Single-leg landing: Determining the risk of knee joint injuries in relation to frontal plane projection angles and lower leg muscle strength among recreational athletes

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Abstract:

Knee and hip muscles play a significant role in orientation of lower extremities during weight-bearing activities. The frontal plane projection angles during single leg landing movements and their relationship with lower extremity muscular strength were investigated in this study. This study followed a cross-sectional study design with 30 male participants of the age of 21.07 ± 1.23 years, heights of 171.70 ± 7.78 cm, weights of 70.74 ± 10.55 kg, and BMIs of 23.89 ± 2.88 kg/m². All the participants were university recreational athletes and free from any musculoskeletal injury. Frontal plane projection angles of the knee and hip joint were measured during single leg landing with the help of Vicon three-dimensional movement analysis systems. Muscle strength of knee extension, external rotation of the hip, and abduction of the hip were measured using an isokinetic dynamometer. A significant moderate negative relationship between hip abduction strength with the knee joint angle ($r = -0.420$, $p = 0.021$) and hip adduction angle ($r = -0.458$, $p = 0.011$) was found during landing. The hip external rotator strength was negatively correlated with the knee joint angle ($r = -0.089$, $p = 0.639$) and hip joint angle ($r = -0.191$, $p = 0.311$) during landing. The knee extensor strength was negative correlated with the knee joint angle ($r = -0.057$, $p = 0.765$) and hip joint angle ($r = -0.085$, $p = 0.653$) during landing. This study found a negative significant correlation between hip abductor strength and knee valgus during landing, which means that if the hip adduction angle increases, the knee valgus increases, possibly causing injuries in athletes. The findings of the current study emphasize the need to strengthen the lower extremities to increase hip strength to reduce knee instability during sports activities. This may allow coaches, trainers and clinicians to discover the causes of injury and develop strengthening programmes and neuromuscular control to reduce the risk of injuries.

Key Words: Knee valgus, Injury risk, Hip external rotator, Hip abduction, Knee extension

Introduction

All around the world, a significant number of athletes indulge in sports activities and competitions every day. All athletes experience injuries because of participation in sports. According to one study, 8.6 million athletes aged 5-24 year have a sports injury every year (Sheu et al., 2016). A high percentage of injuries occur in the lower extremities (Hootman, Dick, & Agel, 2007). Any change in knee alignment increases higher knee abduction when performing functional tasks, such as landing, that contribute to joint instability as a result of weight-bearing by the knee (Bittencourt, Ocarino, Mendonça, Hewett, & Fonseca, 2012). A higher knee abduction angle has been proposed to be a component of the dynamic valgus, in which alignment of the hip (higher femoral adduction) and lower leg (higher tibia external rotation) positions the knee medial to the foot (Hewett et al., 2005). Any imbalance of motion could potentially expose the ligament or muscle to high injury risk (Huxel Bliven & Anderson, 2013). Harty et al. (2011) reported that knee valgus angles and moments across the drop jump and step-down have a correlation. However, Kristianluund and Krosshaug (2003) revealed that a significant correlation existed between knee valgus angles in the drop jump and cutting tasks. The knee valgus angle may be calculated using three-dimensional (3D) motion analysis that requires expensive equipment, technical knowledge and extensive time.

3D motion analysis systems allow us to evaluate movement kinetically and kinematically. 3D motion analysis is the best choice because it has strong reliability and validity, and it is considered the gold standard for movement assessment (McGinley et al. 2008; Meldrum et al. 2013). The 3D technique was utilised to examine subjects predicted to be at high risk of non-contact knee injuries (Imwalle, Myer, Ford, & Hewett, 2009). Using this technique, knee valgus can be measured during dynamic tasks with the frontal plane projection angle (FPPA), i.e. a digital video measure of frontal plane knee position formed by the intersection of the thigh and leg segment, which is a method that has proven to be reliable and valid (Uebayashi et al. 2019). Kinematics of the knee valgus demonstrated that single leg landing is a useful screening tool to assess an individual's lower limb

