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Lower Limb Kinetics and Kinematics in Healthy Female Soccer Players During the Vertical Drop Jump Test

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Abstract

Lower Limb Kinetics and Kinematics in Healthy Female Soccer Players During the Vertical Drop Jump Test.

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Background: The Anterior Cruciate Ligament **(**ACL) is the third most commonly involved structure of knee injuries. Much controversy exists on the patterns involved at the injury. Various biomechanical variables have been associated with the injury, however none of them independently. A commonly used task to identify the involved biomechanical variables is considered to be the Vertical Drop Jump (VDJ)
Aim: Identify differences in knee kinematics and kinetics between two groups of healthy female athletes.
Method: A mild training group and an intensive training group were compared during the VDJ task. Motion analysis cameras and force plates were utilized for the kinetic and kinematic analysis.
Results: The intense training group had more internal hip rotation at initial contact and more knee valgus at maximal knee flexion, compared to the mild training group ($p<0.05$). Internal hip rotation was positively correlated to knee valgus angle ($p<0.05$).
Conclusion: Some differences between the two groups were observed with the mild group exhibiting less dangerous biomechanical variables than the intense training group.

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1.0 Introduction

1.1 The Anterior Cruciate Ligament (ACL)

The necessary mechanical stability in the knee joint and containment of excessive motions within certain limits is provided by the complex interrelation of the bone-cartilage-ligament-meniscus apparatus of the knee. This vital mechanical stability is mainly attained by joint compression and muscle activity during weight bearing conditions. Fleming et al 2001 (1) supported that during weight bearing conditions, knee muscles activate to increase stability. When however, the knee is slightly flexed (between 45° to full extension) compressive loading together with quadriceps activation, increased ACL strain. Thus, it can be assumed that weight bearing conditions will increase knee stability and at the same time increase strain forces in the ligament. It has been suggested that mechanoreceptors in the ACL act as detectors of extreme motions, initiating signals that will activate or inhibit muscle activity. Thus the necessary knee stability can be attributed to an athlete's level of neuromuscular control (2).
In case of ACL rupture the general ability of the knee to maintain joint stability is decreased, allowing joint surfaces to slide or rotate until soft tissue restrain the motion. Thus, the joint follows a unique path visible in passive flexion and extension which represents the least resisted path imposed by the restraining structures. Muscle activation, stiffness of the joint capsule and ligaments therefore define the limits of motion. This space in which this altered motion occurs is called "envelope of passive motion" which is observed in both, healthy and injured knee joints and differs between individuals (4). This variation explains why stability examination tests may give different results even with intact ligaments in the knee joint.

1.2 Function of the ACL in the knee joint

The two main functions of the ACL (1) are:

- Restrain of anterior translation of the tibia relative to the femur
- Restrain of internal rotation of the tibia

Both restrain mechanisms have been verified in various studies. Initially the ACL prevents anterior translation of the tibia relative to the femur. Cadaver studies have shown that at 30° of knee flexion, ACL represents a high percentage (approximately 85%) of the total capsular and ligamentous resistance (5). As stated previously, joint compression increases strain on the ACL. Torzilli et al 1994 (6) showed that joint compression resulted in significant greater tibial anterior translation in ACL sectioned cadaveric knees compared to intact knees. Application of an external posterior force could not reduce the anterior translation. This study strengthens the fact that ACL prevents anterior translation of the tibia.

Meyer et al 2008 (7) found similar results. They tested 7 cadaveric knees during excessive compression loads, with knee flexed at 30°, and showed that the tibia displaced anterior relative to the femur and continued after ACL failure. Meyer also stressed the fact that during joint compression to ligament failure, the direction of the tibia rotation changed from internal (in prefailure) to external (after ACL failure). ACL resists internal rotation by its orientation on the axial plane, where it attaches medial on the anterior tibial plateau and lateral in the femoral notch (7, 8) .

