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# GROUND REACTION FORCE DURING A COUNTERMOVEMENT JUMP IN A POPULATION OF ATHLETES

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## Abstract

**Introduction:** Physical activity includes all forms of human movement and active life, including walking, exercising and practicing sport, being a natural behavior that confers considerable benefits. However, increasing participation, regular practice of sports, and their intensity of training and specialization, increase the risk of injury in athletes. There are several types of sports injuries, one of the most frequent is an anterior cruciate ligament injury, that brings adverse consequences for the athlete as well as his future of competition. Consequently, there is a great need for development strategies that allows to identify potential athletes at risk of injury, so that it is possible to correct with adapted training exercises.

**Objectives:** The aim of this project is to identify the athletes who have a higher injury risk through their biomechanical profile and the recognition of neuromuscular deficits of the inferior limbs in kinetic patterns.

**Methods:** Through a previous study of Video analysis of three jumps (countermovement vertical jump without arm swing- CMVJ) performed by 27 basketball athletes, we recorded the flexion and varus/valgus knee angles. Anthropometric data, training hours per week. The data obtained from the ground reaction forces (GRF) in the force plate during this study will be evaluated and related to the kinematic study of the same athletes, to try to recognize the neuromuscular deficits visualized in the previous kinematic analysis.

**Results:** The relationship between forces and joint moments was obtained along the 3 jumps. Other important inverse statistical relation is between the Joint Moments and the Angles in the frontal plane, respectively between the left Knee Joint Moment and left Angle ($p = 0.002$, $r = -0.558$) in the 2nd jump and the Right Knee Joint Moment and the right Angle ($p = 0.002$, $r = -0.558$) in the 3rd jump. A statistically significant negative relationship was found between the joint moments and the flexion angle, respectively, with the Left Knee Joint Moment ($p = 0.035$, $r = -0.407$) and the Right Knee Joint Moment ($p = 0.031$; $r = 0.416$) in the 2nd jump and in the 3rd jump the Left Knee Joint Moment ($p = 0.03$, $r = -0.419$) and the Right Knee Joint Moment ($p = 0.035$ $r = -0.407$). At the end, through a linear regression, it was obtained a statistical relationship between BMI and right and left forces ($p = 0.022$, $p = 0.001$).

**Conclusion:** The results obtained in this study are in agreement with current literature, predicting that the increase of the valgus is associated with an increase of the knee joint moment and that a smaller angle of flexion in the landing is associated with a greater knee joint moment. These factors are predictors of ACL injury, having the potential to improve athlete performance.

**Key words:** Ground Reaction Force (GRF), Countermovement Jump (CMVJ), Anterior Cruciate Ligament (ACL), Kinetic**,** Kinematic, Right Knee Joint Moment, Left Knee Joint Moment, Knee Flexion Angle, Right Angle on Frontal plane, Left angle on frontal plane.

## Index of abbreviations

***ICBAS-UP*** - Abel Salazar Institute of Biomedical Sciences of the University of Porto

***CLIP*** - Luso-International College of Porto

***CETI*** - Ethics Committee

***GRF*** - Ground Reaction Force

***CMVJ*** - Countermovement Jump

***SVCSBB*** - Vertical jump with countermovement and without swing with the arms

***ACL*** - Anterior cruciate ligament

***3D*** - 3 dimensions

***ET*** - Ankle Sprain

***BMI*** - Body mass index

***MI*** - Lower Member

***FZMDIRT*** – Force of right lower limb

***FZMESQ*** - Force of Left lower limb

***MomentKDIRT/ MomentKneeDIRT*** - Right knee joint moment

***MomentKESQ/ MomentKneeESQ***- Left knee joint moment

***AngFlexão*** - Knee flexion angle

***AngDIRT*** - Right angle on frontal plane

***AngESQ*** - Left angle on frontal plane

***KAM***- Knee Abduction Momentum

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## Introduction

Physical activity includes all forms of human movement and active life, including walking, exercising and practicing sport. Physical exercise is a natural behavior that confers considerable benefits[1]. That's why Physical Activity is one of the most basic human functions, and one of the pillars of healthy lifestyle[2].