dynamic alignment and potential risk of injury (Whatman et al 2011). Previous studies have investigated the FPPA during popular dynamic tasks exploited to determine people who have a high injury risk (Boling, 2009; Nilstad, 2015). However, as some previous studies have found, the lower extremity measures are influenced by the strength of the lower extremity muscles (de Marche Baldon, 2011; Wallace, 2008). Claiborne et al. (2006) found that participants with greater knee strength have a lower valgus angle. However, Willson et al. (2006) showed that with a greater strength of knee flexors, the greater the knee valgus angles. The relationship between the strength of hip/knee muscles and the FPPA of the knee and hip during different functional movements has been reported in the literature for different age groups and populations using various methods. These differences resulted in very conflicting outcomes. This study aimed to investigate the relationship between joint angle kinematics and lower limb strength during functional movements for healthy participants.

Identifying the relationship between the strength of the hip muscles and the FPPA for the hip and knees will assist in identifying those people who are most likely to be injured. Moreover, this will contribute to the potential development of more effective prevention strategies to decrease the rates of knee injury by targeting muscle support improvement for dynamic knee stability in the frontal plane.

Materials & methods

Study design and setting

This study followed a cross-sectional study design to achieve the objective. The study was conducted in the laboratories of the physical therapy department in the College of Applied Medical Sciences at Imam Abdulrahman Bin Faisal University (IAU). Each subject made a single visit to the laboratories that lasted a total of 1–2 h.

Ethical considerations

The approval for this study was received from the IAU Institutional Review Board, following its meeting on Wednesday, October 7, 2019 (IRB-PGS-2019-03-275). Participants who agreed to participate in the study voluntarily were given a detailed written and verbal explanation of the study procedure and then asked to sign a consent form.

Sample size

A sample of convenience was used; available subjects who fitted the criteria were recruited from the IAU. One group contained all the participants. A website link [<https://www.ai-therapy.com/psychology-statistics/sample-size-calculator/>] was used to calculate the sample size. Sample size = 29, the power of the test = 0.20 (1- β), and the sample of correlation (r) = 0.50.

Participants

Thirty male participants were recruited for this study who participated in recreational active sports activities. The age range was 19–23 years of age. All the participants were recruited from the IAU through an advertisement.

Eligibility criteria

The following eligibility criteria were obtained before data collection: the participants were healthy males, age range between 18 and 30 years, they actively participate in recreational sports activities, and their level of sport activity of at least level 3 based on the Noyes Scale (Noyes, Barber, & Mangine, 1990). Participants with a history of musculoskeletal injury or lower limb surgery within the previous year were excluded from this study.

Outcome measures

Frontal plane projection angle (FPPA)

The FPPA was measured using a 3D motion analysis system and Nexus software (VICON Motion System, Oxford Metrics Ltd., Oxford, UK) version 2.8.1 during single leg landing, a method that has been proven reliable and valid (Alenezi, 2014). The angle of the hip joint was defined as: “the angle between the thigh and pelvis” (Malloy, Neumann, & Kipp, 2019). In addition, the knee FPPA was defined as the angle between the thigh and shank (Dwyer, Boudreau, Mattacola, Uhl, & Lattermann, 2010).

Muscular strength

The muscle strength (peak torque) was measured with the help of an isokinetic dynamometer (Biodex Corp., Shirley New York) for a multi-joint system during knee extension, the external rotation of the hip, and the abduction of the hip. This isokinetic dynamometer has the highest correlation coefficient for reliability, accuracy, validity, and repeatability (Chamorro, Armijo-Olivo, De la Fuente, Fuentes, & Javier Chiroso, 2017). The isokinetic dynamometer provides objective, repeatable measurements that can be linked to different types of participants' physical demands.