1.3 ACL injury

In Sweden, the ACL injury incidence is approximately 71 per 100.000 inhabitants for the 20-39 year age group (9). In a U.S study about injury epidemiology across 15 sports in both genders, the ACL is the third most commonly involved structure of knee injuries (after medial collateral ligament sprains and patellar injuries). Specifically among all sports, girls' soccer had the highest ACL injury rate of 1.17 per 10.000 athlete exposure (defined as one athlete participating in one practice or competition) (10).

ACL injuries are distinguished between contact and non-contact injuries. Contact injury is called when the injury occurs during impact or collision between athletes. Non-contact is called when the injury occurs during functional activities in the absence of any external forces other than the ground reaction force. In the majority of the studies, non-contact injuries are more commonly reported as injury mechanism, with women sustaining ACL injury at higher rates (11).
In a study by Myklebust et al 1998 (12) the injured players mentioned that injury incidence was during movements they had done numerous times before. According to Arendt et al the most common reported non-contact mechanism of injury, was during landing and pivoting (foot firmly fixed on the floor and femur rotating relatively to the tibia) (13).

Video analysis of 20 ACL injuries that occurred during handball seasons 1988-2000 support that landing (mainly 1 leg landing) with a small knee flexion and pivoting, are primary factors during injury (14). In the landing and pivoting injuries, the foot was firmly fixed to the floor and in the lateral side of the knee, thus the tibia relative to the femur was creating a valgus knee angle approximately 15°. The knee was also slightly flexed, about 15° but the rotation of the tibia observed, was either internal or external. A large number of noncontact ACL injuries have been reported during the deceleration phase of a cutting manoeuvre, during a rotation torque together with either a varus or valgus moment when applied to a knee flexed 10-30° (15).

Boden et al. 2000 (16) also observed that a common non-contact mechanism was during sudden deceleration prior to a change of direction. Additionally, the study concluded that ACL injuries occur during landing manoeuvre and right after foot strike with the knee almost fully extended. In that position, the inclined tibial surface can potentially cause anterior slide relative to the femur. In that way, quadriceps dominated activities near full extension may be a considerable factor in ACL disruption (16, 1).

Concluding, trying to simplify the most common variables identified as contributing factors for the non-contact ACL injury, we could say that; in the sagittal plane, a low flexion angle is usually present, in the frontal plane either a valgus or a varus angle; and in the transverse plane an internal or external rotation can be observed. All of the abovementioned variables together with a high knee compression force, which in some cases may be multiple times higher than the body weight, can vaguely manifest an injury pattern. The reason is that even though the same variables may appear, non-contact ACL injuries are not of the same injury mechanism (13, 17). For example, muscle activation during landing to balance flexion moments will increase tibiofemoral compression forces beyond the vertical ground reaction force (VGRF) that will be measured at the foot (7). Thus, it leaves us with estimations of the true values and a margin of error is always possible. In addition to that, a study by Krosshaug et al 2007 (17) stated that the injury mechanisms are poorly understood and much controversy exists on the patterns involved which limit the ability to develop improved and targeted prevention programs.

1.4 Differences between genders in relation to ACL injury

Agel et al (11), reported that the rate of female soccer ACL injury was 0.31/1000 exposures as opposed to male soccer ACL injury rate of 0.11/1000, which in other words is a 2.78 gender ratio. When comparing injury rates between gender and sport, girls' soccer consistently declared more ACL injuries than basketball.
In a study by Arendt et al (13), conducted from 1989-1999, similar results were reported with an ACL injury rate of 0.31/1000 exposures for female soccer players and 0.13/1000 for males. ACL injuries for female soccer players were reported to be non-contact in 63% of all cases and it was 3 times more likely for female to obtain a noncontact injury than their male counterparts. Agel et al (11), also reported a non-contact mechanism in 67% of females and 58% of males in soccer collegiate athletes of all ACL injuries reported.

Variations in morphology and physiology between genders, which may predispose females to ACL-injuries, have been well examined. These include variances in pelvic size and shape, intercondylar notch width, ACL size, ligamentous laxity, and Q angle. In addition, tibial rotation and excessive foot pronation have been examined as potential reasons for ACL injury. However, no specific anatomical risk factors have been directly and independently correlated to noncontact ACL injury increase (18). Some reports attribute injury rate to increased joint laxity among women (3). There has been increasing speculation that the hormonal changes that occur throughout the menstrual cycle may increase a female athlete's susceptibility to ligamentous injury (18).