Insufficient sports practice is one of the main causes of various diseases. It is estimated that worldwide around 3.2 million deaths per year are related to lack of exercise, associated with other risk behaviors such as alcohol, tobacco and unhealthy and balanced diets[3]. Scientific evidence demonstrates that regular physical activity and sport benefit physically, socially and mentally health to the entire population, men or women, of all ages, including people with disabilities[4]. Regular practice of moderate physical activity can increase the average life expectancy of 3 to 5 years[5].

However, regular practice of sports has risks. Doing sports is related to the likelihood of injury. Knee and ankle injuries are common, resulting in costs for the health system, decreasing physical activity and a large regression of the athlete's level of competition and athletic performance[6-9].

There are several types of injury inherent in sports. Anterior cruciate ligament (ACL) injury being one of the most common, totaling about 250,000 injuries per year, in the USA alone, with females presenting a higher risk of 3.5 to 4 times of injury[7,10-12]. It is the most frequent sports injury of the knee, especially in modalities that involve landing practices and cuts with lower limbs, such as soccer, volleyball and American football. Most of the population involved is young with an annual incidence reaching almost 69 per 100,000 person-years. The consequences of ACL injury can be serious even after a successful ACL reconstruction. Only 55% of athletes return to competition levels for the first year. Most importantly, cutting over ACL often leads to post-traumatic osteoarthritis of the knee, regardless of treatment[9]. Therefore, there is a great need to develop strategies to identify which athletes are most at risk of injury so that it is possible to prevent such events through validated exercises, and this is the aim of this article.

Multiple modifiable and non-modifiable risk factors have been associated with this type of injury[13]. Joint contact forces are influenced by many elements, including external forces acting on the knee, as well as the internal forces generated by the dynamics of soft tissues such as muscle contraction. The knee joint moments and the muscle contraction patterns after ACL injury are modifiable through rehabilitation programs that incorporate neuromuscular training. However, it is unclear the responsibility of these factors in the development of preventive strategies for this type of injury. Neuromuscular training strategies continue to evolve in line with these findings and represent a growing and equally important focus for research[11,13].

Jump is an essential capacity in a sporting activity, whose athletes require a good stage of landing for their modality. Such force of reaction to the ground is a determinant object for the study and prevention of injuries, especially those that are done in jumps[14]. Ground Reaction Force (GRF) is a force that acts on the body, resulting from the body at rest or in motion on the floor. It is a force of equal value to which the person exercises on the ground but in opposite form. The position on the ground of the reaction force comes from the center of pressure, this center represents a mean pressure between the feet / foot. This force is divided into 3 plans and projections respectively, in the vertical, anterior-posterior and mid-lateral vector[15].

The author proposes to evaluate a population of school age athletes, with the biomechanical characterization, trying to recognize in these the kinetic patterns of each athlete through the ground reaction force, that identify individuals with higher risk of suffering ACL lesions. In the future, it is intended to attest to the validity of prevention programs that can overcome these imbalances, allowing a personalized intervention with the intention of preventing the occurrence of injuries, which can reduce expenses for the sports clubs, the health system and improve the life quality of athletes.

## Materials and Methods

### Participants

The participants involved in this study were basketball athletes from CLIP (Luso-International College of Porto) aged between 12 and 18 years. Written informed consent was obtained from the participants' parents or from themselves if they were more than 18 years old. Approval was obtained by the Ethics Committee (CETI) of the Biomedical Sciences Institute of Abel Salazar of the University of Porto (ICBAS-UP) identified the project by nº 193/2017.

### Harvesting the data

After obtaining informed consent, the data was recorded during two sessions held in CLIP by a team of 6 people. The harvest was divided into two parts. In one study, two investigators recorded anthropometric data, weekly training hours, and ranked athletes on the Beighton scale, where a score equal to or greater than 4 meant that the athlete has hypermobility.

In the other section the remaining investigators recorded the video and reaction forces to the ground. Each athlete made five at six vertical jumps, being encouraged to jump as high as possible. Participants were pre-prepared with the placement of 5 markers on each leg, one on the upper iliac spine, two on the medial and lateral knee interlining, and two on the lateral and medial malleoli, always being placed by the same investigator to avoid bias in the study. The jumps were recorded by two CANON EOS1100D® cameras, one in the frontal plan and the other in the right sagittal plane, placed at 2.5m of the athlete, at a height of 1.5m, and the images were collected at 30fps. The athletes jumped on a plate of forces that had two platforms for each foot, from which it registered the forces of reaction to the ground of each foot and each jump of the respective athlete.

