the ACL during extension. (16)

2.2.2.2 Axial stabilization

When being in extension, no rotation movements are possible owing to the fact that the collateral ligaments and the ACLs are tensed (*screw-home-movement).*

Performing a flexion of the knee joint allows a rotation of same. During an internal rotation, the CLs change – in horizontal plane - from a parallel position to a position where they are winding around each other, thereby limiting the internal rotation. External rotation of the tibia makes the CLs relax and get into a parallel position in horizontal and frontal plane. (16)

The CLs do not only serve a stabilizing but also an active moving purpose due to the fact that the femur's condyles are not just rolling on the tibial plateau but also sliding over it.

When flexing the knee, the ACL pulls the femur's condyle to the anterior and slides it over the tibial plateau while the condyles are simultaneously rolling backwards. The importance of the PCL during extension can be considered likewise, as it is pulling the condyle to the posterior, while it is rolling to the front.

This explains the pathological sign occurring after a CL (cruciate ligament) rupture called *drawer sign* that can be detected in clinical examination, when the tibial bone can be shifted against the femur to the front or to the back. (16)

Gender differences: Former MRI-Scans studies show that men tend to have a greater ACL volume compared to women. (19)

2.3 Pathophysiology & Biomechanics

Usually, ACL injuring maneuvers show a typical body posture consisting of three major movements: a valgus collapse of the knee, a full extension to a slight knee flexion – between 0° and 30° – and an external tibial rotation with a fixed foot on the ground while performing a deceleration move. (9) Simplified, fast acceleration and deceleration moves have high risks of containing an ACL injury. This can be explained by the fact that while casually walking, the ACL is exposed to a tensile loading of 400 to 500 Newton (N), but during fast acceleration or deceleration, loading of 1700 N can be measured. (20)

Women do show an increased knee valgus angle during landing. Although this is identified as a risk factor for sustaining an ACL injury, this mechanism alone does not enable sufficient load to injure the ACL without injuring the medial collateral ligament first. (21) Often a combination of three injuries occurs: injury of the ACL, a tear of the medial meniscus and an injury of the medial collateral ligaments, the so-called *unhappy triad*. (22) Instead, the combination of knee valgus and other ACL loading mechanisms, such as anterior translation of the tibia, increases ACL loading during flexion of the knee at 0 to 40° and will rather lead to an injury of the ACL alone. (21) Typically, ACL injuries occur during high-risk sports, such as skiing, soccer and tennis. (20)

2.4 Epidemiology of ACL rupture

According to a study by Childs et al., the number of ACL injuries in athletes younger than eighteen has doubled in number. This may not only be caused by the rising number of young recreational athletes and intensified trainings at an early age, but also by higher diagnosis rates due to enhanced medical imaging. (12)
Furthermore, there was a geometric rise of ACL injuries in female athletes in the US owing to the inception of Title IX of the Education Amendments of 1972 (10), which allows students of any gender to participate in any educational program or activity. (23)

"*No person in the United States shall, on the basis of sex, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any education program or activity receiving Federal financial assistance*." (24)

In consequence, since 1972, the number of female athletes in high school sports has nearly increased by the factor of twelve - from 294,015 participants to 3,415,306 in 2018. (25)
Compared to knee injuries, which have male predominance (26), female athletes have a four- to sixfold greater risk of an anterior cruciate ligament injury than their male counterparts performing cutting and jumping sports. (10)
Even the season-ending effect of ACL ruptures are higher in female than in male athletes. (27)
Usually, ACL ruptures do not occur in children younger than 12 years, although there have been reports of ACL injuries in 5-year-old children during sports. (12)
For girls, the risk of sustaining an ACL injury rises significantly at 12 to 13 years and at 14 to 15 years for boys. It seems that the rate in gender disparity starts around the time of the growth spurt, between the age of 12 to 14 for girls and 14 to 16 for boys, climaxes at adolescence and diminishes later on. In high school, injury rates are already approximately two to six times higher for girls than for their male counterparts in comparable sports (soccer, basketball). At the time of leaving high school and performing at a professional sports level in college, the injury rates of males and females approach each other. (8)

2.5 Etiology of ACL ruptures

The most common causes for ACL injuries are so-called “high-risk” sports including volleyball, basketball and skiing. Those sports involve pivot shift movements, fast changes of direction and acceleration. This may lead to typical injury maneuvers including an internal rotation of the tibia in comparison to the femur and a combination of valgus stress and external rotation. (28)
Additionally, in the literature, various external and internal risk factors are named.

2.5.1 External risk factors

2.5.1.1 Footwear and playing surface
Although good traction can improve sport performances, it may potentially increase the risk of ACL injuries. (8)

2.5.1.2 Competition
According to Myklebust et al., athletes tend to sustain ACL injuries during competition rather than in practice. (29)

2.5.1.3 Meteorological conditions
Similar to the footwear, studies find that a higher friction, which can be a result of drier grass conditions due to periods of scarce rainfall, causes higher numbers of ACL injuries. (8)

2.5.2 Internal risk factors

2.5.2.1 Anatomy

Controversial data exist for the association of narrow intercondylar space and ACL ruptures. Some studies suggest that indeed the risk of rupture indeed increases the narrower the intercondylar notch is, as this usually indicates a smaller and weaker ACL. (12) Other studies did not find any correlation. (30)
In female soccer players, the incident rate was significantly increased by general joint laxity and knee hyperextension, which means that athletes showing an anterior-

posterior laxity of the knee have a three times greater risk of suffering an ACL injury. (12)

2.5.2.2 Genetics

A familial accumulation in ACL injuries seems to exist and there have been findings about potentially predisposing genetic variants, but those still need further investigation. (31)

2.5.2.3 Hormones

Hormones play a very controversial role, given the fact that in the midst of the menstrual cycle the knee laxity appears to slightly increase, but injuries accumulate near the start of menses. (31)

2.5.2.4 Neuromuscular Deficits

According to Hewett et al., neuromuscular deficits represent one of the main risk factors for ACL injuries in female athletes. (32)

- Ligament dominance

The neuromuscular imbalance responsible for the knee valgus during landing is called *Ligament dominance*. This biomechanical deficit manifests itself via an insufficient absorption of the ground reaction forces by the muscles and, therefore, mainly the ligaments are held responsible. Thus, the muscles do not cushion the landing, but the joint and ligaments must absorb high amounts of force over a short period of time. (32)

- Leg dominance

This imbalance in the muscular symmetry between strength and flexibility and the differences in muscle recruitment patterns result in favoring one leg when performing landing tasks. Especially women tend to show greater asymmetries resulting in one limb absorbing the majority of the landing forces. (32)

- Trunk dominance

The third imbalance is defined by the inability to control one`s trunk in the three dimensions during landing. This loss of control eventuates in tilting the trunk to one side. Especially female athletes who just had a growth spurt tend to be overtaxed with the “changed” body. Furthermore, the modified body mass center and fat distribution, particularly on the trunk, can lead to problems in stabilizing. (32)

- Quadriceps dominance

Quadriceps dominance can be simply defined as the tendency to stabilize the knee joint during landing tasks mainly by activating the quadriceps muscles. This relates to a more extended landing manner for the knee. The quadriceps tendon, which uses the patella as a hypomochlion, inserts into the tibial tuberosity. Therefore, when tensing up the quadriceps, the tibia is translated to the anterior leading to an increased ACL tension. (32)

2.5.2.5 Gender-specific risk factors

Taken all the given imbalances into account, it may be concluded that women tend to land in a more upright position than men, as their knee joint stiffens because they primarily activate the quadriceps muscle. Hence, they perform a hard landing with the ligaments and joint absorbing the majority of the landing forces. (32)

2.6 Diagnosis of an ACL injury

2.6.1 Clinical symptoms

Usually, an acute ACL injury can be connected to a distinctive trauma resulting in acute loss or limitation of function due to heavy pain. (17) Sometimes, patients even report a definite snap in their knee joint. (20) Clinically, a hemarthrosis, which is an intra-articular bleeding leading to acute swelling within 24 hours, is the cardinal sign for an ACL rupture and the volume of the effusion is correlating with the rupture grade. A punction of the knee joint can confirm the diagnosis. (17)

2.6.2 Clinical signs and examination

The clinical examination should always be done on both knees and in comparison to the other side. To get a feeling for a patient`s individual band stability, the non-injured knee joint will get examined first. These findings will provide a collation for the injured knee. (20)

2.6.2.1 Drawer sign

The so-called “drawer sign” occurs after an injury or rupture of the cruciate ligaments. (15) For this examination, the patient is lying on his or her back with his or her knees flexed at 90°. The examiner sits down slightly onto the patient’s forefoot, for stabilizing reasons, puts his or her thumbs onto the tibial tuberosity and grabs the lower leg. Now, he or she tries to shift the tibia to the front and pushes it backwards. (16) This test is positive for the ACL if the translation, compared to the opposite limb, is increased or a firm end-point is absent at the front. In contrast, it is positive for the PCL if a firm endpoint is absent at the back. This test is limited to acute trauma situations due to its painfulness. (33)

2.6.2.2 Lachman-test

For this purpose, the patient stays on his or her back and the examiner bends the patient’s knee only 20 to 30° with his or her non-dominant hand, thereby stabilizing the femur, and with the dominant hand the examiner tries to dislocate the tibia to the front. This test is more sensitive than the drawer sign test because at a 20 to 30° flexion, the myotonus and the tension of the ACL are decreased. (16)

2.6.2.3 Pivot shift

The pivot shift test examines the impaired rolling and sliding mechanisms. In a lying position, the examiner lifts the tested leg and grabs the patient's sole with one hand. The other hand stabilizes the upper leg and performs a valgus stress. Starting in an extended position, the examiner then flexes the leg. This test is positive if a snap is noticeable. (17)

A fresh ACL rupture associated with strong pain, to be precise, a hemarthrosis, usually does not allow an adequate clinical assessment of the knee's instability and, therefore, diagnosing an ACL just clinically is very difficult. (17)

2.6.3 Imaging

2.6.3.1 X-ray

For basic radiologic diagnostic radiographs in three planes are necessary: an antero-posterior, a lateral radiograph of the knee joint and one of the patella in 60° flexion to exclude other injuries. In acute cases, osseous avulsions can be seen.

2.6.3.2 MRI scan

The MRI has the best sensitivity (95-100%) for diagnosing ACL-injuries. Its role is therefore beyond dispute. Direct signs for an ACL rupture are diffuse reduction of signals, a distended and an unsharp outline or wavy ACL and a discontinuity in sagittal and horizontal radiographs. (17) Indirect signs include a subluxation of the tibial head ventrally and the corresponding bone marrow edemas, the so-called "bone bruises". (34)

Despite all clinical and imaging options, in some cases the diagnosis of ACL ruptures may be complex and difficult.