There are also differences in kinematics between genders. Krosshaug et al 2007 (19) observed through video analysis, that the majority of female ACL injuries were cases of "valgus collapse" that is, the knee collapsing medially by a combination of hip internal rotation, knee valgus and external rotation of the tibia.

An additional factor predisposing to injury is playing surface and shoe design which should be also taken into consideration when determining factors that could independently increase the rate of noncontact ACL injuries in females (18).

1.5 Consequences of ACL injury

The ligament has poor potential for spontaneous healing after complete rupture (20) thus a surgical reconstruction (ACL-R) is usually necessary. Moreover, the muscle protection mechanism may be disturbed due to changes in the neuronal feedback. There is no evidence that ACL-R leads to ingrowth of new nerve fibres in the substitute ligament and the neuronal function of the ACL is deteriorated (20).
Data has revealed that ACL-R is successfully limiting anterior tibial translation but seemed insufficient to control rotational loads of internal tibial rotation and valgus

torques. The reconstruction procedure is focused mainly on replacing the anteromedial bundle with no sufficient attention on the posterolateral bundle (21) (22).
Yagi et al. 2002 (22) concluded at the fact that the anatomic double bundle ACL reconstruction could more closely restore knee kinematics in comparison with the single bundle. However, a recent study by Yasuda et al 2010 (23) stated that meta-analysis has not reported differences between the two types thus the utility of the anatomic double bundle is yet to be established.

In a literature review conducted by Guillquist and Messner 1999 (20) it is mentioned that 50-70% of patients with complete ACL rupture and associated injuries (ligaments, menisci) have radiographic evidence of osteoarthritis (OA) after 15-20 years. In a study by Lohmander et al 2004 (24), sixty seven female soccer players were examined 12 years after ACL injury and 51% fulfilled the criterion for radiographic knee OA.

Although ACL-R is considered by many as the gold standard treatment, it does not reduce the risk of osteoarthritis development. Considering that many patients sustain such ACL injury before the age of 16, place them at risk of premature OA. Therefore, new treatments will always be of interest. A recent study conducted by Murray and Fleming 2013 (25), developed a bioactive scaffold that was placed in the torn ends of the ACL in animals to stimulate healing; with interesting results.
A systematic review study from Kruse et al 2012 (26) about rehabilitation after ACL-R, claimed that although neuromuscular interventions are not likely to be harmful, they also not likely to have large improvements in outcomes and should be performed together with strength and knee ROM exercises.

1.6 Injury prevention

Neuromuscular control has been previously mentioned as an attribute correlated with knee stability. It is believed that neuromuscular control is manifested in lower limb biomechanics (2), it can be affected by fatigue and decision making (27) and can be improved by neuromuscular training programs (28). A neuromuscular training usually consists of strengthening exercises, dynamic joint stability, balance training, jump training and plyometric exercises. However, the exact role of neuromuscular control in lower extremity injuries and particularly in non-contact ACL injury is yet to be understood (29).
Hewett et al 1999 (3)tested a neuromuscular training program on two female high school athletes group for 1 season, in order to evaluate the effects on the knee injury incidence. The untrained group presented an incidence of 0.43 injuries per 1000 exposures in contrast with 0.12 injuries per 1000 exposures in the trained group with the non-contact injury incidence for the trained group being zero. Thus, the results indicated that neuromuscular training may decrease injury risk.
Mandelbaum et al 2005 (18) applied a neuromuscular and proprioceptive training program designed to replace traditional warm-up, in female athletes. During the first year, the training group had 0.05 ACL injury rate per 1000 exposures; while the control/untrained group showed 0.47 ACL injuries per 1000 exposures. The second year the rate of ACL injuries increased to 0.13 per 1000 for the trained and 0.51 per 1000 for the untrained. The results indicated that a neuromuscular training program may reduce ACL injury incidence.