Procedures

All procedures were performed in the biomechanical and musculoskeletal laboratories at IAU. Before starting the test, the research idea and objectives were explained to the participants, including its benefits and risks. Participants were free to ask questions if they had any queries. All participants provided their consent to participate in the study voluntarily. Participant's age, height, weight, and sports activity level were measured. To measure the biomechanical variables the Plug-in Gait Lower Body Model was used, which required 16 bony prominence digitisations. Reflective markers (14mm diameter) were attached to 16 body landmarks as follows:

four markers applied to the superior iliac spine (two ASIS and two PSIS); two markers on both the upper and lower lateral thigh; and two markers on the flexion extension axis of both knees. In addition, two markers were applied to both the upper and 1/3 lower shank, and two markers were applied to both the upper and lower 1/3 surface of the shank. Foot markers were attached to the second metatarsal head, calcaneus and lateral malleoli, and the test was performed without shoes (Baudet, 2014). Calibration residuals were determined in accordance with VICON's guidelines with a position data accuracy of 1 mm. To organise a static standing trial, the participants were requested to stand in a stationary stance on the force plate with the T position. For Single Leg Landing (SLL), the FPPA of the knee and the hip adduction angles was measured by requesting that participants stood at a height of 31 cm above the ground. The participants were asked to bend forward and then drop as perpendicularly as possible by utilising the limb that was being tested in the squatting task with the arms abducted. The angles of hip adduction and knee valgus were taken from the lowest point of knee flexion.

This was necessary to ensure that a participant's other limb did not touch the ground when landing (Yeow, 2010). The angle applied for the analysis was the average of the frontal plane projection of the knee and the angle of hip adduction from three trials with the dominant leg (Herrington, 2014). Data were then analysed, followed by a calculation of the average. To measure the muscular strength of the hip abductor using the isokinetic dynamometer, a side lying position was implemented. The participant abducted his leg from 0 to 30°, and waist, pelvis and untested limb were stabilised by strapping. The alignment of axes was performed by placing the actuator axis opposite the hip joint at a coronal level at about 1 cm medial to the ASIS. The resistance pad was set on the lateral aspect of the thigh below the greater trochanter of the femur, and the velocity was applied at 30°/s. The strength of hip external rotation was measured while participants were seated on the dynamometer's chair and their hip and knee flexed at 90°. A participant would rotate the femur externally approximately 30° whilst stabilising the distal hip across the pelvic crests and across the chest by using straps. The dynamometer axis height was aligned to the long axis of the femur. A resistance pad was placed above the medial malleolus. To measure the strength of the knee extensor for all participants, the dynamometer's axis of rotation was individually aligned to the knee joint with the hip angle at 90°. The resistance pads were placed superior to the medial malleolus (Steffen, 2016). The subject extended their knee at maximum effort, while stabilisation was accomplished with femoral and pelvic strapping.

Statistical Analysis

The IBM SPSS v. 20 software package (IBM SPSS Inc., Chicago, IL) was used for statistical analysis to evaluate the relationship between the FPPA angle and muscle strength. The normality of the continuous variables was tested using the Shapiro–Wilk test. Most of the variables were normally distributed. Descriptive statistics were calculated for all the measurements. The correlation between the angles and muscle strength was assessed using a parametric test, the Pearson correlation coefficient test. The statistical significance was set at $p \leq 0.05$.

Results

All participant data are presented in the below mentioned tables. Demographics data for all participants can be found in Table 1, the normality test data for muscle strength and frontal plane projection angle are presented in Table 2, and relationship analysis data are provided in Tables 3 and 4 for different parameters.

Table 1. Descriptive characteristics of the subjects

Measurements	Minimum	Maximum	Mean	Standard Deviation
Age (years)	19.00	23.00	21.07	1.23
Height (cm)	151.00	189.00	171.70	7.78
Weight (kg)	46.20	90.10	70.74	10.55
Body Mass Index (kg/m ²)	17.10	28.90	23.89	2.88

In total, 30 healthy recreational athletes were included in this study, and there were no missing data. The age of the studied participants was in the range of 19–23 years with a mean (SD) age of 21.07 (1.23) years, height of 171.70 (7.78) cm, weight of 70.74 (10.55) kg, and BMI of 23.89 (2.88) kg/m², as shown in Table 1.