"No isolated question, test or image can accurately identify an ACL injury every time." (35)

2.7 Therapy

2.7.1 Conservative treatment

Patients can be treated conservatively when they show no giving-away sign, a negative pivot shift test, no subjective complaints and low athletic requirements. (17) Conventional therapy implicates a primary immobilization and further intensive muscle strengthening and physical therapy for muscular stabilization of the knee joint. In fact, the main focus of conventional therapy is to stabilize the knee joint. Therefore, an isolated training of the quadriceps muscle in flexion as well as a combined training of quadriceps and ischiocrural muscles should be emphasized.
To achieve a satisfactory therapeutic outcome, it is essential to accomplish sufficient quadriceps function, good neuromuscular control of the leg and an adequate trunk stability. Consequently, sensomotoric training and training on unstable surfaces (feedback training) should be done. (36)
For children, the Olympic Committee Consensus declares that patients who are close to skeletal maturity can use rehabilitation programs for adults. For those who are prepubescent, some considerations are important, for example, home-based and playful programs should be favored. (35)

2.7.2 Surgical intervention

Repairable accompanying injuries (e.g. meniscus tear), knee instability showing recurrent giving-away and high athletic/functional demands are indications for a surgical treatment. (34)

In general, it can be stated that the principles of surgical intervention in children is similar to those in adults: A well-positioned autograft in a fitting size should be adequately fixed for good rehabilitation. Furthermore, it is very important to minimize the rate of physeal damage and to avoid bone plugs and fixation devices crossing the physis, as this can respectively lead to growth disturbances. (35)

In pediatric ACL reconstruction, three techniques are mainly used:

- Transphyseal ACL reconstruction: This technique resembles the treatment of adults and possibly leads to a better outcome because the surgeon is well trained in this type of surgery. A quadrupled hamstring graft is fixed onto the medial facies of the tibia at the level of the tibial tuberosity. A tunnel, as vertically and centrically as possible, is then drilled through the tibial bone. It should be aimed to drill this tunnel in the anatomical position of the graft. On the femoral side, the tunnel should be considered to be in a more vertical position than in adults and the perichondral ring should be avoided to reduce the risk of growth disturbances.
- Physeal-sparing ACL reconstruction: For patients with considerably wide open physes, this non-drilling technique should be favored to avoid physeal damage. A strip of iliotibial band is wound in an over-the-top technique from the anterior facies of the tibia to the posterior side of the femur's condyles and back to the tibia.
- Partial transphyseal ACL reconstruction: This technique combines the two techniques formerly mentioned by drilling through the tibial bone and winding the graft around the femur's condyles. (35)

Nowadays surgical restoration of the ACL is performed arthroscopically.

2.7.2.1 Advantages

Studies show that surgical reconstructions decrease the rate of secondary meniscectomies. (34) In this context, to lower the risk of early onset osteoarthritis, surgical intervention must emphasize the preservation of the meniscus. (35)
Furthermore, young patients with high functional demand of the knee have a 50 to 60% decreased functional outcome after a conservative therapy, which makes a secondary surgical treatment inevitable in half of the cases. Nonetheless, studies display that a surgical reconstruction of the ACL cannot prevent degenerative transformations, which ties in with the upcoming drawbacks. (17)

2.7.2.2 Disadvantages

Every surgery comes with risks. For children, one of the most serious risks are growth disturbances. Fortunately, with a 2% risk, they are relatively rare. By implementing drills and tunnels through the physis, which represents the anatomical center of growth, a higher risk of growth disturbance and graft rupture exists in comparison to when physeal-sparing technique is used. Furthermore, every tenth patient under the age of 25 who returned to high risk sports, such as, volleyball and basketball, experiences a rerupture of the ACL. (35)

2.8 Consequences of an ACL injury

Starting with the rupture, followed by surgery and many months of rehabilitation and taking a break from sports, ACL ruptures constitute a life-changing event. Moreover, in financial terms (costing 17,000$ – 25,000$ per injury) and in terms of academic performance, those injuries have a considerable effect. Athletes being 18 years old or younger, who had an ACL reconstruction surgery during the school year, experienced a negative effect on their school grades.

Clinically, patients who had an ACL tear are known to develop degenerative knee osteoarthritis ten times more likely (10). Several follow-up studies examined patients' x-rays after ACL reconstructions. They showed that after 10 years 27.9% suffered from moderate and 23% already from severe arthritis of their knee. The two main risk factors for arthritis in this case are meniscus injuries and meniscectomies after a surgical intervention of the ACL. This can be undergirded by the fact, that studies show that 21 to 50.5% of the patients show signs of arthritis after an ACL reconstruction with a concomitant meniscus injury, whereas just 0 to 16% of the patients continue living without any meniscus injury. (37) The outcomes vary due to the fact that it is difficult to measure the damage of the cartilage. Especially in the early stages the degeneration and chondral changes are hard to quantify. (1) Although operatively and nonoperatively treated knees showed early osteoarthritis, bigger chondral changes can be seen in ACL-reconstructed knees. (37) Early-onset arthritis leads to decreased participation in sports but also to chronic pain and disability. (8)

3 Methods

3.1 Aims of the study

This study aims to clarify whether young female recreational athletes show a different landing technique than young male recreational athletes in drop-jumps.
To ensure this, 12 female and 12 male recreational athletes performing unilateral and bilateral drop-jumps, hop tests, Y-Balancing and doing a 3D kinematic analysis will be examined.

3.2 Hypothesis

Before conducting the empirical study, the following outcomes have been hypothesized.

The primary hypothesis stated, that matched male and female recreational athletes will show significant gender-specific differences in their landing technique while performing a bilateral drop-jump measured by their LESS Score. Furthermore, a general variety in hops and knee stability during balance tasks is expected. In particular, it is predicted that young recreational female athletes will demonstrate similar landing techniques to adult females, such as, the performance of a knee valgus and the achievement of a high LESS Score.

3.3 Description of the study

This diploma thesis is a prospective comparative cohort study design to compare two gender-specific groups of recreational athletes and their landing behavior in drop-jumps.

3.4 Participants

Sample size calculation was conducted for the comparison of the two means of the two independent samples. Based on the main target value, the Landing Error Scoring System, and power of 0.9 with an α of 5%, a group size of 12 participants was calculated.

In total, twenty-five children and adolescents participated in this study. One of the participants dropped out during the testing due to pain in her foot. Consequently, twenty-four children and adolescents (12 males, 12 females) completed the test and their results were used for the statistics.

3.4.1 Inclusion criteria

- Probands between the age of 10 to 18
- Young recreational athletes
- An informed written consent was signed by the participants and the participants' parents before starting the test.
- Voluntary participation

3.4.2 Exclusion criteria

- Any kind of knee injury in the last six months
- Any pain at knee joint
- Any impairment of the movement of the knee joint
- Any sport restriction

3.5 Measurement methods

In advance to measuring the participants' performance in different jumping scenarios, anthropometric measures, such as, height (in cm), weight (in kg) and leg length (in cm) were surveyed before doing the tests. Furthermore, the probands' knee stability was examined with the Lachmann test and the pivot shift test.

To evaluate human gait, physical examination alone is not sufficient. Therefore, human movement analysis is used to ascertain information about a subject's walking pattern. For the analysis five main elements are relevant: kinetics, kinematics, electromyography, energy expenditure and clinical examination.

Consequently, this subchapter will deal with those kinds of jumps that were indispensable for the analytical part of this diploma thesis, to be precise, drop-jumps, tappings and hop as well as Y-balancing tests.

3.5.1 Motion capture

Motion capture is used to locate an object in a 3D space and to transform it into a form that can be read on a computer. It is often used in film production and game production. (38) To trace and locate the object in a room a three-dimensional model is generated. Therefore, passive reflective markers are placed onto the important subject's bony landmarks. The position of the markers is spotted by the cameras by emitting and receiving infrared light, therefore one marker has to be visible for two or more cameras to locate it in the room. While walking the three-dimensional motion data capturing system is processing the cameras' data.

For 3D-reconstruction three markers are necessary: Two markers define an axis and are completed by the third, transforming it into a plane and hereby making rotations in the room possible. (39)

Altogether, 50 retroreflective markers were placed on each proband after the Cleveland clinical marker set as shown below (Figure 6). These markers were detected by fourteen Vero 3D cameras and two Vue cameras running on the Vicon System. To detect the landing two amti force plates were used.

Anthropometric measures such as the participant's height, weight, the length of his or her upper and lower leg, hand thickness, elbow thickness and the spina iliaca superior anterior (SIAS) width were examined for the computer calculation.

Cleveland Marker Set

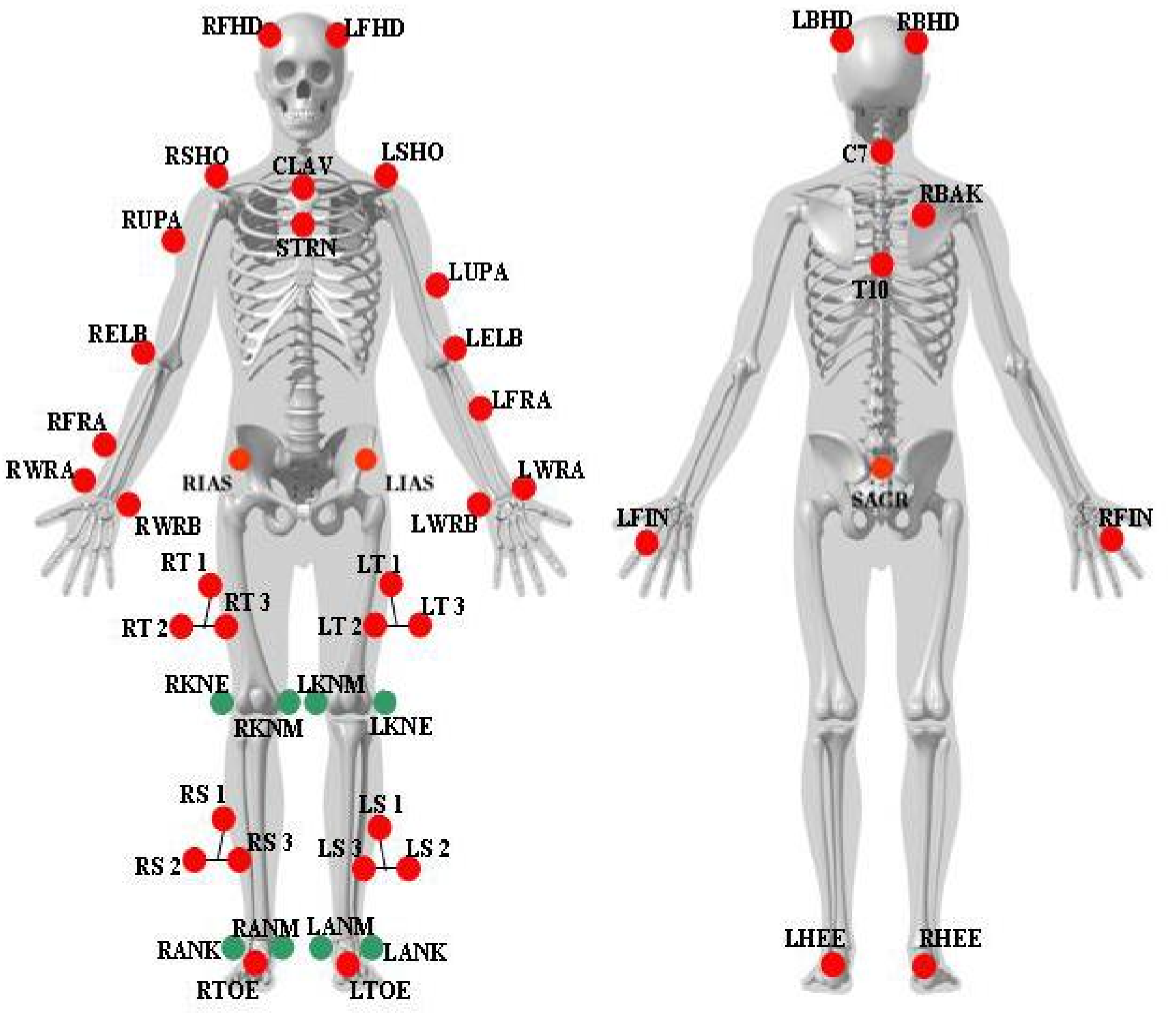

Figure 6: Cleveland Marker Set, shows positions of the retroreflective markers on the participant's body (modified after (40)*)*