1.7 Kinematics and kinetics related to ACL injury

Kinetics is a term describing the relationship between the motion of bodies and its causes, namely forces and torques. Kinematics describes the motion of bodies without consideration of the causes of motion. Practically this means that kinetics study motion of objects and the forces that cause those motions while kinematics study the motion of objects by just examining the motion itself(without considering forces).
Various studies have supported the fact that during daily activities (20) and consequently landing from a jump, (7,14), multiplied body weight compression forces are applied on the knee which may increase the risk of ACL injury. Other variables have also been stressed to correlate with ACL injury such as excessive knee valgus(mainly) or varus(less observed) moments (2,18), hip internal rotation (19), internal or external tibial rotation (14), and hip and knee flexion (30). The presence of many poor biomechanical variables (especially knee valgus) during the injury can be attributed to an athlete's low level of neuromuscular activity (2) which is responsible for muscular co-contraction, allowing more of the knee valgus load to be absorbed through joint compression, protecting the ACL from high loads. A more equal distribution of forces transmitted across both medial and lateral compartments of the joint; would lead to decreased landing forces.
One task commonly used to evaluate neuromuscular control and simulate most of the biomechanical factors related to ACL injury is the Vertical Drop Jump (VDJ) task.

The Vertical Drop Jump (VDJ) task is initiated with a subject standing erect on top of a 31-cm box with their feet positioned 35 cm apart and arms held at their sides. The subject drops down from the box onto dual force platforms and, upon landing, immediately transitioned into a maximum vertical jump. A target is usually suspended above the force plates high enough to encourage maximum jump effort. The VDJ is completed with a second landing on the force platforms (2).
The VDJ it is not a clinical evaluation test and it could not possibly be used as diagnostic tool. In fact it is considered to be an easy task, easily executed by patients. However, at the same time the VDJ is sufficient to place the lower limb, in adequately demanding conditions. With the help of motion analysis cameras (3-D) kinematic and kinetic variables observed during the task have been associated with increased ACL injury risk. The reliability of the kinematic and kinetic analysis of biomechanical variables in young athletes during landing from a VDJ has been well stated (31)(2), as well as the utility of the task as a potentially screening tool for knee injury when compared to other tasks Harty et al 2011 (32). Jumping and landing from a jump (i.e rebounding for a ball) is frequently cited as a mechanism of ACL rupture in female basketball players (42). The reason is that rebounding is a task that involves a rapid and often unstable deceleration as athletes land from a maximal vertical jump; which is in the nature of the VDJ task to evaluate.

1.8 Lack of knowledge

In the literature, ACL injury has been placed under scrutiny by various studies. Many variables have been correlated with the injury mechanism however, none of them independently. Moreover, neuromuscular activity has been correlated with knee stability and injury prevention affecting these ACL correlated variables. Thus it is expected that a group training 6 times per week (intensive) will show higher levels of neuromuscular control- knee stability than a group training 3 times per week (mild). In this study an evaluation of these stressed variables that have been correlated with the injury will be determined through kinematic and kinetic analyses. Monitoring healthy individuals may provide a standard for later comparison with an injured cohort.

2.0 Aims

The purpose of this study was to determine differences in lower extremity kinematics and kinetics between two groups of healthy female soccer athletes.
Hypotheses

- There are differences between right and left leg biomechanics between the two groups of the cohort.
- The mild training group would exhibit altered biomechanics, such as increased knee valgus, increased vertical ground reaction force and increased internal hip rotation, compared to the intensive training group.
- Correlations will be observed between, hip rotation and vGRF's. Moreover, greater frontal plane angles (varus/valgus) will be correlated with vGRF's and finally the greater the hip rotation, the higher the frontal plane angles (varus/valgus) will be observed.