The jump chosen to obtain the data was a vertical jump with countermovement and without swing with the arms (SVCSBB). The athletes were instructed to place their feet shoulder-width apart, to look ahead and make the jump when given the order. The athlete then proceeded to perform a slight squat (they were advised to use the degree of squat they thought necessary), followed by a jump to the maximum height they could reach.

**Video analysis**

Subsequently, the videos were analyzed using KINOVEA sports video analysis software (version 0.8.15, 2011, Creative Commons, California). The initial process was excluded from the first jump making it as a reference to the learning of the movement to analyze the second, third and fourth leap. The valgus / varus angles were recorded in the two MIs and flexion in the right knee. The moment selected to obtain these measurements was the moment of maximum flexion in the landing. During the thesis, the value of the angle of valgus / varus will be mentioned, and if it is 180º it corresponds to neutral, >180º will be varo and <180º valgus.

**Analysis of ground reaction forces and Joint Moments**

The force projections obtained on the jump on the force plate were obtained with a script / routine in MATLAB R2014a. They were divided in 3 derivations, in the vertical vector, anterior-posterior vector and in the medio-lateral vector. Due to the type of technology that was worked and the measurement conditions, we chose to work only the vertical vector, being this the main force of action in this movement. The first step was to transform the time difference between the ground attack and the point of greatest flexion of each jump, of each athlete, in frames, dividing by 0.0005 representing the frequency of measurement of the plate of forces of 2000Hz, to discover the force resulting in that point through a routine developed in the MATLAB R2014a program.

The second step was the calculation of the joint moment, which is the result of force times the distance of this force to the joint, mathematically by the following expression: Moment (Nm) = Force x Distance[15]. This process was developed by calculating the distance of a vertical vector from the center of the foot to the center of the knee of each limb in each jump with the KINOVEA Software. Afterwards, the distances of each limb were multiplied by the previously calculated forces and the articular moment was obtained. These processes are demonstrated in figure 1, as calculation of the joint moment.