3.5.2 Drop-jump

Drop-jumps tests were designed in a manner that they could be easily used by the examiners. It gives a general indication of the subject's lower limb axial alignment in straight frontal plane. (41)

Most injuries occur during pivot shift movements or quick direction-changing movements. In those situations, the movements seem to be uncontrolled, as athletes do not specifically think of landing in a joint-protecting manner. Thus, analyzing the conduction of a drop-jump approaches this uncontrolled situation best. Every subject was instructed to drop off a box and perform a maximal vertical jump immediately after landing onto the force platforms. The subjects were shown how to perform the drop-jump first and then they were allowed to practice it at a maximum of two times prior to testing.

Two video cameras, one in the sagittal and one in the frontal plane and eleven infrared cameras captured the subject performing the drop-jumps.

The task used a box measuring 27cm in height and 30 cm in depth to jump off. The subjects started with three both-legged drop-jumps followed by both three left- and three right-legged drop-jumps. They were not given any feedback, unless they did the task incorrectly, nor were they encouraged or praised.

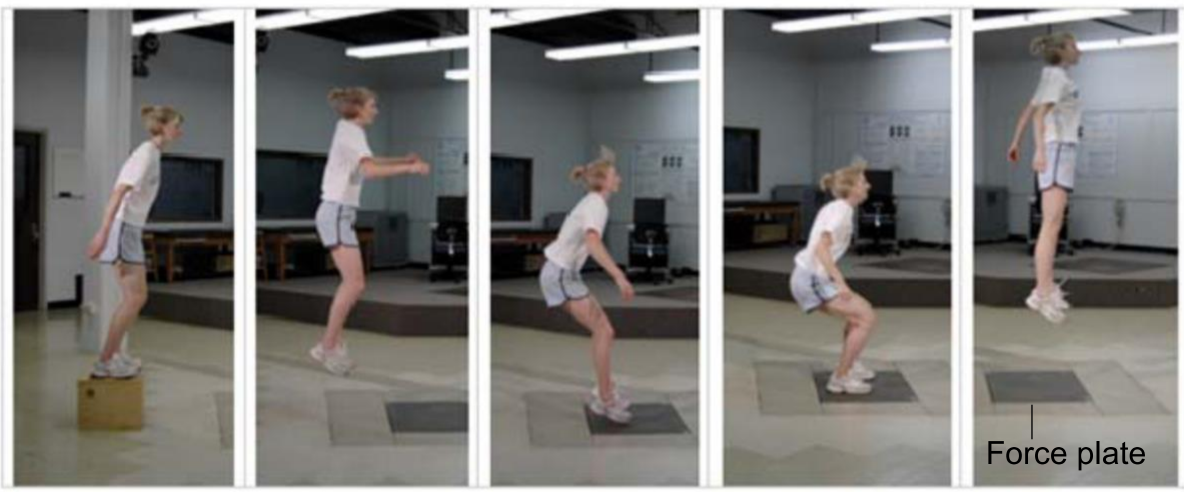

Figure 7: Performing a drop-jump. The proband drops off a 30 cm box, lands on the force plate before immediately jumping off as fast and high as possible. (modified after (6)*)*

3.5.3 Tapping

Tappings are high-frequent, repetitive and voluntary movements of the legs – which leads to a mechanical contact to the floor. Measured are the foot contacts to the floor in a certain time, in other words, tappings are used to measure high frequencies of movements and they resemble a sprint performed without moving forward. (42)
It requires three main capabilities: coordination, stamina of the muscles and anaerobic capacity of the muscles. (42)
According to Weineck, foot tappings are a reliable measure to gather a subject's coordinative performance. (43)
This test is not only used in sport physiology but also in neurology to evaluate diseases, such as, cerebellar illnesses, Mb. Parkinson and hemiparesis. For this purpose, tests are performed while sitting due to the fact that the probands often lack balance and the ability to hold their own weight.
In athletic training, the tapping test is an often-used tool to evaluate sport motoric performance as well as for the reason of warm-up and of training speed of action. (42)

Participants were told to tap as fast as possible onto two force plates for 15 seconds while being told that the timer was about to reach 5, 10 and 15 seconds.

3.5.4 Hop-tests

Hop tests are often used to assess a functional and quantitative measurement of the subject's strength and power. (42) The main parameter to quantify a single leg hop test is the Limb Symmetry index (LSI). It expresses the length of the involved leg's jump in comparison to the uninvolved leg's jump [involved/uninvolved * 100 = LSI]. In simple terms, the LSI compares the strength and power of the subject's left to the right leg. (44)
According to Fitzgerald et al. (44), a single leg hop test could be a promising tool to evaluate a subject's dynamic knee stability. (44)
Therefore, three types of hops will be examined in the following, namely, the single, the triple as well as the cross hop.

3.5.4.1 Single hop

Being told to jump as far as possible but still being capable of balancing after landing for two to three seconds without narrowing the other leg to the floor and to use the right and then the left leg, participants were allowed to practice one jump on each side prior to testing.

3.5.4.2 Triple hop

Subjects were advised to jump three times on one leg as far as possible and to balance on the tested leg for two to three seconds before lowering it. It was measured by using a measure tape fixed to the floor.

3.5.4.3 Cross hop

Probands started the cross hop with balancing on their right leg on the left side of the secured measuring tape. Starting with their toes on the zero mark of the measuring tape they had to cross over the line three times by hopping as far as possible while holding their stance for two to three seconds after landing. (45) (As seen in Figure 8)

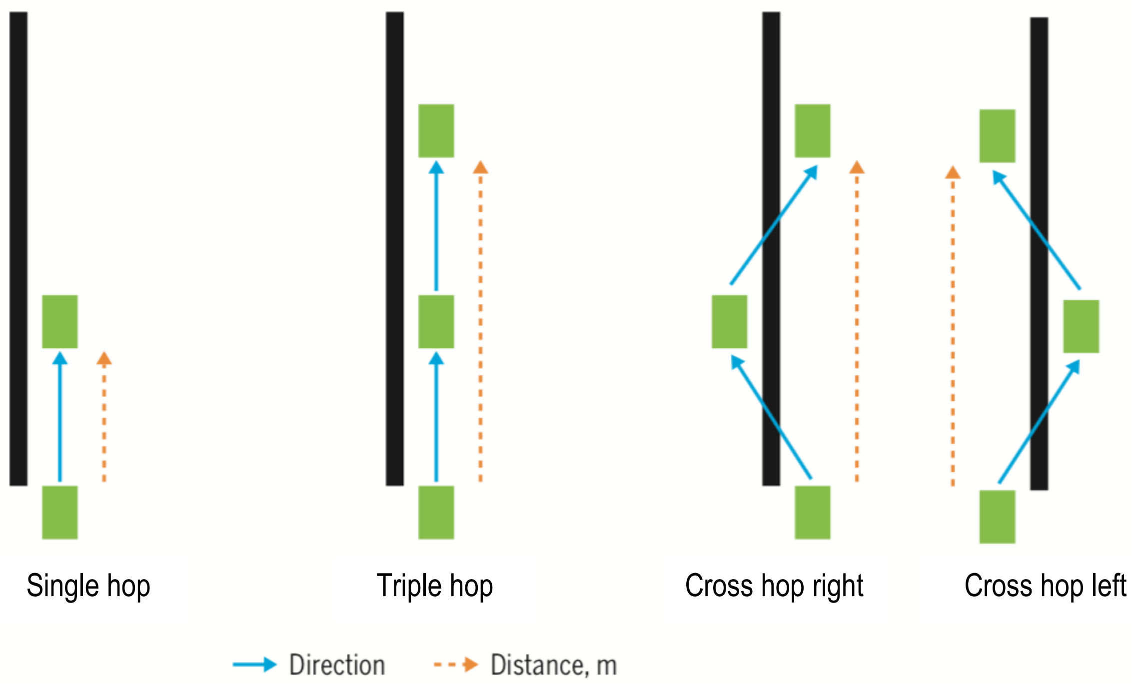

Figure 8: Illustration of hops (modified after (46))

3.5.4.4 Limb symmetry index

The limb symmetry index (LSI) is a frequently used tool to rate a proband`s balance in muscle strength and hop performance. Usually, it is used to compare the performance of an injured to a healthy leg. A high difference in capacity indicates a possible overuse and/or acute trauma when returning to sports. Rates smaller than 90% are associated with an imbalance of the two limbs. (47) In this study, as only probands without a history of knee injuries were tested, the capacity of both limbs was compared and put in relation to show possible imbalances.

3.5.5 Y-Balance test

The Y-Balancing test is a valid test for verifying the subject’s dynamic equilibrium. The participants were told to start with balancing single-legged on a center footplate. The free limb then reached to an anterior, a posteromedial and a posterolateral moveable plate along a measuring stick. The goal of this exercise was to push the indicator box as far as possible while maintaining a single-leg stance. Trials were annulled when probands lost their balance, touched the floor with their free limb or failed to return to their initial position. (48)

3.6 Outcome measures

3.6.1 LESS Score

According to Padua et al., the Landing Error Scoring System (LESS) is a valid and reliable clinical tool for evaluation of jumping biomechanics. (21) To use the LESS Score, only two standard video camcorders are needed to identify potentially high-risk movement patterns during landing after performing a drop-jump. In simple terms, the LESS Score is counting the “errors” during landing tasks. Altogether, 17 items are evaluated, which in turn form three sets. Items 1-6, forming set 1, refer to the lower limb and trunk position at IC (initial contact). Set 2 (items 7-11) addresses the errors in the positioning of the feet. The last set assesses lower limb and trunk movements between IC and MKM. [1] Scoring a lower LESS Score and therefore “error” score indicates a better landing technique, whereas high LESS Scores indicate a poor landing technique. (21)

LESS Scores:

- Excellent: ≤ 4 points
- Good: 5 points
- Moderate: 6 points
- Poor: > 6 points

(21)

3.6.2 3D Kinematics

3D Kinematic analysis uses the data of motion capture. To generate a 3D of the proband, the program calculates and works with the data that has been acquired with 14 Vero infrared light cameras and the passive reflective markers positioned on the proband’s body on specific bony landmarks. In the Vicon System program, it is possible to calculate multiple angles of joint angles of the body throughout different specific moments during the drop-jumps.