3.0 Materials and Methods

3.1 Subjects

This is a cross sectional study consisting of sixteen healthy female soccer players which were collected by convenience and through a list of athletes interested to participate in the study; mean age 21.7(SD±2.9), height 169.9(SD±7.1) and weight 64.8(SD±7.3). Inclusion criteria were; age 16-25 and active soccer-players. Exclusion criteria were; previous ACL injury and injuries hindering them to participate in soccer training. The subjects were classified into two groups:

- Mild training group, 2-3 sessions per week; mean age 23.6(SD±2), weight 62.3(SD±7.8) and height 166.3(SD±7.5)
- Intensive training group, 6-7 sessions per week; mean age 19.5(SD±2.2), weight 67.6(SD±6) and height 174(SD±3.9)

The dominant leg was determined by asking which leg they would use to kick the ball, 13 athletes reported right leg dominance and 3 athletes reported left. Knee and hip kinematics in right and left foot were collected for both groups.
Subjects underwent one testing session at the motion analysis laboratory at Linköping University.

3.2 Test Protocol

The test session started with a warm up, initially two minutes of jogging were instructed followed by a mix of running exercises in a 10m pathway. High knees, back kicking, side jogging, zig-zag running, short fast steps and long steps were instructed in a total of three minutes approximately. Finally, one minute of skipping rope, 2x10 squats and 2x10 heel raises were applied in the last part of the warm up.

For the measurements, a box of 31cm height was positioned in front of the force plates in a way that each foot would contact a different plate during the landing phase of the vertical drop jump. An overhead target was suspended 280cm approximately right above them. Verbal instructions and demonstration of the task was provided beforehand and the subjects were given one possible trial for familiarization.

The VDJ task started with the subject standing on top of the box with feet positioned 55cm apart (distance between lateral sides of the feet). Subjects were then instructed to drop off the box and immediately perform a maximum vertical jump, raising both their arms at the same time upward to maximal height in an effort to reach the suspended target and if possible to surpass it. Three successful trials were recorded for each participant with valid trial being the impact phase of the jump occurred on two force platforms. The first landing on the force plates (i.e the drop from the box) was used for the analysis and the mean value of the 3 trials was utilized during the statistical analyses.

3.3 Kinematic and Kinetic Analysis

Before testing, each subject was instrumented with 44 retro-reflective markers to specific anatomical locations by an experienced tester (figure 1-5). Ten motion analysis cameras were utilized (Qualysis AB, Gothenburg, Sweden) which were firmly fixed on the walls, covering adequately the designated area. Two force platforms (Kistler Nordic AB, Gothenburg, Sweden) collecting ground reaction forces were embedded into the floor. A neutral stance trial was measured before the VDJ task to align the subject with the coordinate system and as a reference position for the analysis.

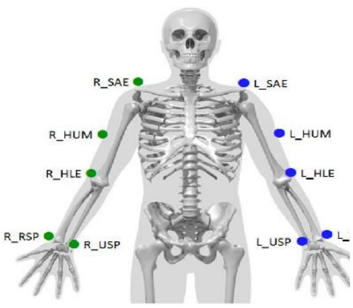

Figure 1. Marker locations on upper body. Frontal view. External markers were used to obtain 3-D joint kinematic data.

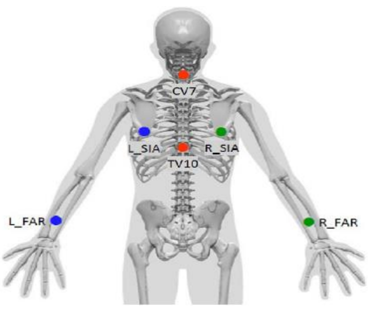

Figure 2. Marker locations on upper body. External markers were used to obtain 3-D joint kinematic data. Upper Body dorsal view

For the analysis, data from the force plates were used to identify the initial contact (IC) for the first landing. Two events of the VDJ task were analysed; the IC and maximum knee flexion.

During these events, hip flexion and knee flexion in the sagittal plane were measured. Hip rotation and knee rotation in the transverse plane and knee valgus angles in the frontal plane were analysed. In addition, maximum vertical ground reaction force (vGRF) at IC was analysed.

Figure 3. Lower Body marker locations, dorsal view. External markers were used to obtain 3-D joint kinematic data.