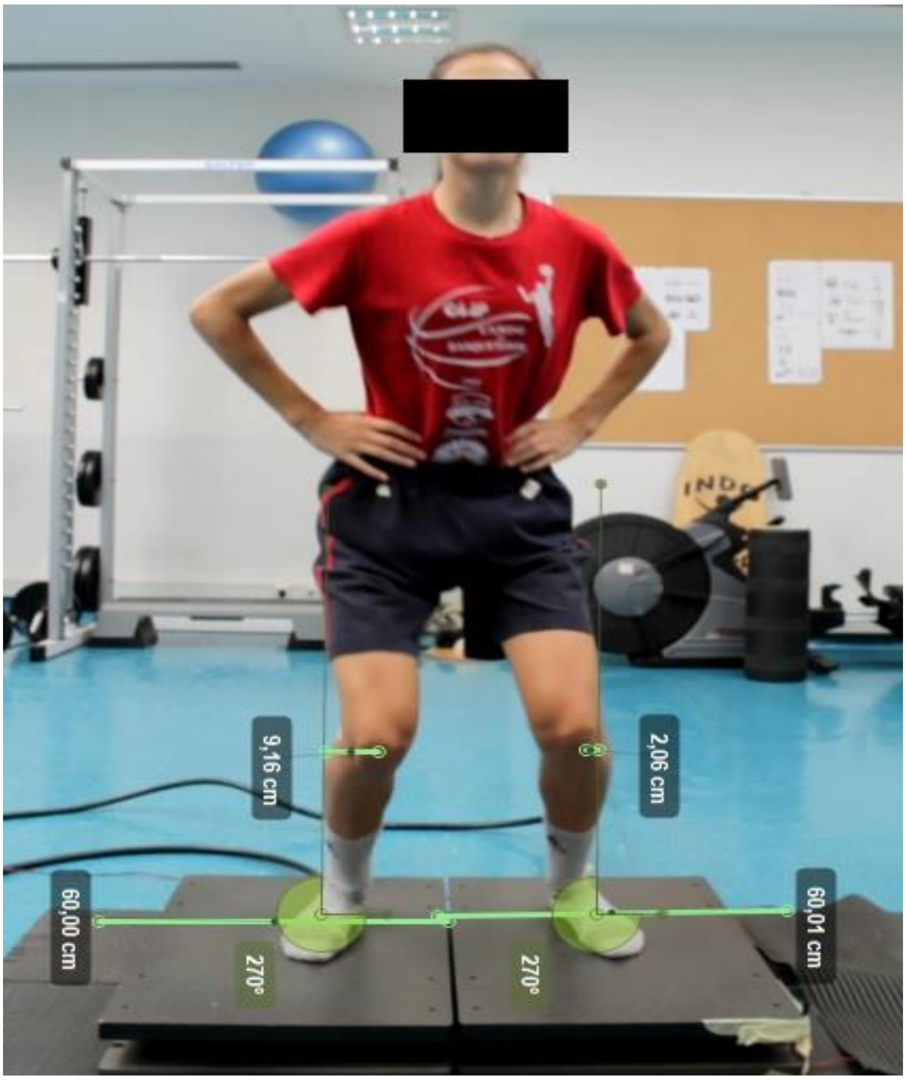

*Figure 2 Demonstration of the calculation of joint distances*

The last data analysis was based on obtaining the landing difference in each lower limb, this analysis was obtained by analyzing each force graph in each limb and with a routine developed in the MATLAB R2014a program.

## Statistical analysis

A descriptive analysis of the different variables collected was carried out. To evaluate the quantitative variables, the t-Student test was used, while the analysis of the categorical variables was performed using the Qui-square test. To evaluate the relationship between the variables Lower limb Force Right, Lower limb Force Left, Joint Moment of the right knee, Joint Moment of the left knee, Angle of Flexion, The knee joint Angle in the right and left frontal plane and the Landing Difference between the two lower limbs, Pearson's correlation was used. Afterwards the effect of some variables on the Right and Left Lower Limb Force, Right and Left knee joint Moment; Angle of Flexion and Angle in the frontal plane of the Right and Left knee, with Body Mass Index (BMI), Sex, Age; Training and its Duration and Sprains were analyzed using a multiple linear regression. It was considered that a value of $p < 0.05$ was statistically significant. Statistical analysis was performed using the IBM SPSS Statistics software (version 25, 2017, IBM corp, NY).

## Results

*Table I Sample Characterization*

| **Participants** | **Male** | **Female** | **Age (mean)** | **Height (mean)** | **BMI (mean)** |
|---|---|---|---|---|---|
| **27** | 6 | 21 | 14.63 | 1.67 | 20.76 |
| **Trainings** | **Lower** | **Higher** | **Major %** | | |
| | 2 | 5 | 3-4 (51.9%-40.7%) | | |
| **Duration** | **Lower** | **Higher** | **Major %** | | |
| | 1.5 | 2 | 2 (92.6%) | | |
| **Weekly hours** | **Lower** | **Higher** | **Major%** | | |
| | 4 | 10 | 6 (51.9%), 8 (37%) | | |

In this study, as shown in table 1, 27 athletes participated, 6 males and 21 females. Featuring a mean age of 14.63 years ranging from a minimum of 12 years to a maximum of 19 years. They had a mean height of 1.67m and a mean Body Mass Index (BMI) of 20.76. The athletes under study performed between 2 and 5 weekly training sessions with a higher frequency between 3 and 4 weekly training sessions, respectively of 51.9% and 40.7%. The Duration of the training was between 1 hour and a half and 2 hours, with 92.6% of the population performing in 2 hours. The total weeks hours varied between 4 and 10 hours, with 51.9% of the population performing in 6 hours and 37% in 8 hours. In this population, 2 had lesion in the anterior cruciate ligament ACL and 14 athletes, about 51.9% of the population, suffered an ankle Sprain.

Regarding the 3 jumps, the forces, articular moments and angles were grouped into quartiles for better characterization of these same variables followed in Table 2.