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[1] See Table 13, page 80

3.7 Statistics

The statistical analysis of the data was done using Statistica 6.0 program and Microsoft Excel.

3.7.1 Statistical methods

For the analysis of the data, descriptive methods of statistics were used. Gender-specific differences between independent samples (males vs. females) were analyzed using a student's T-test. The significance level was set to p = <0,05.

4 Results

With the help of the sport clinic and the gait lab of the university hospital “Universitätsklinikum Graz”, Department of Paediatric Orthopedics, it was possible to examine these participants in the time from January 2019 to November 2019.

4.1 Participants

The patient database (n=24), which was enrolled in this study, consisted of 12 female (50%) and 12 male (50%) participants.
At the time of the data collection the participants had an average age of 14.75 years (SD 1.73). The boys had a mean age of 14.4 years (SD +-2.25), whereas the girls had a mean age of 15.1 years (SD +- 0.94) with a total range of 10 to 18 years. The youngest proband was 10 years old and the oldest 17. None of them had a history of knee injuries, problems or pain nor a sport restriction. They all were recreational athletes, performing sports at least 3-times a week. As can be seen in Table 1, no significant gender differences concerning the demographic data of the participants can be found.

	Males	**Females**	**All**	**p-Value**
Age (years)	14.4 SD 2.25	15.1 SD 0.94	14.7 SD 1.73	0.14
Weight (kg)	65.0 SD 17.9	61.3 SD 13.2	63.1 SD 15.7	0.42
Height (cm)	170.5 SD 14.6	165.4 SD 5.5	167.9 SD 10.9	0.14
BMI (kg/m^2)	21.9 SD 3.4	22.2 SD 3.7	22.1 SD 3.5	0.73

Table 1: Demographic data of probands, no significant gender differences

4.2 Landing Error Scoring System

The LESS Score was evaluated by Kempf Anna Sophie via examining the video recording of the jumps in frontal and sagittal plane recorded by the two Vue Vicon cameras. A Quick Time Player software was used to play the videos at slow speed. To measure the angles of the knee, hip and torso, by which the LESS Score evaluates jump performances, a goniometer was used. Probands performed three bilateral drop-jumps, all of which were analyzed. Then, a mean was taken.

As the LESS Score counts mistakes, a high LESS Score implies a bad landing performance. This means that scores bellow 4 points are defined as being excellent, 5 points as being good, 6 points as being moderate and everything over 6 points as displaying a very poor technique.

Unfortunately, contrary to the already mentioned hypothesis, it was not possible to prove that boys have a superior landing technique compared to girls, as seen in Figure 9. There was no statistical difference between the groups (p= 0,42).

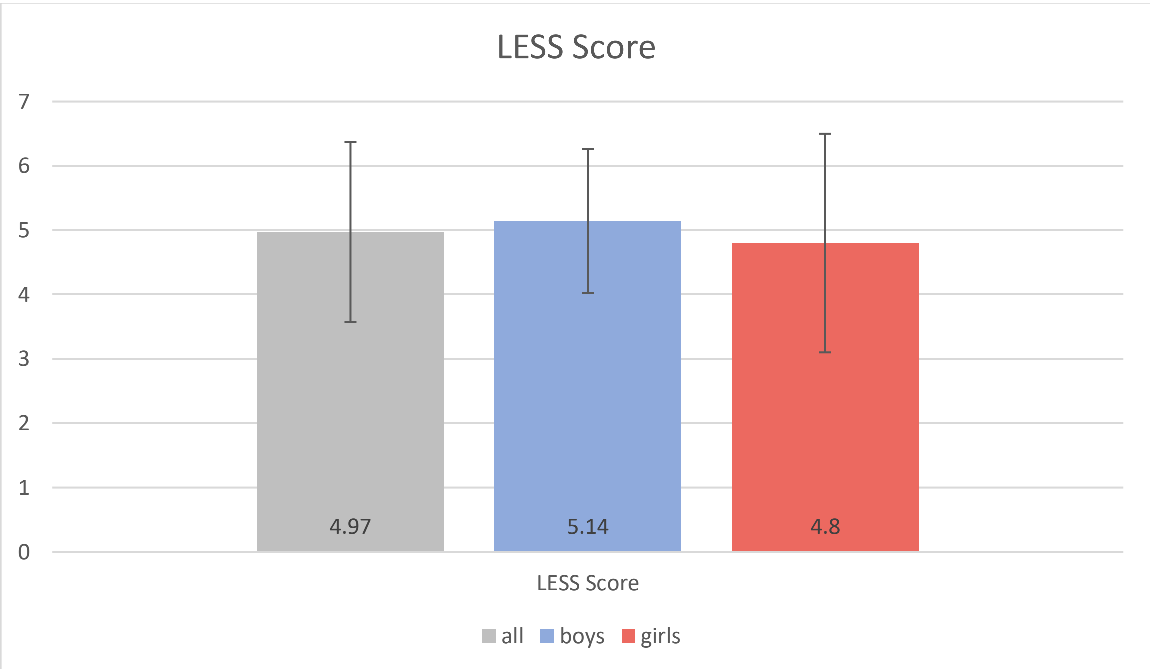

Figure 9: Diagram LESS Score with SD, SD all: 1,4, SD boys: 1,12, SD girls: 1,7 (p= 0,42), no significant difference

4.3 Test battery

4.3.1 Measurements

Before starting the tests, the probands were measured by their height, weight, leg length in total and by the length of their upper and lower leg. These elicitations were not only used for statistics but also to normalize data for comparison. The participants' demographic data is shown in Table 1.

4.3.2 Muscle forces

The measurement of the probands' muscle forces was performed with a hand-held dynamometer for the quadriceps, ischiocrural and abductor muscles of both sides. For evaluation, the mean of two measurements was used. When both genders are compared, male participants could reach better results of their abductor muscle's strength than girls with p= 0,018. Boys reached a mean force of 262.54 N/kg on their abductor muscle, whereas girls reached a mean of 205.90 N/kg. (Table 2) To be able to compare subjects with different body morphology, muscle forces were also normalized to their weight (N/kg). Hereby, boys also performed better results in their abductor muscle strength (p=0.0029) compared to girls. (Table 3 & Figure 10)

Forces	**Mean boy**	**Mean girls**	**p-Value**
Quadriceps (N/kg)	246.0 (SD 74.4)	220.2 (SD 66.5)	0.2
Ischiocrural muscles (N/kg)	150.3 (SD 53.6)	141.9 (SD 39.7)	0.2
Abductor (N/kg)	262.5 (SD 94.0)	205.9 (SD 61.9)	*0.018

*Table 2: Analysis of absolute muscle forces of boys and girls (SD) *significant gender differences*

Forces	Mean all	Mean boys	Mean girls	p-Value
Quadriceps (N/kg)	3.7 (SD 0.8)	3.8 (SD 0.9)	3.6 (SD 0.7)	0.35
Ischiocrural muscles (N/kg)	2.4 (SD 0.5)	2.5 (SD 0.5)	2.3 (SD 0.4)	0.26
Abductor (N/kg)	3.7 (SD 0.8)	4.1 (SD 0.9)	3.3 (SD 0.4)	0.0029*

*Table 3: Analysis of normalized Muscle Forces, *significant gender difference*

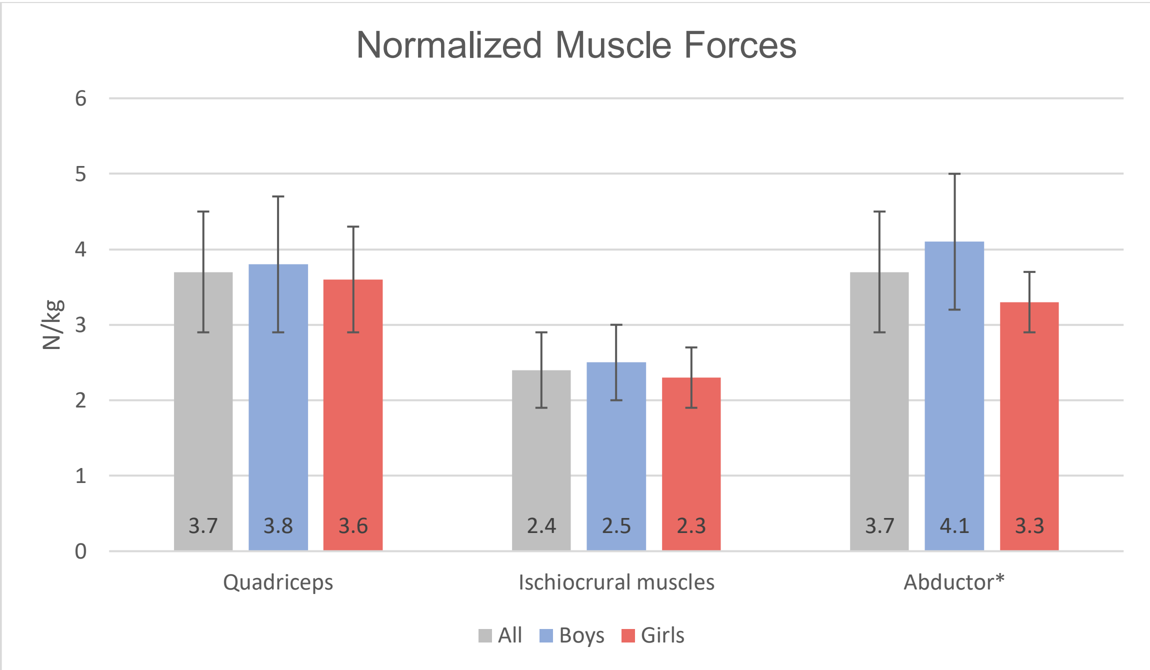

*Figure 10: Diagram of normalized Muscle Forces (N/kg) with SD, *significant gender difference of the abductor muscle (p=0.0029)*

4.3.3 Hops

For the single, triple and cross hop tests, the mean of the three test runs was calculated. To normalize this data, the two sides were put in relation and expressed in percentage, which is called the Leg symmetry index (LSI). A LSI <90% is known to indicate an imbalance between legs. (49) Table 4 shows that, in total the subjects performed well in the hops. Female and male subjects showed no imbalances in the single hop test between their limbs, as none of the outcomes is <90%. Table 5 shows the descriptive statistic of absolute numbers of single, triple and cross hops for boys and girls with no significant gender difference.

