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Original Article

Influence of increasing knee flexion angle on knee-ankle varus stress during single-leg jump landing

Mariam A. Ameer, PhD * and Qassim I. Muaidi, PhD

Department of Physiotherapy, College of Applied Medical Sciences, Imam Abdulrahman Bin Faisal University (formerly University of Dammam), Al-Dammam, KSA

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الملخص

أهداف البحث: يهدف البحث إلى تحديد العلاقة بين أعلى زاوية لثني الركبة والضغط الفحجي لمفصلي الركبة والكاحل في مرحلة الهبوط من القفزعلى قدم واحدة أثناء الجري.

طرق البحث: أدرج ١٥ لاعبا من لاعبي كرة اليد من الفريق السعودي الأول لكرة اليد في هذه الدراسة. حيث أدى كل لاعب الهبوط من القفز علي قدم واحدة بعد الجري مسافة محددة مقدارها ٤٥٠ سم. وقيست البيانات باستخدام جهاز تحليل الحركة ثلاثي الأبعاد. كما قيست أقصى زاوية لثني مفصل الركبة، وزاوية فحج الركبة، ومركز مسار الضغط في الإتجاه المتوسط-من الإنسي للوحشي ولحظة فحج الكاحل.

النتائج: أظهر منتج بيرسون لحظة الارتباط أن زيادة زاوية ثني مفصل الركبة كان مرتبطا ارتباطا أكبر بالنزوح الجانبي لمركز الضغط، وأكبر لحظة فحج للكاحل، وأكبر لحظة فحج للركبة. إضافة إلى ذلك، كانت زيادة لحظة فحج الكاحل مرتبطة بزيادة النزوح الجانبي لمركز الضغط.

الاستنتاجات: يمكن أن تساعد هذه النتائج العاملين بالعلاج الطبيعي والمعالجين المهنيين لمعرفة تأثير زيادة زاوية ثني مفصل الركبة على مفاصل الطرف السفلي. كما يمكن أن تسهم هذه النتائج في تطوير بروتوكولات التدريب لتعزيز رد الفعل الجانبي للجسم أثناء مرحلة الهبوط للحفاظ على مفصلي الركبة والكاحل من فرط الإجهاد الفحجي.

الكلمات الافتتاحية: حركة الكاحل؛ مركز مسار الضغط؛ حركة الركبة؛ القفز على قدم واحدة؛ جهاز تحليل الحركة الثلاثي الأبعاد؛ لعبة كرة اليد

Abstract

Objectives: The primary aim of this study was to identify the relationship between the peak knee flexion angle and knee-ankle varus stress in the landing phase of the single-leg jump during running.

Methods: Fifteen male handball players from the first Saudi Arabian handball team were incorporated in this study. Each player performed a single-leg jump-land after running a fixed distance of 450 cm. The data were measured using a 3D motion analysis system. The maximum knee flexion angle, knee varus angle, centre of pressure pathway in the medio-lateral direction, and ankle varus moment were measured.

Results: The Pearson Product Moment Correlation showed that a greater knee flexion angle was related to a greater lateral displacement of the centre of pressure ($r = 0.794$, $P = 0.000$), a greater ankle varus moment ($r = 0.707$, $P = 0.003$), and a greater knee varus angle ($r = 0.753$, $P = 0.001$). In addition, the greater ankle varus moment was related to the greater lateral displacement of the centre of pressure ($r = 0.734$, $P = 0.002$).

Conclusions: These findings may help physical therapists and conditioning professionals to understand the impact of increasing knee flexion angle on the lower limb joints. Such findings may help to develop training protocols for enhancing the lateral body reaction during the landing phase of the single-leg jump, which may protect the knee and ankle joints from excessive varus stresses.

Keywords: 3D motion analysis; Ankle kinetic; Centre of pressure pathway; Handball playing; Knee kinematic; Single-leg jump

* Corresponding address: Department of Physical Therapy, College of Applied Medical Sciences, Imam Abdulrahman Bin Faisal University, Al-Dammam, KSA.