*Table II Percentiles related to Forces (FZMDIRT,FZESQ), Joint Moments(MOMENTKDIRT, MOMENTKESQ), Flexion Angles (AngFlexão) and Angles in the Foreground Plane (AngDIRT, AngESQ)*

| Percentis | 25% | 50% | 75% | Percentis | 25% | 50% | 75% |
|---|---|---|---|---|---|---|---|
| FzMDIRT 1 | 472,04 | 608,648 | 709,106 | FzMEsq1 | 249,106 | 435,986 | 614,62 |
| FzMDIRT 2 | 403,17 | 526,264 | 806,33 | FzMESQ2 | 326,114 | 454,789 | 703,476 |
| FzMDIRT 3 | 469,19 | 524,932 | 733,269 | FzMESQ3 | 303,07 | 454,605 | 589,364 |
| MomentK DIRT1 | 0 | 9,979 | 24,888 | MomentKE SQ1 | 0 | 14,712 | 30,362 |
| MomentK DIRT2 | 4,201 | 25,568 | 55,068 | MomentKE SQ2 | 0 | 13,9 | 37,884 |
| MomentK DIRT3 | 0 | 16,148 | 48,513 | MomentKE SQ3 | 0 | 13,761 | 42,138 |
| AngDIRT1 | 176 | 181 | 188 | AngESQ1 | 176 | 182 | 187 |
| AngDIRT2 | 172 | 183 | 188 | AngESQ2 | 177 | 183 | 189 |
| AngDIRT3 | 174 | 179 | 188 | AngESQ3 | 177 | 184 | 189 |

| Percentis | 25% | 50% | 75% |
|---|---|---|---|
| AngFlexão1 | 56 | 60 | 67 |
| AngFlexão2 | 53 | 59 | 70 |
| AngFlexão3 | 54 | 63 | 68 |

## First Jump

*Table III Correlations in 1st jump*

| | | Ang.Flexão1 | MomentKnee DIRT1 | MomentKneeE SQ1 | FzMIESQ1 |
|---|---|---|---|---|---|
| Ang.Flexão1 | Correlação de Pearson | 1 | -0,345 | -0,346 | -,448* |
| | Valor p. | | 0,078 | 0,077 | 0,019 |
| MomentKnee DIRT1 | Correlação de Pearson | -0,345 | 1 | ,915** | ,398* |
| | Valor p. | 0,078 | | 0 | 0,04 |
| MomentKnee ESQ1 | Correlação de Pearson | -0,346 | ,915** | 1 | ,409* |
| | Valor p. | 0,077 | 0 | | 0,034 |

Regarding the first jump, confirm to table III, there is a statistically significant relationship between the Force of the Left Lower Limb and the Joint Moment of the Right and Left knee ($p = 0.04$; $p = 0.034$). There is another statistically significant relationship between the Right knee Joint Moment and the Left knee Joint Moment ($p<0.001$) with a negative correlation ($r = -0.147$). There is a statistically significant relationship between the Force of the Left Lower Limb and the Angle of Flexion ($p = 0.019$) in a negative correlation ($r = -0.448$). In the other variables not present, there is no statistically significant relationship between them.

## Second Jump

*Table IV Correlations in the 2nd jump*

| | | Ang.Flexão2 | Ang.DTO2 | Ang.ESQ2 | MomentKneeDIRT2 | MomentKneeESQ2 | FzMIDIRT2 | FzMIESQ2 |
|---|---|---|---|---|---|---|---|---|
| Ang.Flexão2 | Correlação de Pearson | 1 | 0,235 | 0,110 | -,416* | -,407* | -,461* | -,526** |
| | Valor p. | | 0,237 | 0,586 | 0,031 | 0,035 | 0,015 | 0,005 |
| Ang.DTO2 | Correlação de Pearson | 0,235 | 1 | ,594** | -0,196 | -0,298 | -0,251 | -0,363 |
| | Valor p. | 0,237 | | 0,001 | 0,326 | 0,131 | 0,207 | 0,063 |
| Ang.ESQ2 | Correlação de Pearson | 0,110 | ,594** | 1 | -0,110 | -,558** | -0,162 | -0,221 |
| | Valor p. | 0,586 | 0,001 | | 0,584 | 0,002 | 0,420 | 0,268 |
| MomentKnee DIRT2 | Correlação de Pearson | -,416* | -0,196 | -0,110 | 1 | ,627** | 0,297 | 0,331 |
| | Valor p. | 0,031 | 0,326 | 0,584 | | 0,000 | 0,133 | 0,092 |
| MomentKnee ESQ2 | Correlação de Pearson | -,407* | -0,298 | -,558** | ,627** | 1 | ,457* | ,420* |
| | Valor p. | 0,035 | 0,131 | 0,002 | 0,000 | | 0,017 | 0,029 |
| FzMIDIRT2 | Correlação de Pearson | -,461* | -0,251 | -0,162 | 0,297 | ,457* | 1 | ,589** |
| | Valor p. | 0,015 | 0,207 | 0,420 | 0,133 | 0,017 | | 0,001 |
| FzMIESQ2 | Correlação de Pearson | -,526** | -0,363 | -0,221 | 0,331 | ,420* | ,589** | 1 |
| | Valor p. | 0,005 | 0,063 | 0,268 | 0,092 | 0,029 | 0,001 | |