Jumps	LSI all	LSI boys	LSI girls
single hop (%)	101.8 (SD 6.6)	104.4 (SD 7.9)	99.2 (SD 9.4)
triple hop (%)	99.1 (SD 6.0)	98.6 (SD 5.1)	99.5 (SD 7.1)
cross hop (%)	99.0 (SD 7.2)	102.1 (SD 6.7)	95.9 (SD 7.2)

Table 4: LSI of hops all, boys and girls; LSI <90% indicates an imbalance between legs (49)

Jumps	mean all	mean boys	mean girls	p-Value
single hop (cm)	149.1 (SD 33.9)	141.4 (SD 17.9)	145.3 (SD 27.1)	0.34
triple hop (cm)	491.2 (SD 94.2)	445.8 (SD 62.9)	468.5 (SD 82.5)	0.06
cross hop (cm)	450.1 (SD 100.7)	416.1 (SD 73.8)	433.1 (SD 89.0)	0.19

Table 5: Analysis of hops left: mean outcome of hops for boys, girls and all (SD), no significant gender difference

4.3.4 Y-Balance

As seen in the p-Value in Table 6 below, there was no significant difference in the outcomes of the Y-Balance Test between boys and girls.

Y-Balance	**boys**	**girls**	**p-Value**
Mean YB ant. (cm)	54.9 (SD 6.0)	55.7 (SD 4.8)	0.65
Mean YB lat. (cm)	90.6 (SD 9.0)	90.8 (SD 5.2)	0.95
Mean YB med. (cm)	94.5 (SD 8.3)	94.8 (SD 9.8)	0.94

Table 6: Analysis of Y-Balance boys vs. girls in absolute numbers (SD), no significant gender difference

4.3.5 Lysholm Score

In advance of every testing, the probands were given the Lysholm Score questionnaire to fill it out.[2] This questionnaire includes questions about pain, limping and instability. This score is a valid tool to quantify the patients' symptoms and function after a knee injury. (50) The analysis of the Lysholm Score showed, that not a single proband had relevant limiting problems with their knees in their daily life. With a maximum of 100 possible points to reach, this score would indicate no limitation in daily life. In total, a mean score of 99 points (SD 2,0) was reached. Boys had a mean score of 98.5 (SD 2.3), while girls had a mean score of 99.5 (SD 1.5). These results were expected, as an existing history of knee injuries, problems or pain was one of the exclusion criteria for this study.

[2] See Figure 23, page 81

4.4 3D Kinematic Analysis

The data below compare male to female motion during the drop-jumps. This way, it was possible to capture 3D motion even in higher detail than using video recording and LESS. The following graphs illustrate the different motions during the drop-jump. They show the angles of motion on their y-axis and the gait cycle on their x-axis in percent.

4.4.1 Frontal knee motion

Figure 11 and Figure 12, as well as Table 7 show the knee motion in frontal plane of both knees. Table 7 shows the knee angles in the frontal plane and, given the p-Values, no gender-specific difference could be found.

	Mean boys	**Mean girls**	**p-Value**
Knee angle IC	0.6°	2.0°	0.08
Max knee angle	4.0°	4.7°	0.4
Min knee angle	-3.5°	-2.4°	0.2
Knee RoM	7.5°	7.0°	0.6

Table 7: Knee angles in frontal plane boys vs. girls, no significant gender difference

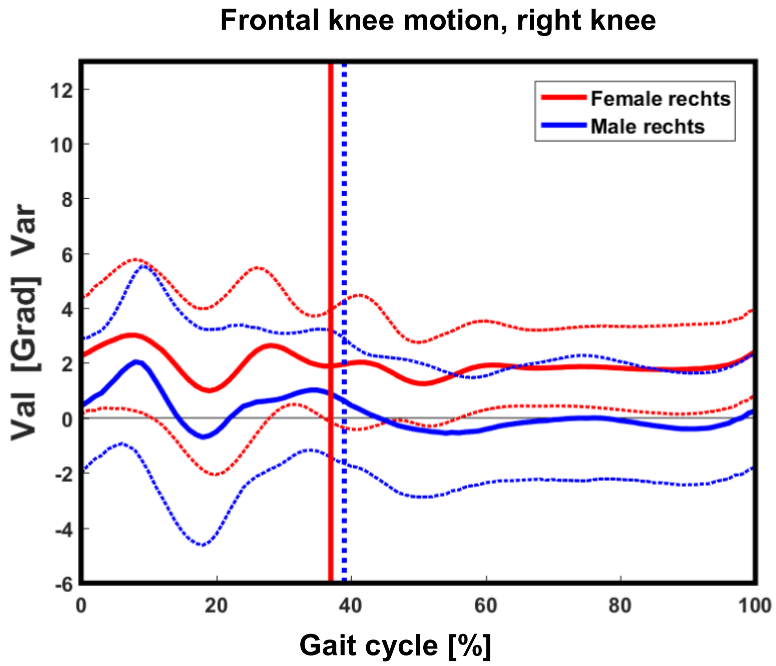

Figure 11: Frontal knee motion male vs. female, right

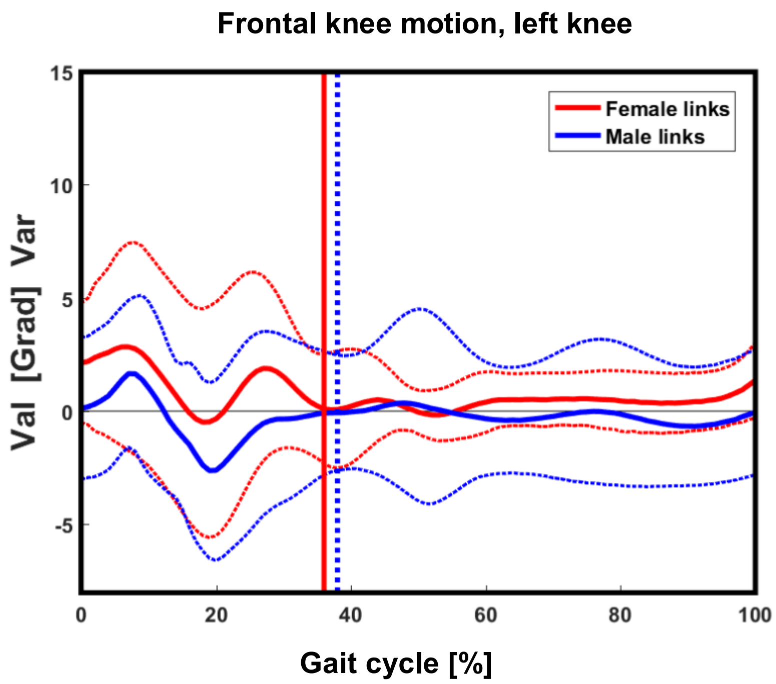

Figure 12: Frontal knee motion male vs. female, left knee

4.4.2 Sagittal knee motion

The sagittal knee motion shown in Table 8 and Figure 13 and Figure 14 exhibits that no gender-specific difference could be found in the knee angle at IC nor in the RoM in sagittal plane.

	Mean boys	**Mean girls**	**p-Value**
Knee angle IC	27.6°	30.0°	0.25
Knee RoM	60.6°	60.7°	1.0

Table 8: Knee motion in sagittal plane, no significant gender difference

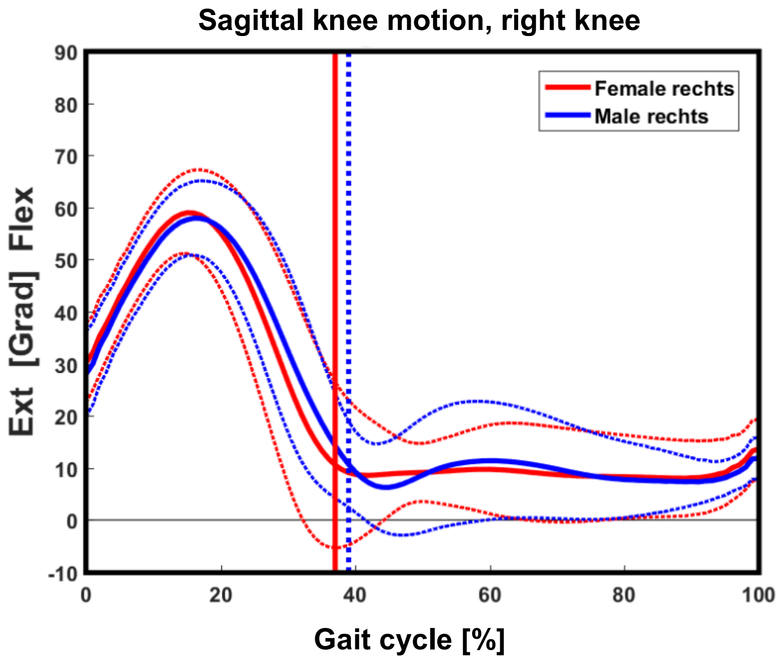

Figure 13: Sagittal knee motion male vs. female, right knee

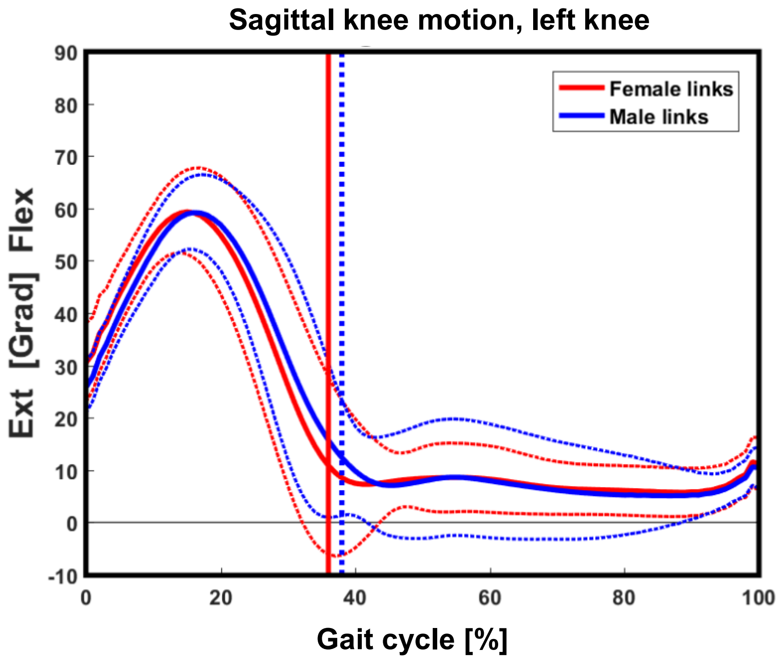

Figure 14: Sagittal knee motion male vs female, left knee

4.4.3 Sagittal hip motion

Figure 15 and Figure 16 display the hip motion in sagittal plane. Table 9 also shows the hip motion in sagittal plane. A significant difference concerning gender could be found at the maximal hip angle and the maximal hip flexion during motion. Girls (46.5°) performed higher hip flexion moments during drop-jumps compared to boys (40.8°)

	Mean boys	Mean Girls	p-Value
Hip angle IC	29.3°	32.8°	0.1
Max hip angle	40.8°	46.5°	0.02*
Min hip angle	5.1°	7.5°	0.3
Hip RoM	35.7°	39.0°	0.2