E-mail: Mariam_ameer7@hotmail.com (M.A. Ameer)

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Introduction

Single-leg jump-landing during running is a stressful task frequently performed in handball. Knee and ankle stresses most frequently occur during the knee flexion in the landing phase of the single-leg jump.[1] This type of activity requires large force attenuation through neuromuscular control to protect the joints of the lower extremities from different stresses.[2] One primary risk factor for the knee-ankle stress is the change of the ground reaction force (GRF) position around the knee and ankle joint.[3–6] The position of the GRF around any lower extremity joint can be detected by the centre of pressure location (COP), which is a point of location for the GRF vector.[7] Understanding the position and movement of the COP in relation to the joint axis is useful in detecting joint pathomechanics.

A study performed by Jamshidi et al.[8] showed the importance of detecting the COP trajectory in steppage gait over time for designing a better shoe and orthotic device that relieves stress from the joints of the lower limb in patients affected with drop foot. Several other studies[9–11] described the ability of the body to maintain its centre of gravity over its base of support for different activities, such as during the stance phase of walking or standing in a single-leg stance. These studies confirmed that the foot tends to pronate and supinate and may be exposed to varus and valgus stresses by the movement of the COP. The ankle joint is maintained in a neutral position by the postural control “ankle strategy” (the pronation and supination of the foot to maintain the body center of gravity over the base of support). Pintsaar et al.[12] showed that the length and velocity of the COP movements are the common signs of postural control during single-leg standing. Shorter and slower COP movements are associated with lesser postural control, which has been determined by other studies.[13–15]

In addition to the GRF and COP pathways, another factor influencing ankle injuries in sports is the proprioception of muscles. Isakov and Mizrahi[13] investigated subjects with uninjured ankles and subjects with recurrent ankle sprains. The importance of the proprioceptive feedback of the muscles was detected with and without visual input. The results of the study showed no difference in postural sway between the healthy subjects and the subjects with chronic ankle sprains. However, standing with closed eyes, regardless of the ankle status, always produced significantly higher reaction forces than standing with open eyes. This finding explains the importance of the proprioceptor feedback of muscles in the absence of visual input. Han et al.[16] showed that the proprioception of muscles plays an important role in joint balance control related to the COP and the effect of a changeable GRF, especially on a sports field. According to a study by Riva et al.,[17] ankle stresses that occur during a single-leg stance could be reduced by improving the neuromuscular and joint proprioceptive control. For example, the action of the peroneal muscle during landing activity helps to resist ankle inversion. If the peroneal muscle action is slow to accommodate the inversion stress of the ankle, an injury can easily occur. This finding is consistent with the results of other studies.[18,19]

Previous studies have mainly focused on the drop–jump activity of both lower limbs,[20–24] while several studies evaluated the knee position and anterior cruciate ligament (ACL) injuries in the sagittal plane.[25–31] There are a limited number of studies evaluating the single-leg jump activity during running in the frontal plane. This type of evaluation is for the detection of the varus stresses on the lower extremity joints, and it represents the real activity of players on the sports field. Moreover, there is a lack of literature regarding the ankle position in the frontal plane during single-leg jumping. Therefore, there is a need to study muscle movement around the most commonly injured and complex joints during single-leg landing with different knee flexion angles in the frontal plane. Additionally, the gender of athletes is an area of interest, as Renstrom et al.[1] stated that female handball athletes had higher injury incidence rates than did their male counterparts. While several studies have been performed with female handball players,[32,33] studies with male handball players are lacking.