Table 2. Descriptive statistics and normality test for the muscle strength parameters and frontal plane projection angle of the knee and hip during single leg landing parameters

Parameters	Mean (SD)	Minimum	Maximum	Shapiro–Wilk test	
				Statistic	P value
Hip Abduction Strength	71.40 (19.54)	33.50	105.00	0.959	0.287
Hip External Rotation Strength	40.47 (11.17)	25.90	80.50	0.861	0.001
Knee Extensor Strength	134.40 (27.16)	73.30	177.70	0.967	0.455
Hip Angle	1.52 (6.50)	-12.90	13.00	0.949	0.157
Knee Angle	-5.27 (8.94)	-20.20	13.20	0.972	0.592
Peak Knee Flexion Landing	53.45 (9.64)	39.20	79.50	0.906	0.012

Table 2 presents the descriptive statistics and normality test data for all participants for the muscle strength parameters. The Shapiro-Wilk test showed that hip abduction strength ($p=0.287$), and knee external strength ($p=0.455$) data were normally distributed. However, hip external rotation strength ($p=0.001$) was not normally distributed. The hip adduction angle (HAA) is represented by a positive value, whereas a negative value represents the hip abduction angle. The negative values for the knee angle (KA) represent valgus positioning, and positive values represent varus positioning. The Shapiro-Wilk test showed that hip ($p=0.157$) and knee ($p=0.532$) angle data were normally distributed, whereas the peak knee flexion angle ($p=0.012$) during landing was insignificant.

Table 3 Relationship between hip abduction strength, hip external rotator strength, and knee extensor strength to knee and hip joint angle during single leg landing

Variables	Number of subjects	Correlation coefficient	P value
HABS and KAL	30	-.420*	.021
HABS and HAL	30	-.458*	.011
HERS and KAL	30	-.089	.639
HERS and HAL	30	-.191	.311
KES and KAL	30	-.057	.765
KES and HAL	30	-.085	.653

HABS = hip abduction strength, HERS = hip external rotator strength, KES = knee extensor strength, HAL = hip angle landing, KAL = knee angle landing

*Correlation significant at the 0.05 level (2-tailed)

Table 3 present a significant moderate negative correlation between hip abduction strength and knee angle landing (valgus) with the correlation coefficient ($n=30$, $r=-0.420$, $p=0.021$). This means that as hip abduction strength increases, valgus decreases. In addition, a significant moderate negative correlation was identified between hip abduction strength and hip adduction angle landing with the correlation coefficient ($n=30$, $r=-0.458$, $p=0.011$). These negative correlations mean that as the strength of hip abduction increases, the angle of hip adduction decreases. An insignificant weak negative correlation coefficient was identified between the hip external rotator strength and knee angle landing ($n=30$, $r=-0.089$, $p=0.639$). Similarly, a weak negative correlation was identified between the hip external rotator strength and hip angle landing with a non-significant correlation coefficient ($n=30$, $r=-0.191$, $p=0.311$). This means that as hip external rotator strength increases, the angles of hip adduction and knee valgus decrease. No significant correlation was identified between the knee extensor strength and knee angle landing with the correlation coefficient ($n=30$, $r=-0.057$, $p=0.765$). A weak negative correlation was also identified between the knee extensor strength and hip angle landing with an insignificant correlation coefficient ($n=30$, $r=-0.085$, $p=0.653$). The results show that the lower the femur adduction, the greater the concentric knee extensor peak torque.

Table 4. Relationship between knee angle and hip angle at single leg landing

Variables	Number of subjects	Correlation coefficient	P value
KAL and HAL	30	.482*	.007

KAL = knee angle landing, HAL = hip angle landing

*Correlation is significant at 0.05 level (2-tailed)

Table 4 shows that a significantly moderate positive correlation was identified between knee angle landing and hip angle landing with the correlation coefficient ($n=30$, $r=0.482$, $p=0.007$). This showed that when the angle of hip adduction increases, the knee valgus angle increases.

Discussion

The results of this study suggest that there was a significant relationship among hip abduction strength, hip adduction angle, and knee valgus angle during SLL in healthy recreational athletes. Another finding of this study was the significant correlation between knee valgus and hip adduction angles during SLL.