*Table 9: Hip motion in sagittal plane, *significant gender difference*

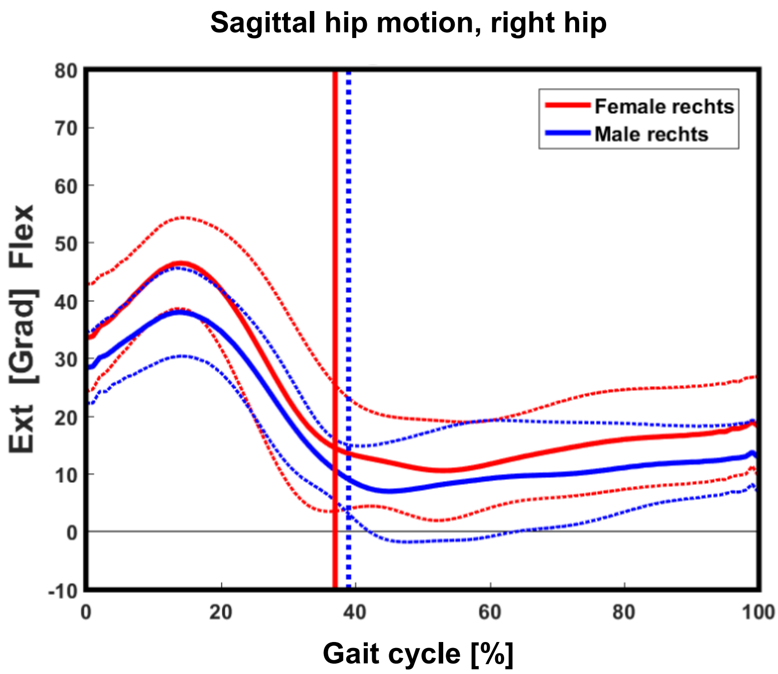

Figure 15: Sagittal hip motion male vs. female, right hip

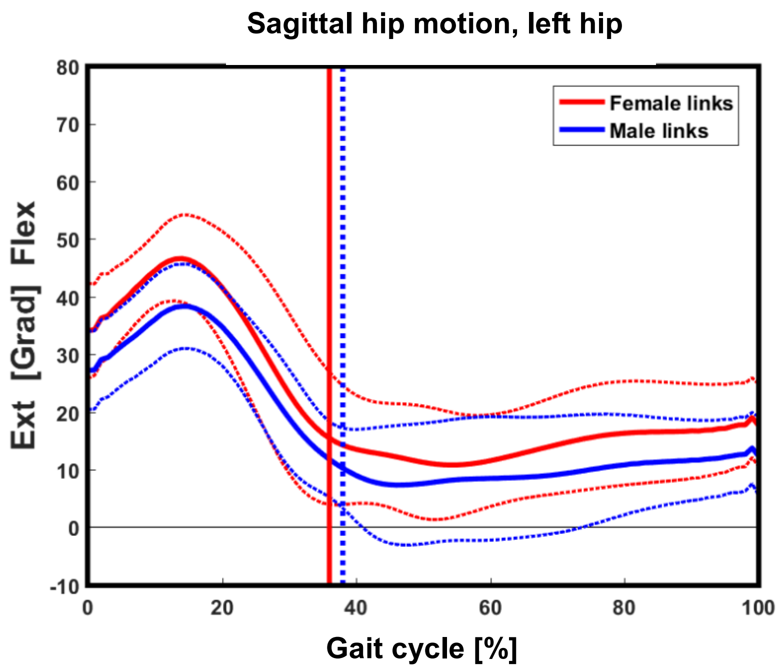

Figure 16: Sagittal hip motion male vs. female, left hip

4.4.4 Transversal hip motion

Table 10 shows the 3D analysis of the transversal hip motion. Hereby, several instances of significant difference could be found. The angle of the hip at IC, the maximum hip angle as well as the minimum hip angle show significant gender-specific differences. Figure 17 and Figure 18 display the hip motion as a graph throughout the jump. This graphs and table show that girls rotate their hips significantly more internally than boys. This result might have important clinical implications.

	Mean boys	**Mean girls**	**p-Value**
Hip angle IC	-5.0°	1.5°	0.0003*
Max hip angle	-0.2°	4.4°	0.009*
Min hip angle	-15.2°	-9.4°	0.003*
Hip RoM	15.1°	13.8°	0.5

*Table 10: Hip motion in transversal plane, *significant gender difference*

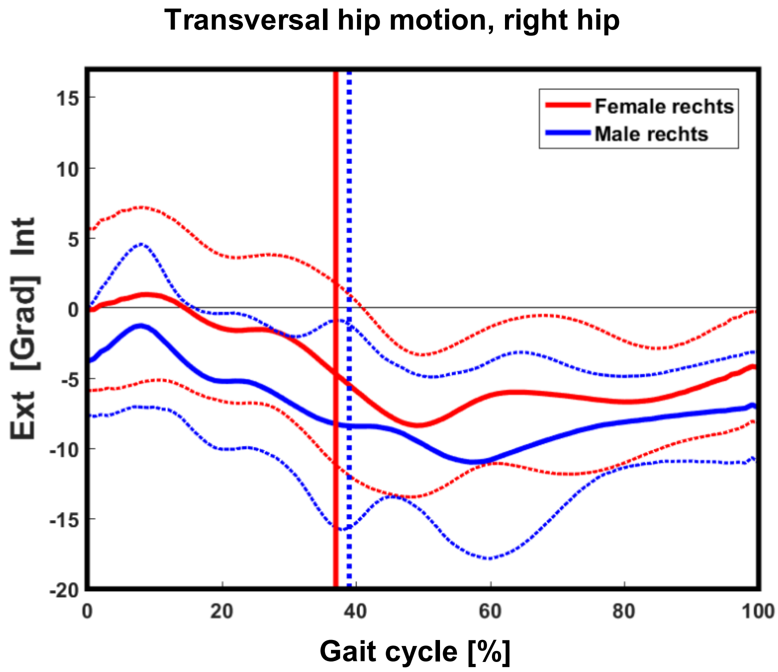

Figure 17: Transversal plane hip motion male vs. female, right hip

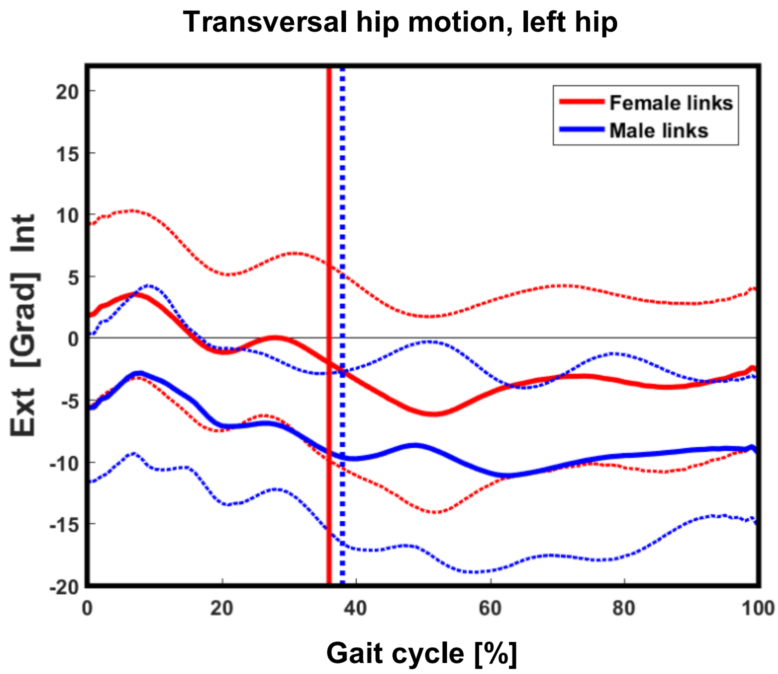

Figure 18: Transversal hip motion male vs. female, left hip

4.4.5 Sagittal ankle motion

Figure 18, Figure 19 and Table 11 display the sagittal movement of the ankle. The table below shows that there is no significant gender difference in the motion of the ankle during sagittal motion.

	Mean boys	Mean girls	p-Value
Ankle angle IC	-15.8°	-12.5°	0.22
Max ankle angle	23.0°	25.5°	0.31

Table 11: Ankle motion in sagittal plane, no significant difference

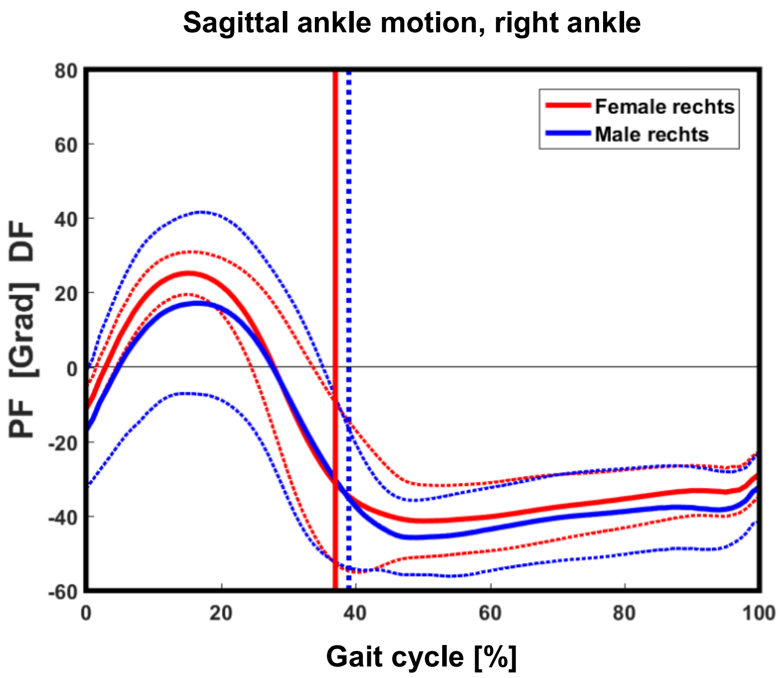

Figure 19: Sagittal ankle motion male vs. female, right ankle

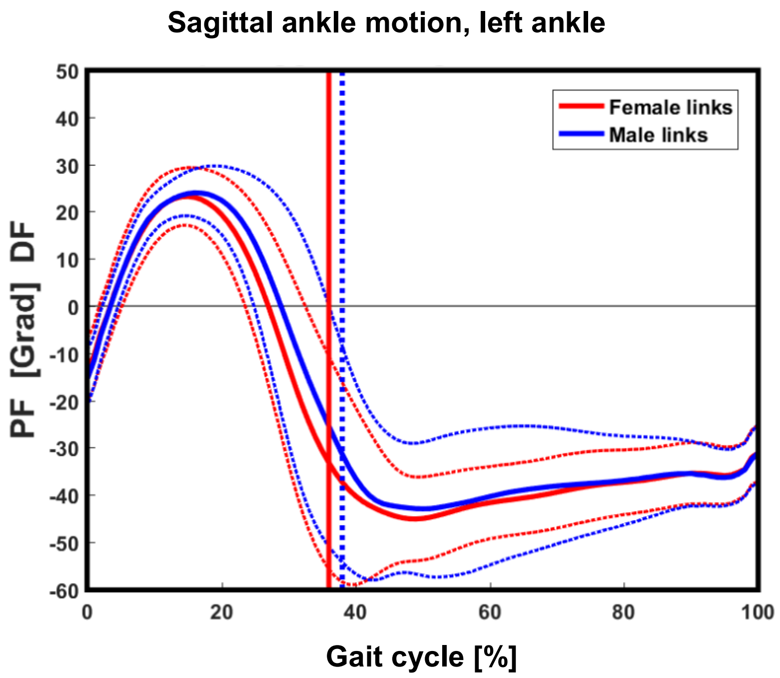

Figure 20: Sagittal ankle motion male vs. female, left ankle

4.4.6 Transversal ankle motion

The last figures, Figure 21 and Figure 22, show the graphs of the transversal motion of the angle during a drop-jump. Table 12 shows the transversal angles of the ankle during motion. As can be observed below, a significant gender difference could be found in the ankle angle at initial contact. This means, boys land with increased internal rotation (12°) at IC compared to girls (7.9°).