The purpose of this study was to examine the relationships among peak knee flexion angle, knee varus angle, ankle varus stress, and the COP pathway in the medio-lateral direction (COPy) in the single-leg jump during running. Using the acquired data, we wanted to determine the relationship between the different knee flexion angles and the frontal plane knee-ankle varus stress during the landing phase of single-leg jumping in male handball players. We hypothesized that increasing the knee flexion angle during single-leg landing will increase the knee-ankle varus stress by increasing the movement of the COP laterally.

Materials and Methods

Participants

Fifteen healthy adult male handball players were randomly selected from the 2015 first Saudi handball team. The participants' demographic data are presented in Table 1. All participants were competent and active in regular sports activities. Subjects with a history of advanced knee or ankle injuries or subjects diagnosed with structurally unstable knees or ankles were excluded from the study. All participants had the same level of sports experience and participated in the same sports competitions. The subjects were asked to sign a consent form approved by the ethical committee of the University of Dammam.

Table 1: Mean (SD)* of participants' demographic data.

Parameters	Mean ± SD
Age(y)	22.6 (3.5)
Height (m)	182 (3.7)
Weight (kg)	87.5 (10.2)

*SD, Standard deviation.

Study design

A cross-sectionally designed study was conducted to detect the relationships among the variables of interest, such as the peak knee flexion angle, knee varus angle, ankle varus moment, and the COPy. Data were collected using the dominant lower extremity (preferred leg for kicking the ball). Each participant performed a single-leg jump-land on a force plate from running a fixed distance. Three successful trials were performed by each participant. The data of three trials were collected in the same session by the same investigator.

Instrumentation

A three-dimensional motion analysis system (VICON; 10 Bonita cameras) at 250 frames/second and two force plate platforms (AMTI Model OR6, Advanced Mechanical Technology Inc., Watertown, MA, USA), 46 cm × 50 cm, embedded in the middle of the running pathway, sampled at 1000 Hz, were used to measure knee kinematics (peak knee flexion angle and knee varus angle), ankle joint kinetics (ankle varus moment), and the COPy. Prior to data collection of each session, the system calibration was performed and the volume origin of the lab was set by using the T-shaped Wand Marker. The 16 markers, lower body plug-in gait model was used in a certain arrangement on the participants' lower extremities. The retro-reflective markers were held on the body's landmarks by double-sided adhesive straps (adhesive tape, QTY5). The Vicon Nexus software (2.3) and Polygon software (3.5) were used to capture and analyse the required data.

Procedures

The study was performed by one investigator under repeatable conditions in the biomechanics laboratory of the University of Dammam, KSA. The primary aim of this study was explained to each subject prior to participation in the study. Each participant warmed up for the exercise by running on a treadmill for at least 15 min. Each participant wore clothes suitable for motion capturing. Sixteen retro-reflective markers were attached to both lower limbs of each participant by double-sided adhesive straps in the following order: two markers were placed on the right and left anterior superior iliac spine, two markers were placed on the right and left posterior superior iliac spine, one marker was placed on the lower one-third of the left thigh, one marker was placed on the upper one-third of the right thigh, two markers were placed on the left and right lateral surface of the knee, two markers were placed on the upper and lower one-third of the left and right lateral surface of the tibia respectively, two markers were placed on both the right and left lateral malleolus, two markers were placed on the right and left heels, and two markers were placed on the right and left head of second metatarsals. Each participant stood in the T-shape position (Figure 1a) for measuring the static reference trial. Each participant then ran a fixed distance approximately 450 cm before jumping with both lower limbs and landing with a single leg (dominant leg) on the force plate, which was located on the running pathway.