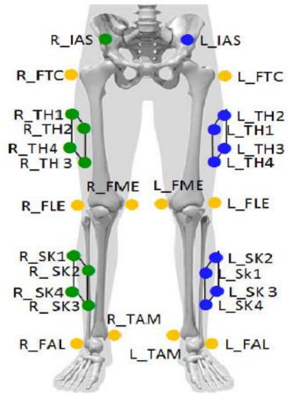

Figure 4. Lower Body marker location. Frontal View. External markers were used to obtain 3-D joint kinematic data. Hip-knee-ankle (yellow markers) were removed after the static trial.

Statistical analyses

Data from both Qualisys motion analysis and Kistler platforms were exported and analyzed with SPSS (IBM SPSS Statistics)

Figure 5. Frontal view of the feet markers used to obtain 3-D joint kinematic data.

The study was consisted of 16 females in total, which is considered a small cohort and in that case the best course of action was to utilize ”median” instead of ”mean” and ”Interquartile Range” instead of ”Standard Deviation” . Mann-Whitney U test was utilized for differences between groups and for the correlation between variables, Spearman’s test was used.

In this study, positive values in the frontal plane will be referred as “varus angles” and negative values as “valgus angles”. Additionally, positive values in the transverse plane will be referred as “external rotation” and negative values as “internal rotation”.

The mean value of the 3 trial jumps was utilized during the statistical analyses.

4.0 Results

The mild group consisted of, 9 subjects reporting 2-3 training sessions per week and the intensive training group, 7 subjects reporting 6-7 times per week.
The average hip rotation at initial contact was external for the mild training group (Median=6.1°, Interquartile Range=7.8°) while on the other hand, for the intense training group an internal rotation was observed (Median= -2.4°, Interquartile Range=5.17) with nearly statistically significant differences between the two groups ($p=0.06$) (Table 1).

However, the mild group had external rotation in the right hip 8.2°±7.6°IQR at IC that was statistically significant different ($p=0.023$) to the intense group that had internal hip rotation -3.6°±7.6°IQR . Left hip rotation at IC were not significant different ($p>0.1$) between mild 0.3°±12.1°IQR and intense -2.7°±8.9°IQR (Table 2).

Knee flexion at initial contact was 24.9°±5.8°IQR for the mild practice group and 25.3°± 11.4°IQR for the intense group with no statistical significant differences ($p>0.1$). Maximum knee flexion for the mild practice group was 75.9°±12.5°IQR and 72.4°±17.3°IQR for the intense training group, with no statistical significant differences ($p>0.1$) (Table 1).

The mild practice group showed an average varus angle at initial contact 4.2°±7.15° IQR and the intensive group 2.9°± 5.9° IQR with no statistical significant differences between the two groups($p=0.1$) (Table 1).

On the other hand a knee varus angle at maximum knee flexion was observed for the mild group 0.1°± 8.1° IQR but a knee valgus angle of -4.2°±4.2° IQR for the intense group was observed. The angle in the frontal plane was significant different between the group ($p=0.05$) (Table 1).

Finally, the average VGRF for the mild group was 1429±553N and the intense group showed 1584±414N with no significant difference ($p>0.1$) (Table 1). No significant differences between the two groups were observed for the right ($p>0.1$) (Mild: 1518±497N, Intense: 1675±302N) as well as for the left foot ($p>0.1$) were observed (Table 2).

A statistically significant correlation was found between average hip internal rotation at IC and the average knee valgus angles, both at IC ($p=0.001$) ($r=0.74$) and at maximum knee flexion ($p=0.001$) ($r=0.75$).

Table 1. Median kinematic and kinetic values of the two groups for both feet (±IQR)

	Mild training group (n=9)	Intense training group (n=7)	P
Hip rotation IC	6.1°±7.8°	-2.4°±5.2°	0.06
Knee flexion IC	24.9°±5.8°	25.3°±11.4°	>0.1
Knee flexion MAX	75.9°±12.5°	72.4°±17.3°	>0.1
Varus/Valgus IC	4.2°±7.15°	2.9°± 5.9°	0.1
Varus/Valgus MAX	0.1°± 8.1°	-4.2°±4.2°	0.05
vGRF(N)	1429±553	1584±414	>0.1

Positive angles are; external rotation, flexion and varus.