	Mean boys	Mean girls	p-Value
Ankle angle IC	12.0 °	7.9°	0.03*
Max ankle angle	21.9°	19.7°	0.24
Min ankle angle	-1.5°	-4.1°	0.13

*Table 12: Ankle motion in transversal plane, boys vs. girls, *significant gender difference*

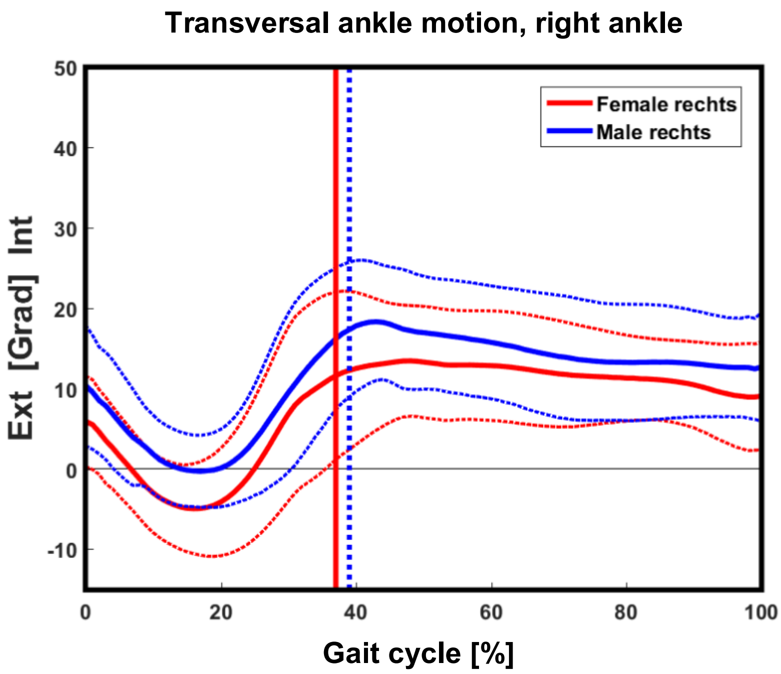

Figure 21: Transversal ankle motion male vs. female, right ankle

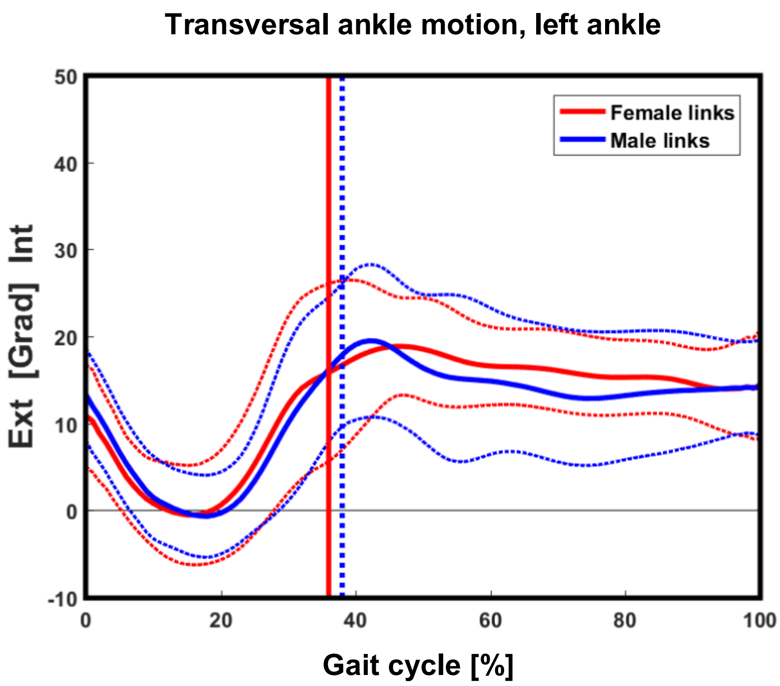

Figure 22: Transversal ankle motion male vs. female, left ankle

5 Discussion

This prospective analysis of 24 probands investigated gender-specific differences of adolescents and their landing technique while performing a drop-jump. To evaluate participants’ landing performance, the LESS Score was used, which is a valid method to identify individuals that are at high risk to suffer from knee injuries, such as ACL-injuries. (21) As the rates of this kind of injury is greater in female athletes compared to male athletes performing the same sports, e.g., handball or basketball, it necessary to identify the risk factors and to improve the existing prevention strategies. Usually, ACL-injuries occur during non-contact events, such as abrupt deceleration or change of direction. (8) Especially the age group of 14 to 19 is affected and the number of incidents even increased during the last two decades. (12)

Based on literature, it was hypothesized that adolescent female participants were going to have a poorer landing technique and therefore a higher LESS Score compared to male participants. This study could not prove any gender-specific differences in the individuals’ landing technique using a standardized LESS Score in this given age group. However, the 3D kinematic analysis of a drop-jump motion revealed gender-specific differences, thus, it was feasible to describe different landing strategies between adolescent male and female participants.

According to large studies, adult female recreational athletes do show differences in their landing techniques compared to male recreational athletes. As Beutler et al. could show, female cadets had a significantly higher LESS Score in drop-jumps (5.34 ± 1.51) in comparison to male cadets (4.65 ± 1.69). There are even gender-specific errors, as females tend to land with a decreased knee flexion angle and in a knee valgus, whereas men showed a poor landing technique due to landing with the heels first and their feet in toe-out position, for instance. (6) These are some of many examples of literature on adult athletes, but review showed a lack in studies on gender differences of young and adolescent athletes. Therefore, this study was conducted to reveal gender-specific differences in the age group of children and teenagers.

5.1 LESS Score

This diploma thesis hypothesized that male and female recreational adolescent athletes would show significant gender-specific differences in their landing technique while performing a bilateral drop-jump measured by their LESS Score. It was assumed that girls score higher LESS Scores – translated as “more errors” – which would indicate poorer landing techniques compared to those of the boys. As Padua et al. showed, the Landing Error Scoring System is a valid system to classify and measure the landing technique after performing a drop-jump and to identify probands that may be at a higher risk to experience lower limb injuries. To verify this information, it is not possible to score the LESS Score in real time, instead it has to be recorded with two video cameras, one for each plane of interest, to get a valid analysis. (21)

The hypothesis had to be rejected. It was not possible to show significant differences in the LESS Score of boys and girls while performing a drop-jump. These findings were surprising and stood in contrast to earlier studies conducted with adults, such as the findings of Beutler et al., who analyzed the drop-jumps of 2,753 sportive cadets and could thereby prove a significant gender-specific difference of the LESS Score of adult cadets performing a drop-jump. (6) Other studies, in contrast hereto, could not find gender-specific differences: Orishimo et al. were not able to find differences in landing techniques of adult male and female professional ballet dancers, although, classical ballet can be compared to sports like basketball, soccer or football in terms of physical demands and jump-intensity. (51) However, it has to be stated that these studies, as already mentioned, only involved adults.

Several reasons could be accountable for the discrepancy between literature on the landing technique of adults and the results of this study of adolescents. Considerable factors could be the anatomical differences, e.g. increased joint laxity and knee hyperextension in adult females as risk factors sustaining ACL injuries (12)(31), as these gender differences start to develop after the onset of the influence of sex-hormones and the menstrual cycle. The possibility of no gender-specific differences before the onset of puberty should therefore be considered.

Due to the fact that this conducted study did not ascertain the participants’ pubertal stage, it is possible that the lack of concrete results in this diploma thesis is linked to the lack of attention to different development stages of the probands, as they can have great impact on the anatomical, hormonal and neuromuscular development of adolescents. (52) Even more, the height of the girls (165.4cm SD=5.5) does not vary as much as the boys' height (170.5 SD=14.34) in this study. This could be a hint indicating a different stage of development. As a matter of fact, in support of this consideration, Hewett et al., states that boys have a rapid spurt of their development of neuromuscular performance throughout their puberty, whereas girls fail to demonstrate this process. Given neuromuscular imbalances may lead to an increased risk of ACL injuries in females. (53) As boys had such a high standard deviation of 14.34cm in their height, this could indicate that the probands were proceeded in very different and maybe – to a certain degree - less advanced stages of their puberty during the examination. In comparison, girls with a decidedly lower, SD of 5.5cm were rather similar in their estimated pubertal development. This probable imbalance in the development could have disguised gender differences in the results, as no gender-specific differences in the LESS Score could be found.

5.2 3D Kinematic analysis

The examination of a 2D video analysis with the LESS Score helps to identify risk factors for ACL injury during drop-jump. However LESS is not able to exactly quantify the knee motion. For example, LESS distinguishes if the probands center of the patella lies medial or lateral to the greater toe. It is functioning as an easy method to identify a knee valgus, but it is not a very qualified tool in terms of the valgus' dimension. Therefore, we conducted the 3D kinematic analysis. Hereby, it was possible to ascertain the exact angle measurements of the knee during a drop-jump from the IC over the RoM to the end of the landing. However, in doing so, it was still not feasible for this study to identify significant gender differences in the knee's motion in frontal plane. Conversely, K. Ford et al. found increased knee valgus motions, both at IC and maximum knee valgus, for female adults. (54)

Continuing with the motion of the knee during a drop-jump, the research conducted by J. Decker et al. needs to be addressed once again. In their study, they compared 12 male to 9 female adult recreational athletes and according to it, males and females demonstrated similar maximum knee flexion angles, but females showed greater RoM in comparison to their male counterparts. (55) With mean RoM angles of 60,6° (SD 9.6) for boys and 60,7° (SD 10.8) for girls, this study could not find any significant difference in the sagittal knee RoM during a drop-jump.