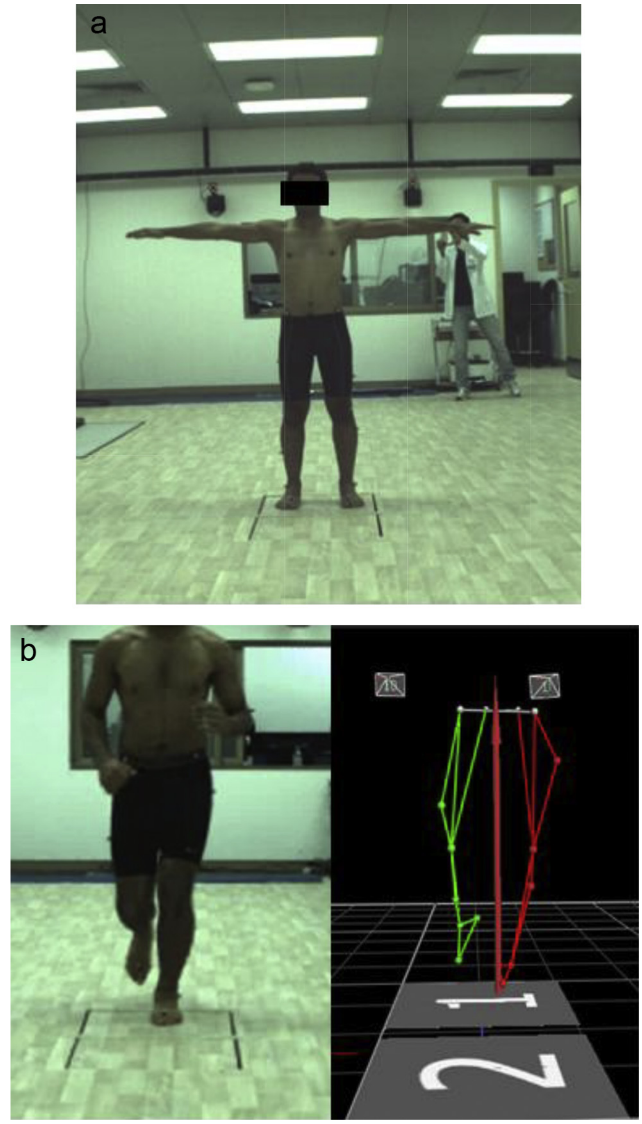

Figure 1: Starting, running, and landing phases. a) Starting T-shape position. b) Running and Landing Phase.

The participants maintained the position of landing on the dominant leg with maximum knee flexion for a three second duration. The participants were instructed to keep their hands as much close to the body as possible to prevent moment variability around lower extremity joints (Figure 1b). To prevent any data variability due to different shoe types, each player performed three trials while barefoot. The kinetic data were synchronized with kinematic data and processed at 1000 Hz by using Nexus 2.3. All of the variables of interest were normalized to body mass (in kilograms).

Statistical analysis

The data were analysed by using SPSS version 20. Descriptive analysis was performed to obtain the mean and standard deviation for all the variables of interest. The

Pearson Product Moment Correlation was used to examine the relationships between the variables of the study. The level of significance was set at $P < 0.01$, as obtained from the SPSS software.

Results

The homogeneity of the sample was confirmed by Shapiro–Wilk test ($P > 0.05$) and the single session (between trials) reliability test (ICC) of the variables of interest was between .89 and .91. Descriptive analysis for all variables shown in Table 2.

The Pearson Product Moment Correlation matrix between the variables of interest are shown in Table 3. All variables were highly correlated at the time of peak knee flexion angle. The results show a relatively high positive correlation between the peak knee flexion angle and the ankle varus moment ($r = 0.707$, $P = 0.003$). In addition, a high positive correlation was detected between the peak knee flexion angle and the knee varus angle ($r = 0.753$, $P = 0.001$). Additionally, the COPy pathway towards the lateral direction showed a strong positive correlation with the peak knee flexion angle ($r = 0.794$, $P = 0.000$). In addition, a strong positive correlation was observed between the ankle varus moment and the COPy pathway towards the lateral direction ($r = 0.734$, $P = 0.002$). The scatterplots for the relationships among the peak knee flexion angle, the ankle varus moment, the knee varus angle, and the COPy are presented in Figures 2–5, respectively.