In the second jump, according to table IV, there is a statistically significant relationship between the Force of the Right Lower Limb and the Left Force and Joint Moment of the Left knee ($p = 0.001$; $p = 0.017$). The Joint Moment of the Right Knee has a statistically significant relationship with the Joint Moment of the Left Knee ($p<0.001$). Regarding the Force of the Right Lower Limb, there is a statistically significant relationship between the Flexion Angle ($p = 0.015$) in a negative association ($r = -0.461$). On the Force of the Left Lower Limb there is a statistically significant relationship between the force and the Flexion Angle ($p = 0.005$) in an inverse correlation ($r = -0.526$). There is a statistically significant relationship between Right and Left Angle in the frontal plane ($p = 0.001$). There is a statistically significant relationship between the Right Knee Joint Moment and the Flexion Angle ($p = 0.031$) with a negative association ($r = -0.416$). The Joint Moment of the Left Knee and Flexion Angle presented a statistically significant relationship ($p = 0.035$) in an inverse way ($r = -0.407$) and a statistically significant association between the Left Knee Joint Moment and the Left Angle ($p = 0.002$) in a negative correlation ($r = -0.558$). In the other variables not present, there is no statistically significant relationship between them.

**Third Jump**

*Table V Correlations in the 3rd jump*

| | | Ang.Flexão3 | Ang.DTO3 | MomentKneeDIRT3 | MomentKneeESQ3 | FzMIDIRT3 | FzMIESQ3 | DiferentAterr3 |
|---|---|---|---|---|---|---|---|---|
| Ang.Flexão3 | Correlação de Pearson | 1 | 0,030 | -,407* | -,419* | -0,128 | -0,265 | 0,244 |
| | Valor p. | | 0,883 | 0,035 | 0,030 | 0,524 | 0,182 | 0,219 |
| Ang.DTO3 | Correlação de Pearson | 0,030 | 1 | -,558** | -0,093 | -0,102 | 0,003 | 0,069 |
| | Valor p. | 0,883 | | 0,002 | 0,645 | 0,613 | 0,987 | 0,733 |
| MomentKneeDIRT3 | Correlação de Pearson | -,407* | -,558** | 1 | ,753** | -0,100 | 0,090 | -0,159 |
| | Valor p. | 0,035 | 0,002 | | 0,000 | 0,619 | 0,655 | 0,427 |
| MomentKneeESQ3 | Correlação de Pearson | -,419* | -0,093 | ,753** | 1 | -0,289 | -0,159 | 0,012 |
| | Valor p. | 0,030 | 0,645 | 0,000 | | 0,144 | 0,428 | 0,952 |
| FzMIDIRT3 | Correlação de Pearson | -0,128 | -0,102 | -0,100 | -0,289 | 1 | ,468* | -0,287 |
| | Valor p. | 0,524 | 0,613 | 0,619 | 0,144 | | 0,014 | 0,146 |
| FzMIESQ3 | Correlação de Pearson | -0,265 | 0,003 | 0,090 | -0,159 | ,468* | 1 | -,531** |
| | Valor p. | 0,182 | 0,987 | 0,655 | 0,428 | 0,014 | | 0,004 |
| DiferentAterr3 | Correlação de Pearson | 0,244 | 0,069 | -0,159 | 0,012 | -0,287 | -,531** | 1 |
| | Valor p. | 0,219 | 0,733 | 0,427 | 0,952 | 0,146 | 0,004 | |