The hip and knee mechanics used in single leg landing may be viewed as risk factors for knee injury, so understanding the particular strength types that have the strongest correlation with these motions is necessary during evaluation and when prescribing exercise to lessen risk. Supporting the alternative hypothesis, knee abduction and hip adduction angles at maximal knee flexion during SLL in the frontal plane are correlated negatively with hip abduction strength in males. In other words, males with greater hip abduction strength showed smaller knee valgus and hip adduction angles when performing SLL. Several studies generally support these findings, regardless of the variation in methodological tools and participants.

Suzuki, Omori, Uematsu, Nishino, and Endo (2015) and Jacobs and Mattacola (2005) observed a negative correlation between hip abduction and knee valgus in females performing SLL. In addition, McCurdy et al. found a moderate negative correlation between the hip abductor strength and knee abduction angle during double-leg landing in females (McCurdy, Walker, Armstrong, & Langford, 2014). Z. Neamatallah, Herrington, and Jones (2020) reported a strong negative correlation between the hip adduction angle and hip abduction concentric strength during single forward landing (SFL) in males, whereas there was no correlation with the knee valgus angle. There was, however, a strong negative correlation between hip abduction concentric strength and KV angle during SFL in females. The current study findings are consistent with the findings of previous studies, which mean the strength of hip abduction may help in stabilising the knee and consequently lessening ACL injury risk. McCurdy et al. (2014) found a negative correlation between the hip abduction strength and knee valgus angle. There is also no conflict with the findings of Jacobs and Mattacola (2005), who discovered a relationship between the strength of hip abduction and knee valgus angle during hopping task in females.

However, Hollman et al. (2009) found a positive correlation between the hip abduction strength and knee valgus during single leg step down in females. That indicates that increased hip abduction strength increases the knee valgus angle. Nedergaard, Dalbø, Petersen, Zebis, and Bencke (2019) identified a significantly higher peak knee valgus angle for side cut, SLL and single leg drop landing. The reason for the difference in the results of the previous studies and those of the current study may be due to differences in gender in addition to the functional tasks used.

In the present study, we revealed a positive correlation between the hip adduction and knee abduction angles. This means that when the angle of hip adduction increases, the knee abduction angle also increases. Previous studies are in line with the current findings, showing a correlation between hip adduction and knee valgus in females during landing tasks (Hollman et al., 2009; Z. A. Neamatallah, 2018). Therefore, this may indicate that the hip adduction angle may predict knee valgus injury. Another finding in this study was that there is no significant correlation between hip external strength and the angles of knee abduction and hip adduction during SLL. Suzuki et al. investigated the relationship between hip external strength and knee valgus in both genders for single leg medial drop landing. No significant correlations were found in males and females for peak knee valgus, whereas initial contact was insignificant for males only (Suzuki et al., 2015). Furthermore, Sigward, Ota, and Powers (2008) reported no correlation between hip external rotator strength and knee valgus during double leg landing in females.

Additionally, it was assumed that the knee extensor strength would affect the knee valgus and hip adduction angles during SLL, but no correlation was found between the variables. Munkh-Erdene et al. (2011) supported the findings of this study, as they also found no relationship between knee extensor strength and knee valgus in females. In addition, McCurdy et al. (2014) reported no correlation between eccentric knee extension and hip adduction and knee abduction in females during single leg jump from a box (30-cm height). The current study discovered a negative relationship between hip abductor strength and knee abduction and hip adduction angles. This suggests that hip abductors play an important role in reducing knee valgus and hip adduction angles. Therefore, stronger hip abductors provide dynamic knee stability during the landing task and lessen the risk of injury.