Discussion

The purpose of this study was to investigate the relationships between the peak knee flexion angle and the knee ankle varus stresses and to confirm these relationships by determining the COP pathway in relation to these joints with the increase in the knee flexion angle. The results of this study show strong correlations among all of the variables of interest, which indicates that the increase of the knee flexion angle during the landing phase of single-leg jump leads to excessive movement of the COP towards the lateral side of the foot. This greater lateral displacement of the COP tends to increase the varus stress on the ankle and knee joints (Figures 6 and 7). The increase of the ankle varus moment creates a greater stress on the ankle's lateral side during the landing phase of the single-leg jump and may contribute to the development of a lateral ankle sprain. Additionally, the increasing knee flexion angle may result in the subject's attempting to approximate the non-weight bearing limb from the supported limb to maintain the body's stability. This may occur as a result of an increase in the hip adduction of the weight bearing limb and a drop of the pelvis on the non-weight bearing side. However, with a further increase in the knee flexion angle (greater than 80 degrees of knee flexion), the participant may shift the body laterally to decrease the knee ankle varus stress. This body shift is a protective mechanism. The lateral shifting of the body during the landing phase of single-leg jumping may be a technique that protects the lateral knee-ankle ligaments from excessive stress.

Table 2: Means (SD) for each variable at maximum knee flexion angle.

Variables	Mean ± SD
Peak knee flexion angle, °	59.87 ± 39.37
Normalized ankle varus moment, Nmm/kg	219.59 ± 54.55
Knee varus angle, °	16.94 ± 12.74
COPy, mm	48.092 ± 3.94

*SD, Standard deviation.

Table 3: Pearson product moment correlation matrix among the variables of interest.

	Ankle varus moment	Knee varus angle	COPy
Peak knee flexion angle	r = 0.707, P = 0.003	r = 0.753, P = 0.001	r = 0.794, P = 0.000
Ankle varus moment	–	r = 0.811, P = 0.000	r = 0.734, P = 0.002
Knee varus angle	r = 0.811, P = 0.000	–	r = 0.809, P = 0.000
COPy	r = 0.734, P = 0.000	r = 0.809, P = 0.000	–

*COPy; centre of pressure in medio-lateral direction, $P < 0.01$.

The correlations in this research are confirmed by the results of other research studies that revealed that the frontal plane of motion of the pelvis and trunk could influence the moment of the lower extremity joints during the single-leg jumping. With the pelvis level, the resultant GRF vector (GRFV) passes medial to the joints of the lower limb, which results in varus stress. The drop of the pelvis shifts the GRFV more medial to the joints, which increases the varus stress. However, shifting the body over the standing limb can create the valgus stress on knee and ankle joints or maintain the ankle in a neutral position (Figure 8) (Powers, 2010).[34]

A study performed by Hung et al.[35] suggested that the measurement of the COP movement during the landing of single-leg jumping activity was a better way to evaluate the stability of different joints in the body. Patients with ankle instability showed greater variability in the medial-lateral displacement of the COP than healthy patients. Another study by King and Zatsiorsky[36] stated that a decreased maximum ankle inversion may help the center of mass (COM) align with the COP in an appropriate manner in the medial-lateral direction, and may also decrease the COP sway in the medial-lateral direction. These extreme foot inversion-eversions were characterized by large medial-lateral displacements of the gravity line, COP, and large horizontal forces.