On the third jump, as verified in table V, there is a statistically significant relationship between Right and Left lower Limb Force ($p = 0.014$). It presents a statistically significant relationship between the Joint Moment of the Right and the Left Knee ($p<0.001$). There is a statistically significant relationship between the Right Knee Joint Moment and the Flexion Angle ($p = 0.035$) in a negative association ($r = -0.407$), there is also a statistically significant relationship between Right Knee Joint Moment and Right Angular ($p= 0.002$) in an inverse relationship ($r = -0.558$). There is a relationship between the Joint Moment of the Left Lower Limb and the Flexion Angle ($p = 0.030$) in a negative correlation ($r = -0.419$). It presents a statistical association between the Landing Difference and the Left Lower Limb Force ($p = 0.004$) in an inverse association ($r = -0.531$). In the other variables not present, there is no statistically significant relationship between them.

**Other relationships**

At the end, when performing a linear regression between the mean of the forces, articular moments and angles of the jumps with the other variables described previously, the following relations were found: a statistically significant correlation between the BMI and Right and Left Force of Lower Limb, ($p = 0.022$) ($p=0.001$) ; a statistically significant relationship between the Left Force and Age ($p<0.001$) and the Duration of the training ($p = 0.015$).

Finally, there was also a statistical relationship between Flexion Angle and the Age ($p = 0.037$), the BMI ($p = 0.001$) and with Sprains ($p = 0.009$). This last one has an inverse association of the Flexion angle with Age and BMI ($\beta = -2.295$, $\beta = -3.253$) with the 95% confidence interval, respectively -4.440 to -0.150 and -5.027 to -1.479.

## Discussion

The Biomechanical study with the kinetics and kinematics of the human joints potentiates a greater work efficiency of the athlete's performance as well as its recovery. This research aimed to study a population of basketball athletes at school age.

With analysis of the data obtained and with the 3 jumps simultaneously, there is a constant and transverse relationship during the study, the relationship between the two right and left joint moments. In the first jump the association between the two articular moments is in an inverse correlation whereas in the following it is in a direct relation. This premise may be justified by the process of learning that the athletes are still in, regarding the jump movement and some instability and poor safety that the athlete may have, due to perform a greater force with his dominant member. After a few jumps, the athlete will already have mastered the technique and the proportion of force and work by the two members will be similar and proportionate as time passes.

In a transversal way, between the tree jumps, despite the existence of a association between the variables, they are not always statistically significant. The mentioned relations, that are not always statistically significant, between variables, are between the Forces of the Lower Limbs and the Angle of Flexion, the Joint Moments and the Angles of Flexion, both situations in inverse correlation. Interpreting this situation, as the moments or forces decrease, there is an increase of the knee flexion angle, which has already been reported particularly by Carolyn[12], that prospective studies reveal that the decrease in flexion angle and increase in GRF are associated with an increase in ACL lesions. This relationship comes in agreement with current literature. One example is Daniel Hahn[16], who found that the external angular forces significantly decreased 3,369 ± 575 N at 30º of knee flexion at 1.015 ± 152N of 100º knee flexion, concluding further that the joint produced forces would be more dependent on the knee extensor muscles for angles ≥70º, while the plantar flexor and the hip extensor would have a more important role for angles ≤50º. These authors reveal that increased knee flexion may be a protection for ACL injury. This because, with a larger angle seen by Daniel Hahn [16], there is a smaller isometric contraction, resulting in greater joint stability, but with a greater flexion angle, a greater stretching of the muscle fibers and greater maximum strength is obtained. It has already been observed in other studies[17] that the tension stress produced by the contraction of the quadriceps can be reduced with the angle of flexion and activation of the hamstring muscles, and that a flexion with a small angle of flexion is associated with a greater risk of ACL lesion, as well as the increase of GRF by the increase of the moment of activation of the quadriceps.