This study was not without limitations. The first limitation concerns the frontal plane assessment for the lower limb kinematics: ACL injury may occur with rotation in the hip and tibia, and this movement cannot be assessed from the frontal plane—it should involve the transverse plane. Consequently, it is better to include all the planes for the assessment of lower limb kinematics (frontal, sagittal and transverse). In addition, during sports activities, players are required to control knee displacement from multiple directional forces. The second limitation is that during the landing task, an ACL injury can occur not only in forward single leg landing but also in medial or lateral leg landing. Thus, it is more precise to involve medial and lateral landing in the method of assessment as well (Suzuki et al., 2015). The third limitation is the marker placement location—placing the markers directly onto the skin rather than on fixed plates may influence the results of the tasks (Manal, McClay, Stanhope, Richards, & Galinat, 2000). The fourth limitation is that all the participants in this study were male recreational athletes. Previous studies reported the activity skill level as a confounding factor for predicting ACL injury (Arendt & Dick, 1995; Harmon & Dick, 1998). The final limitation of this study is that there was no comparison between genders. Future studies should attempt to assess the kinetics and kinematics for lower limbs in multiple directions during landing tasks for both genders. Additionally, researchers should consider other factors that may influence kinematics during the task, such as core strength and ankle position.

Conclusions

This study investigated the relationship between the FPPA of the knee valgus with the muscle strength of the knee extensors, hip abductor, and hip external rotator during SLL. This study found a negative significant correlation between hip abductor strength and knee valgus during SLL. That means if the hip adduction angle increases, the knee valgus also increases, which might be a cause of injury in athletes. The findings of the current study emphasize the need to strengthen muscles related to hip and knee joints, especially the hip abductor muscles. This is because increasing hip strength plays an important role in reducing knee displacement during

sports activities. This may allow coaches, trainers and clinicians to discover the causes of injury and develop a strengthening programme that includes neuromuscular control to reduce the risk of injuries.

Conflicts of interest - There were no conflicts of interest.

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References:

- Arendt, E., & Dick, R. (1995). Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. *The American journal of sports medicine*, 23(6), 694-701.
- Bittencourt, N. F., Ocarino, J. M., Mendonça, L. D., Hewett, T. E., & Fonseca, S. T. (2012). Foot and hip contributions to high frontal plane knee projection angle in athletes: a classification and regression tree approach. *Journal of Orthopaedic & Sports Physical Therapy*, 42(12), 996-1004.
- Chamorro, C., Armijo-Olivo, S., De la Fuente, C., Fuentes, J., & Javier Chiroso, L. (2017). Absolute Reliability and Concurrent Validity of Hand Held Dynamometry and Isokinetic Dynamometry in the Hip, Knee and Ankle Joint: Systematic Review and Meta-analysis. *Open Med (Wars)*, 12, 359-375. doi: 10.1515/med-2017-0052
- Claiborne TL, Armstrong CW, Gandhi V. (2006) Relationship between hip and knee strength and knee valgus during a single leg squat. *Journal of Applied Biomech*, 22:41-50.
- Dwyer, M. K., Boudreau, S. N., Mattacola, C. G., Uhl, T. L., & Lattermann, C. (2010). Comparison of lower extremity kinematics and hip muscle activation during rehabilitation tasks between sexes. *Journal of athletic training*, 45(2), 181-190.
- Harmon, K. G., & Dick, R. (1998). The relationship of skill level to anterior cruciate ligament injury. *Clinical journal of sport medicine: official journal of the Canadian Academy of Sport Medicine*, 8(4), 260-265.
- Harty C.M., DuPont C.E., Chmielewski T.L., Mizner R.L. & Intertask. comparison of frontal plane knee position and moment in female athletes during three distinct movement tasks. *Scandinavian Journal of Medicine & Sciences in Sports*. 21: 98- 105
- Herrington, L. (2014). Knee valgus angle during single leg squat and landing in patellofemoral pain patients and controls. *Knee*, 21(2), 514-517.
- Hollman, J. H., Ginos, B. E., Kozuchowski, J., Vaughn, A. S., Krause, D. A., & Youdas, J. W. (2009). Relationships between knee valgus, hip-muscle strength, and hip-muscle recruitment during a single-limb step-down. *J Sport Rehabil*, 18(1), 104-117.
- Hootman, J. M., Dick, R., & Agel, J. (2007). Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *Journal of athletic training*, 42(2), 311.
- Huxel Bliven, K. C., & Anderson, B. E. (2013). Core stability training for injury prevention. *Sports health*, 5(6), 514-522.
- Imwalle, L. E., Myer, G. D., Ford, K. R., & Hewett, T. E. (2009). Relationship between hip and knee kinematics in athletic women during cutting maneuvers: a possible link to noncontact anterior cruciate ligament injury and prevention. *J Strength Cond Res*, 23(8), 2223-2230. doi: 10.1519/JSC.0b013e3181bc1a02
- Jacobs, C., & Mattacola, C. (2005). Sex differences in eccentric hip-abductor strength and knee-joint kinematics when landing from a jump. *J Sport Rehabil*, 14(4), 346-355.
- Kristianlund, E. & Krosshaug, T. (2013). Comparison of drop jumps and sport-specific sidestep cutting. *American Journal of Sports Medicine*, 41:684-688.
- Malloy, P., Neumann, D. A., & Kipp, K. (2019). Hip Biomechanics During a Single-Leg Squat: 5 Key Differences Between People With Femoroacetabular Impingement Syndrome and Those Without Hip Pain. *Journal of Orthopaedic & Sports Physical Therapy*, 49(12), 908-916.
- Manal, K., McClay, I., Stanhope, S., Richards, J., & Galinat, B. (2000). Comparison of surface mounted markers and attachment methods in estimating tibial rotations during walking: an in vivo study. *Gait Posture*, 11(1), 38-45.
- McCurdy, K., Walker, J., Armstrong, R., & Langford, G. (2014). Relationship between selected measures of strength and hip and knee excursion during unilateral and bilateral landings in women. *The Journal of Strength & Conditioning Research*, 28(9), 2429-2436.
- Neamatallah, Z., Herrington, L., & Jones, R. (2020). An investigation into the role of gluteal muscle strength and EMG activity in controlling HIP and knee motion during landing tasks. *Physical therapy in sport : official journal of the Association of Chartered Physiotherapists in Sports Medicine*. doi: 10.1016/j.ptsp.2019.12.008
- Neamatallah, Z. A. (2018). Do the gluteal muscles influence dynamic knee valgus when single-leg landing? : ProQuest Dissertations Publishing.