Russell et al.[37] showed that on initial contact, women landed in valgus ($-0.651 \pm 3.32°$), and men landed in varus ($3.85 \pm 4.03°$) ($P < .25$) (Figure 9). At the maximum knee flexion (MKF), men reached a greater varus position ($15.26 \pm 9.41°$) than women ($3.13 \pm 6.84°$) ($P < .025$) (Figure 8). Additionally, these authors confirmed that an increase of knee varus angle of male subjects during the landing of stop-jump tasks may increase the incidence of different knee injuries such as the lateral collateral ligament (LCL) injury. As the knee varus increases, the medial lever

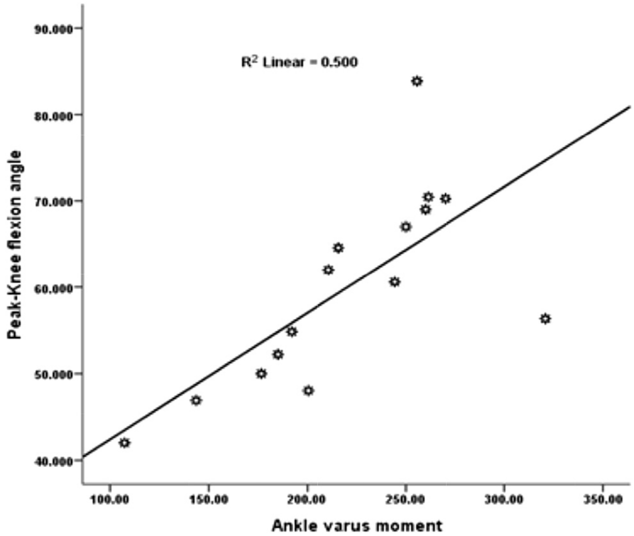

Figure 2: Scatterplot demonstrating the relationship between maximum knee flexion angle and ankle varus moment (N·mm/kg).

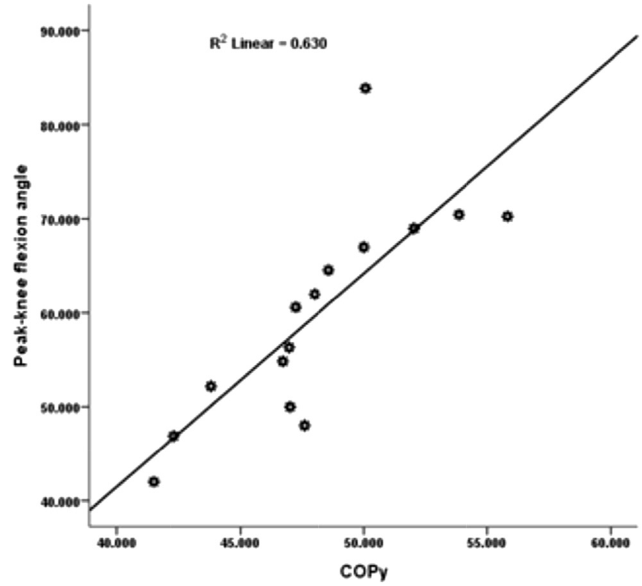

Figure 4: Scatterplot demonstrating the relationship between maximum knee flexion angle and centre of pressure maximum displacement (mm) towards the lateral direction.

arm increases, which requires an increased lateral reaction to prevent the joint from opening.

According to a study by Hewett et al.,[38] women landed with larger valgus knee angles and showed higher adduction loads at the knee joint than their male counterparts. Thus, women are more likely to obtain ACL injuries than men, while men are more likely to obtain a lateral ankle ligament sprain.[38] High-risk manoeuvres such as sudden deceleration while cutting or pivoting and landing from a jump are linked with LCL injuries of the knee and lateral ankle sprain. The landing on a single limb is one of the most common ACL, LCL, and lateral ankle injury mechanisms and thus deserves considerable attention.[29]

The findings of this research explain the fault technique of single-leg jumping. The results also suggest a landing mechanism to protect the ACL and LCL of the knee and ankle joints by enhancing the lateral leaning reaction of the body during the landing phase of single-leg jump. This effect shifts the GRF laterally and decreases the knee-ankle varus stress. Balance training can increase the stability control of the body during the single-leg jump activity.