Several studies proved gender differences of the ankle motion during landing. (55)(56)(57) T. Kernozek et al. investigated gender-specific differences of the lower limb joint kinematics of matched recreational athletes and concluded that females landed with a more dorsiflexed ankle. This is congruent with the insights gained by Decker et al., who further hypothesized that this landing technique may be beneficial to decrease the landing loads of the ACL from the knee joint to the ankle joint. (58) In comparison to this revelations, this diploma thesis could not find gender differences in the motion of the ankle joint in sagittal plane.

Analysis of the hip motion showed that girls exhibited significant greater maximum hip flexion angles during a drop-jump compared to boys. While girls demonstrated landings with a mean maximum hip flexion angle of 46.5°, boys reached mean angles of just 40.8°. It is plausible to assume that this is another strategy to decrease the overall load of the ACL and shift the energy to another joint. (58) These results are similar to those obtained by Salci et al., according to whom female volleyball players performed a decreased hip flexion during block and spike landing. (59)
Another aspect of gender-specific landing differences might be muscle power. Literature indicates muscle strength as an important factor for the prevention of ACL injuries. (52) Beutler et al. provided proof of significant gender-specific differences in normalized quadriceps and ischiocrural muscle strength. (6) Contrary to those results, it was not possible to replicate these findings in this very study. What could be proven was a gender-specific difference in normalized muscle strength of the hip abductor muscles. Male probands had greater abductor power normalized to their weight compared to female probands, which is known to be a factor to prevent valgus movement of the knee during landing. (8)
Statistics showed that girls did not only land with a greater internal rotation of their hip, but also have greater maximum rotation angles throughout the landing process. Seemingly, females already demonstrate an internal rotation of their hip at IC (1.5°), whereas boys land with an externally rotated hip (-5.0°). This tendency continues throughout the jump, as girls have a maximum internal rotation of 4.4°, compared to

boys with -0.2°. It is plausible to state that girls land with a rather internal rotation of their hip in comparison to their male counterparts, who land with external hip rotation angles. As literature shows, a lack of muscle strength or poor neuromuscular control of hip external rotators may be a risk factor for lower limb injuries such as ACL damages. (60)

5.3 Muscle strength

In literature, females have been identified to have decreased ischiocrural muscle and quadriceps muscle forces. Seen from the neuromuscular point, women are quadriceps dominant, meaning they activate their quadriceps muscle first when landing. However, quadriceps dominance combined with the lack of muscle strength leads to a lack of capability to decelerate the landing properly. (61) Nevertheless, this study could not confirm these findings, as no gender-specific differences in the ischiocrural or quadriceps muscle strength could have been found. Still, boys reached higher values for absolute and normalized abductor muscle strength. It is suggested that hip abductor strength may be linked to neuromuscular control of the knee. (62) As a matter of fact the hip abductors play an important role in the loading of the knee joint, as they stabilize the pelvis in the frontal plane and control the position of the body's center of mass during motion. (63) Weak hip abductor muscles are accompanied by a dynamic valgus collapse during landing and a quick change of direction, since the hip cannot be kept abducted. (57) Therefore, poor performance of abductor muscles could be considered as a predicting factor for a knee valgus during landing or performing high-risk sports and consequently for an increased risk for subsequent ACL injuries.

Considering all the given results, it was not possible to prove the hypothesis of this study. Female recreational adolescent athletes did not reach higher LESS Scores than their male counterparts, but it was possible to show, with more in-depth investigation, a gender-specific difference in their strength and landing performances. 3D kinematic analysis could display that girls actually performed a higher maximum hip flexion than boys and an increased hip flexion at IC, which is known to be a parameter of a proper landing technique. (8) On the other hand, girls showed a higher hip internal rotation, which might be a potential risk factor for ACL injury while landing. Furthermore, boys have greater strength of their abductor muscles, which was measured with the hand-held dynamometer. This is known to be a protective factor for knee valgus and increased hip internal rotation. (8) These differences indicate the use of divergent landing techniques between boys and girls, even though the hypothesis formulated with regard to the LESS Score could not be confirmed.

As it is already known, female athletes are at a four- to six-fold greater risk of experiencing an ACL injury than male athletes competing at the same sports. The variety of causal factors include hormonal factors, anatomy and neuromuscular factors. (12)(8)(64) A main risk factor poses the lack of a proper landing technique. (65) Hewett et al. could show prevention programs containing neuromuscular training for adults to prove effective in terms of preventing knee injuries, including ACL injuries. (64) Therefore, a prophylactic neuromuscular prevention program might decrease the number of ACL injuries in young and adolescent female athletes. Furthermore, distinguishing risk factors of ACL injuries in young recreational athletes merit further investigation, as the number of ACL injuries in the age group of 14 to 19 is still rising. (12) Consequently, an inquiry concerning the specific pubertal development when female athletes becoming more sensible for containing ACL injuries should be conducted to start prophylaxis programs appropriate to one’s age and pubertal stage. (53)

5.4 Limitation of the study

The evaluation of the LESS Score can depend on the evaluating person. Although the videos have been evaluated with a goniometer to avoid measurement errors, bias could have been occurred because it was measured on a computer display. LESS Score is a good and reliable low-tech tool for a trainer to analyze the landing technique of an athlete and to detect major risk factors for an ACL injury. However, it is not possible to objectively capture all-important details that might be relevant for knee biomechanics and injury prevention. To analyze all details of 3D motion of lower extremities while landing a kinematic and kinetic motion capture system is advisable. At least, for patients after an ACL reconstruction coming back to sports a proper analysis with motion capture system would be beneficial.

Another missing link to interpret our data would be a pubertal status of our study subjects. For future studies, it might be relevant to link the pubertal status to the landing performance, as it has an important impact on the anatomical, hormonal and neuromuscular development of adolescents.

5.5 Conclusion

In conclusion, this study was not able to show any gender-specific landing differences in children and adolescents using the LESS Score. However, more in-depth analysis of the 3D kinematic motion patterns while landing revealed some significant differences in hip kinematics and abductor strength. Even if LESS is a reliable low-tech screening tool to check for possible ACL injury risk factors in athletes, a more in-depth analysis of kinematic motion patterns would be advisable in subjects after ACL reconstruction returning to sport activities to detect all potential risks for re-injury.

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8 Appendix

8.1 LESS Score

				YES /NO
1	Knee flexion angle at IC	At the time point of IC, if the knee of the test leg is flexed more than 30 degrees, score YES. If the knee is not flexed more than 30 degrees, score NO.	Y=0 N=1	
2	Hip flexion angle at IC	At the time point of initial contact, if the thigh of the test leg is flexed on the trunk score YES. If the thigh is in line with the trunk then the hips are not flexed and score NO.	Y=0 N=1	
3	Trunk flexion angle at IC	At the time point of IC, if the trunk is flexed on the hips, score YES. If the trunk is vertical or extended on the hips, score NO.	Y=0 N=1	
4	Ankle plantar flexion angle at IC	If the foot of the test leg lands toe to heel, score YES. If the foot of the test leg lands heel to toe or with a flat foot, score NO.	Y=0 N=1	
5	Knee valgus angle at IC	At the time point of IC, draw a line straight down from the center of patella. If the line is medial to the midfoot, score YES. If the line goes through the midfoot, score NO.	Y=1 N=0	
6	Lateral trunk flexion angle at IC	At the time point of IC, if the midline of the trunk is flexed to the left or the right side of the body, score YES. If the trunk is not flexed to the left or right side of the body, score NO.	Y=1 N=0	
7	Stance width wide	Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is inside the foot of the test leg then greater than shoulder width, score YES. If the rest foot is internally or externally rotated, grade the stance width based on heel placement.	Y=1 N=0	
8	Stance width narrow	Once the entire foot is in contact with the ground,	J=1 N=0	

		draw a line down from the tip of the shoulders. If the line on the side of the test leg is outside of the foot then score less than shoulder width (narrow), score YES. If the test foot is internally or externally rotated based on heel placement.		
9	Foot position – toe in	If the foot of the test leg is internally more than 30 degrees between the time period of IC and max knee flexion, then score YES. If the foot is not internally rotated more than 30 degrees between the time period of IC to max knee flexion, score NO.	Y=1 N=0	
10	Foot position - toe out	If the foot of the test leg is externally more than 30 degrees between the time period of IC and max knee flexion, then score YES. If the foot is not externally rotated more than 30 degrees between the time period of IC to max knee flexion, score NO.	Y=1 N=0	
11	Symmetrical initial foot contact	If one foot lands before the other or if one foot lands heel to toe and the other lands toe to heel, score NO. If the feet land symmetrically, score YES.	Y=0 N=1	
12	Knee flexion displacement	If the knee of the test leg flexes more than 45 degrees from IC to max knee flexion, score YES. If the knee of the test leg does not flex more than 45 degrees, score NO.	Y=0 N=1	
13	Hip flexion at max knee flexion	If the thigh of the test leg flexes more on the trunk IC to MKF angle, score YES.	Y=0 N=1	
14	Trunk flexion at max knee flexion	If the trunk flexes more from the point of IC to MKF, score YES. If the trunk dies not flex more, score NO.	Y=0 N=1	
15	Knee valgus displacement	At the point of max knee valgus on the test leg, draw a line straight down from the center of the patella. If the line rungs through the greater toe, or is medial to the great toe, score YES. If the line is lateral to the great toe, score NO.	Y=1 N=0	

16	Joint displacement	Watch the sagittal plane motion at the hips and knees from IC to MKF angle. If the subject goes through large displacement of the trunk, hips and knees then score SOFT. If subject goes through some trunk, hip and knee displacement but nor a large amount, then score AVERAGE. If the subject goes through very little, if any trunk, hip and knee displacement, then score STIFF.	soft=0 av.=1 stiff=2	
17	Overall impression	Score EXCELLENT is the subject displays a soft landing and no frontal plane motion at the knee, score POOR if the subject displays a stiff landing and large frontal plane motion at knee. All other landings, score AVERAGE.	ex=0 av.=1 poor= 2	

Table 13: LESS Score modified after (62))

8.2 Lysholm Score

LIMP	
o no	5
o slight or periodical	3
o severe and constant	1
SUPPORT	
o none	5
o stick or crutch	3
o weight-bearing impossible	0
LOCKING	
o no locking and no catching sensations	15
o catching sensation but no locking	10
o locking occasionally	6
o frequently	2
o locked joint on examination	0
INSTABILITY	
o never "giving way"	25
o rarely during athletics or other severe exertion	20
o frequently during athletics or other severe exertion (or incapable of participation)	15
o occasionally in daily activities	10
o often in daily activities	5
o every step	0
PAIN	
o none	25
o inconstant and slight during severe exertion	20
o marked during severe exertion	15
o marked on or after walking more than 2km	10
o marked on or after waling less than 2km	5
o constant	0
SWELLING	
o None	10
o On severe exertion	6
o On ordinary exertion	2
o constant	0
STAIR-CLIMBING	
o no problems	10
o slightly impaired	6
o one step at a time	2
o impossible	0
SQUATTING	
o no problems	5
o slightly impaired	4
o not beyond 90°	2
o impossible	0
TOTAL SCORE	

Figure 23: Lysholm Score (modified after (66)*)*