- Nedergaard, N. J., Dalbø, S., Petersen, S. V., Zebis, M. K., & Bencke, J. (2019). Biomechanical and neuromuscular comparison of single-and multi-planar jump tests and a side-cutting maneuver: Implications for ACL injury risk assessment. *Knee*.
- Noyes, F. R., Barber, S., & Mangine, R. (1990). Bone-patellar ligament-bone and fascia lata allografts for reconstruction of the anterior cruciate ligament. *The Journal of bone and joint surgery. American volume*, 72(8), 1125-1136.
- Sigward, S. M., Ota, S., & Powers, C. M. (2008). Predictors of frontal plane knee excursion during a drop land in young female soccer players. *Journal of Orthopaedic & Sports Physical Therapy*, 38(11), 661-667.
- Suzuki, H., Omori, G., Uematsu, D., Nishino, K., & Endo, N. (2015). The influence of hip strength on knee kinematics during a single-legged medial drop landing among competitive collegiate basketball players. *International Journal of Sports Physical Therapy*, 10(5), 592.
- Whatman, C., Hing, W. & Hume, P. (2011) Kinematics during lower extremity functional screening tests Are they reliable and related to jogging? *Physical Therapy In Sport*, 12(1): 22-29.
- Wild, C. Y., Steele, J. R., & Munro, B. J. (2013). Insufficient hamstring strength compromises landing technique in adolescent girls. *Medicine and science in sports and exercise*, 45(3), 497–505. <https://doi.org/10.1249/MSS.0b013e31827772f6>
- Willson, J. D., Ireland, M. L., & Davis, I. (2006). Core strength and lower extremity alignment during single leg squats. *Medicine and science in sports and exercise*, 38(5), 945–952. <https://doi.org/10.1249/01.mss.0000218140.05074.fa>