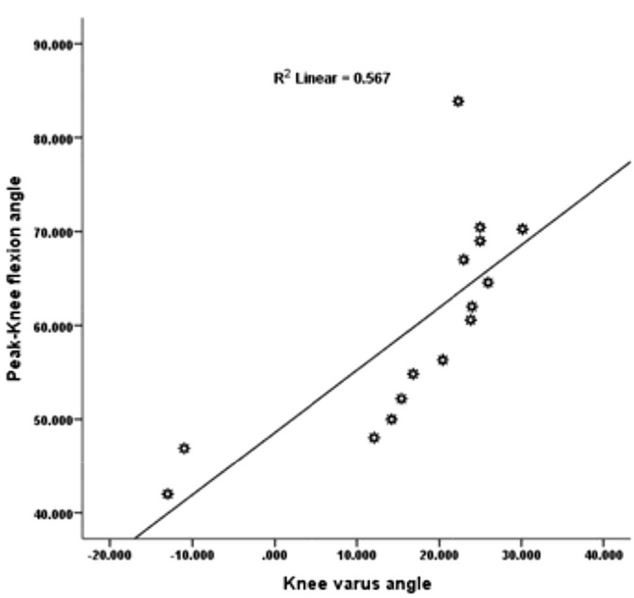

Figure 3: Scatterplot demonstrating the relationship between maximum knee flexion angle and knee varus angle (°).

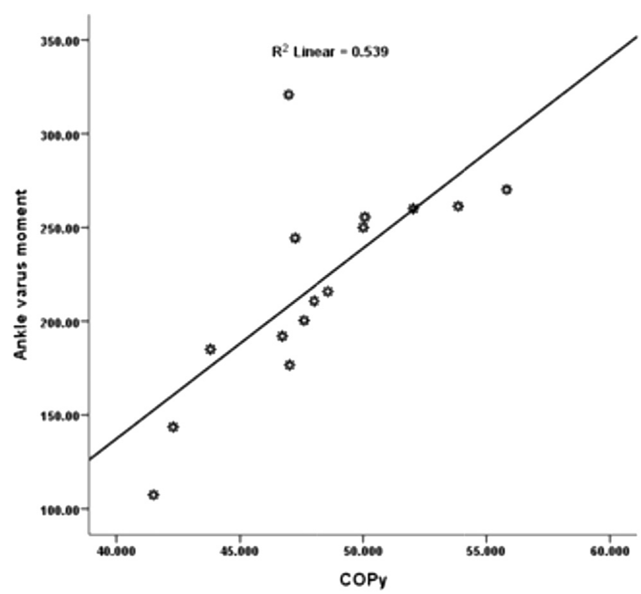

Figure 5: Scatterplot demonstrating the relationship between ankle varus moment and centre of pressure maximum displacement (mm) towards lateral direction.

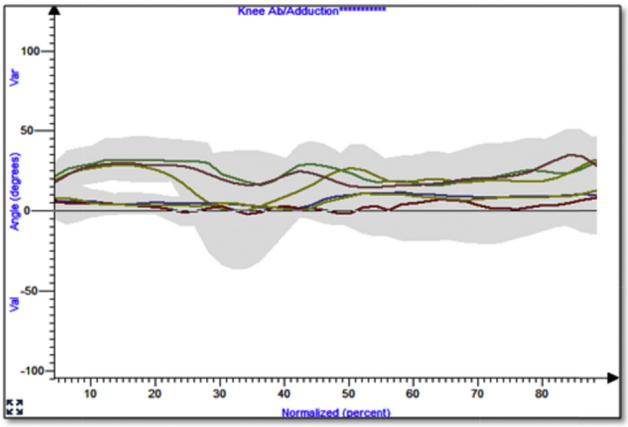

Figure 6: Knee varus angle along the landing phase.