Another pertinent observation similar to the previous one, is the fact that, in a transverse mode, there is an inverse relationship between the articular moments with the articular angles in the frontal plane. In the second jump, the relationship between the left and right angular momentum, and in the third jump, the relationship between Joint moment of the right knee and right angular, both have statistically significance, however, a negative Pearson's correlation is always present between the joint moments and the joint angles in the frontal plane and between the forces of the lower limbs and the articular angles in the frontal plane between all jumps. This shows that the decrease in the frontal plane angles, that is, the decrease of varus and increase of valgus, leads to an increase of forces and joint moments of the knee. This situation is of particular importance because few studies have directly demonstrated it. Instead, the studies demonstrate a relationship with GRF and the knee abduction momentum (KAM), something that is potentiated by a knee in valgus. In a recent study, using a simulator of cadaveric limbs for the study of ACL lesion, it was found that as the vertical component of GRF increased in all models, the KAM increased, and in the end all models had torn the ACL[18]. In another study, with the purpose to identify the effects of a corrective exercise program on landing ground reaction force characteristics, and lower limb kinematics in older adults with genu valgus  for correction of a knee in valgus, it was verified that the decrease of Fz of the vertical component of GRF in patients would lead to an effective correction training because it decreased the angle of valgus [19]. In agreement with the previous studies, Elizabeth Madden and her collaborators with the study in an insole in shoes verified that the diminution of the GRF magnitude in the frontal and medio-lateral plane led to the decrease of the moment of adduction of the knee, and that the diminution of the medial vector of GRF led to a decrease in varus and an increase in valgus[20] . With the literature portrayed previously, and in all studies, it is verified that a knee in valgus is a risk factor along with the GRF for the ACL. A knee in valgus may lead not only to an ACL lesion but also to as patellofemoral pain and osteoarthritis of the lateral compartment of the knee[19]. This type of relationship from the moment of articulation to the frontal angle is important not only to prevent an ACL injury and recovery of an athlete but also to improve his performance. It is recognized that women who have the valgus type during the landing phase tend to decrease hip flexion, increase abduction of the knee, and increase rotation of the knee[19]. These factors previously seen may be associated, not only with the knee flexion angle, but also with the angle in the frontal plane of the knee, which in this study presents a strict transverse relationship during the jumps with joint forces and moments.

Finally, a small reference of the BMI's action on the Vertical Forces of the Lower Limb. There is a direct association with both the right and left lower limb with the BMI. It is recognized with age that both height and weight tend to increase and stabilize until reaching full growth, consequently BMI tends to increase proportionally thus suffering a direct correlation with vertical forces that proportionally tend to increase. Another important situation for future investigations, is the association on the angle of flexion and the sprains. As previously mentioned, increased knee flexion may be a stabilizing and protective factor for injuries. However, evidenced in this study demonstrated that as the flexion angle increases, the number of sprains increases, something not expected according to other studies, showing that greater flexion of the knee represents a greater joint stability[16]. This evidence must be better studied in the future, due to the small population and the school age studied, because these variables could have some deviation. Making this, will be a practical foundation of teaching athletes how to jump better, with a greater knee flexion.

## Conclusion

In conclusion, the kinetic and kinematic study in athletes brings crucial information for their recovery, training, performance and essentially referred preventions of the ACL and foot sprains. This study is adapted to the current literature on the mentioned data, bringing new relations that currently are not referred, or, if referred, they are shown indirectly.

This results are in agreement with the current focus referred in the literature, with the increase of the angle of flexion in the initial contact to the ground, with the balance between the activation of the quadriceps and the hamstrings with the neuromuscular training for the prevention of non-contact lesions of the ACL [13]. By adapting to new relationships not previously reported in the studies, the increasing of joint momentum and lower limb forces provide an increase in knee valgus. These relationships are very important because valgus is a determinant factor for ACL injury, as well as the relationship of sprains and joint stability of the knee in flexion. The jump is a crucial movement and present in several sports modalities, and knowing these determinant predictors for injury prevention, it will be fundamental a training that aims to decrease this impact in the jump to, consequently, decrease the joint moment of the knee and increase the stability of the joint, so the athlete can have better performances and fewer injuries.

Further studies will be needed to prove this theory, with a greater kinematic and kinematic approach to obtain greater associations between the forces, the articular moments and the joint angles.

## Limitations

This study had several limitations. One of them was the technology that was used, obtaining the filming in only 2 planes of which the sagittal plane only presents the right side of the athletes and the lack of coordinates by the point of force in the plates of force. However, the data obtained for this technology is adequate to the variables of the present literature. Another important limitation was the number of athletes. With a larger sample of athletes it could be easier to obtain more statistical relations that in this study was not obtained. Lastly, there is an absence of literature with a study similar to this one or with similar variables in a similar population, which created great difficulty in the analysis of the obtained data.

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