Table 2. Median kinematic and kinetic values of the two groups for each foot (±IQR)

	Mild training group (n=9)	Intense training group (n=7)	P
R Hip rotation IC	8.2°± 7.6°	-3.6°± 7.6°	0.02
L Hip rotation IC	0.3°±12.1°	-2.7°± 8.9°	>0.1
R Knee flexion IC	21.3°± 6.9°	23.2°± 10.9°	>0.1
L Knee flexion IC	30.4°±10.7°	27.8 °±13.3°	>0.1
R Knee Flexion MAX	77.3°± 12.8°	71.7°± 18.1°	>0.1
L Knee Flexion MAX	74.6°± 13.8°	73.5°± 16.6°	>0.1
R Valgus IC	5.2°± 8.1°	3.5°± 6.9°	>0.1
L Valgus IC	3.1°± 6.0°	1.7°± 8.4°	>0.1
R Valgus MAX	6.4°± 14.1°	-1.5°± 8.8°	0.1
L Valgus MAX	0.1°± 10.3°	-7.3°± 8.5°	0.1
R vGRF(N)	1518± 497	1675±302	>0.1
L vGRF(N)	1313± 650	1668 ±583	>0.1

Positive angles are; external rotation, flexion and varus.

5.0 Discussion

It was speculated that the two groups would exhibit alterations in lower limb biomechanics due to differences in neuromuscular adaptations; with the intensive training group reporting less dangerous results. Smith et al 2007 (33) supported that within a female population, athletes who compete at a higher level of sport demonstrate better muscular control. Surprisingly, the present study showed that the mild group exhibited less biomechanical variables correlated with ACL injury than the intense training group. However, it is acknowledged that the present study consisted of healthy female athletes from various divisions with no previous knee injuries and with the only difference being different number of training sessions. Moreover due to small cohort and grouping just by mild or intensive training without any ACL injury problems; render the study's results unclear and possibly bias the outcome.

In the present study, the first landing i.e the drop from the box, was used in order to analyse kinetics and kinematics. Previously, Bates et al 2013 (34) identified differences between first and second landing from a VDJ. Greater knee valgus magnitudes were exhibited in the first landing of the task that indicates that it may serve a better clinical screening tool compared to the second landing. Therefore, the first landing may be a superior overall predictor of ACL injury. Thus, the utility of the first landing in the present study was determined in accordance with the previous statement.

The biomechanical variables that were analyzed in the present study have been thoroughly examined in the international bibliography and have been stated by various studies as possible factors of ACL injury. Boden et al 2000 (16) in their study support that injury, likely occurs shortly after initial contact. Furthermore, knee valgus loading and hip internal rotation amongst others, are considered a primary biomechanical mechanism of non-contact ACL injury according to Alentorn-Geli et al 2009(35). In the present study, an interesting result was that, the median hip rotation at initial contact was external for the mild group while on the contrary was internal for the intense group. Although, this difference did not reach statistical significance (p=0.06). However, when the right foot was separately analyzed the differences between groups were proven statistically significant (p=0.023). This means, considering that 82% of the cohort reported right leg dominance, that right hip at initial contact was internally rotated for the intense group but paradoxically for the mild group was externally rotated.

In an aforementioned study, Butler et al stated that at 30° of knee flexion, ACL restricts the majority of the anterior directed forces on tibia. In addition, studies (1, 16, 19) indicate that ACL injury, usually occurs shortly after initial strike and in angles between 45° and full extension. This study's results showed that at both groups knee flexion at initial contact was approximately 25°. This is not necessarily dangerous for the cohort if we observe flexion angles independently and such angles cannot be avoided during landing. However, if other extreme values coexist, such as knee valgus angles, it should be taken into consideration when developing an ACL prevention or rehabilitation program.

The findings of Pappas et al 2007 (36) provide further evidence that knee valgus is one of the key gender differences that may explain the increased incidence of ACL injuries in females. In addition, a study by Chappell and Limpisvasti 2008 (30) states that maximum knee valgus angle during the landing phase is also stressed as an ACL risk factor. In the present study, both groups at initial contact showed a varus angle, with no statistical significant difference. On the other hand, during maximum knee flexion a slight varus angle was observed in the mild group but also paradoxically a valgus angle was observed for the intense group (p=0.05). Thus, according to the literature, the intensive group is more predisposed to ACL injury when compared to the mild training group.