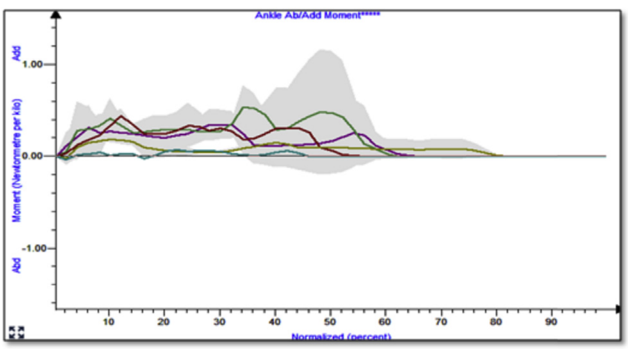

Figure 7: Ankle varus moment along the landing phase.

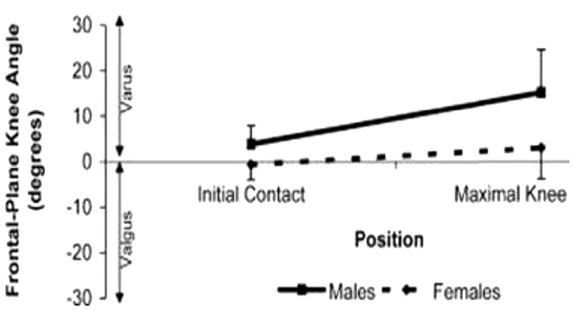

Figure 8: Frontal-plane movement of pelvis and GRFV during the single leg jumping (Powers, 2010).

Study recommendations

For future studies, we recommended increasing the number of samples to substantiate the results of this study. Comparing the data from healthy players with the data from non-healthy players (with knee or ankle injuries) may be of interest, and a future research on this subject may help determine the change of the normal body's reaction in the frontal plane to an increase in the knee flexion angle during the landing phase. In addition, we recommend using electromyography to detect the muscle electrical activities during the landing phase of the single-leg jump.

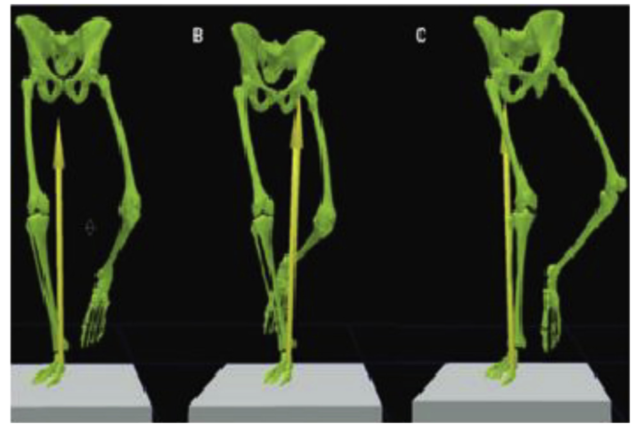

Figure 9: Frontal-plane knee joint angles at (IC) and (MKF) for women and men (Russell et al., 2006).

Conclusion

During a single-leg landing, the increase of the knee flexion angle results in the shifting of the COP laterally. The medial lever arm of the GRF increases, which also increases the knee varus angle and the ankle varus moment. Greater ankle varus moment causes greater stress on the muscles and ligament at the lateral side of the ankle. With a greater degree of knee flexion, the participants in this study tend to perform a protective reaction during the single-leg landing, in which the knee moves inward, and the body shifts laterally. This landing strategy may be an important consideration in developing a knee-ankle LCL injury prevention programme for subjects and athletes engaged in single leg jumping and landing activities.

Authors' contribution

MAA has conceived and designed the study, collected the literature, defined the scientific gaps to be addressed in the study, set the objectives, designed the methodology, conducted the research, collected and organized data, and prepared the initial draft of the paper. QIM has arranged all the participants, facilitated the experimental setup, supervised the work, and checked and finalized the results, analysis, discussion and the manuscript draft. All authors have critically reviewed and approved the final draft, and they are responsible for the contents and similarity index of the manuscript.

Conflict of interest

The authors have no conflict of interest to declare.

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