A study by Matava et al 2002 (37) stated that athletes showed to injure dominant and non-dominant extremity with equal frequency. Moreover in the same study, limb dominance was stressed as a potential etiologic factor in non-contact ACL tears. In relevance with the vertical ground reaction forces, the presence of side-to-side asymmetries (measured as vGRFs) during athletic tasks have been suggested as precursors to non-contact ACL injuries by Pappas and Carpes 2012 (38). The lower the vGRFs the more optimal the landing strategy, while high vGRFs lead to non-contact knee injuries as the impact forces are transferred to more proximal joints of the kinetic chain such as the knee joint (36). In the present study, the vGRFS between the two groups did not show any significant difference. When the right and left foot was tested separately, considering that 82% of the cohort's population reported right leg dominance, no significant difference was observed (p>0.1). However the intensive training group reported slightly higher landing forces in comparison with the mild training group; it is justified though by the weight difference between the groups, were the intensive group is approximately 5kg more in average than the mild training group.

According to Patterno et al 2010 (39) the strongest predictor of a second ACL injury was the hip internal rotation moment during the initial 10 % of the landing cycle. Thus, in the present study it was speculated that hip rotation would correlate with vGRF. However, no correlation was found between these two variables. Same reasoning was applied for correlating frontal plane angles (varus/valgus) with vGRF, where Smith et al 2007 (40) stated that high valgus knee angles have been correlated with increases in ground reaction forces. However, once again no correlation was found between these two variables.

However, one interesting result that comes to agreement with the bibliography is the correlation between hip internal rotation at initial contact and knee valgus angles both at initial contact (r=0.74) and at maximum knee flexion (r=0.75). This means that, when a value is high for the hip internal rotation at initial contact; knee valgus angles during initial contact and during maximum knee flexion will be high respectively. Howard et al 2011 (41) stated that asymmetry in hip rotation has been correlated to an increase in knee valgus, which might be associated with medial collapse during landing.

5.1 Limitations

In one subject, data from only one trial out of three was analyzed due to technical problems; in that case and for this subject only, the values that were utilized throughout the analysis are identical to this one trial.
The statistical method that was used to analyze the data was chosen since the cohort of sixteen subjects is considered limited. In case of one value is excessive, can compromise the outcome of the study by altering the average values or/and the interquartile range. With the present method of statistical analysis the margin of error is minimized. However, due to the limited cohort the results may be considered of dubious validity. In addition to that, the cohort consisted of healthy female athletes of various football divisions and in one case football was declared as a profession. The rest of the cohort stated amateur or semi-professional activities. The selection of the cohort was made by convenience through a list of athletes interested to be subjected in ACL experiments. The grouping of the cohort was made purely by training sessions per week. During grouping some individuals from the mild training group reported supplementary training during their leisure time (such as, gym or cross country running) which might bias the study's results. Considering that higher levels of activity is linked with better neuromuscular control; a subject from the mild training group reporting supplementary training 2-3 times a week, cannot be clearly grouped as "mild". In addition, when comparing the two groups and their vGRF's , should be taken into account that the average weight difference between the two groups is 5kg (62kg the mild and 67 the intense) thus the maximum values during the measurements may not provide reliable results for comparison.

5.2 Conclusion

The initial hypothesis of the study, that there are differences in right and left leg in the two groups was confirmed. The intense group showed greater vGRF on the right leg. On the other hand, the second hypothesis of the study; that in the mild training group, more biomechanical variables correlated with ACL injury, will be observed was not confirmed. In fact differences were observed between the groups but in all statistical significant cases the mild training group exhibit more normal results in comparison with the intense training group. Finally the only correlation that was verified from the hypotheses was the connection between hip internal rotation and valgus angles. The present study had some limitations, resulting in unclear outcomes and stressing the fact that grouping just by training sessions is inadequate.

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