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# Effect of Body Balance on Knee Valgus Angle during Single-Leg Squat and Horizontal Hop Landing in Controls

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Sway area; time to stabilization; knee valgus; hop tests; single-leg squat.

**ABSTRACT**

The mechanisms of the lower limb altered mechanics are still not clearly understood, however, lower limb mechanics and the increase of knee valgus on loaded tasks are believed to play an important role in the development of knee disorders, and this could be affected by body balance after landing from a hop or squatting task. The aim of this study was to figure out if balance tasks including time to stabilization and sway area would have an effect on knee valgus angle during single-leg squat and single-leg horizontal hop for distance tasks in healthy participants. This study also investigated if there are differences found between the dominant and non-dominant limbs in all tests. Twenty-eight recreationally male athletes were participated in the study. The measurements of their performance during all tests were taken for both legs individually. The participants were asked to participate in two different tests, the first test was the balance test which include three different tests, two static tests to measure the sway area and one dynamic test to measure TTS. The second test was to examine knee valgus angle from two different tasks (single-leg squat and single-leg horizontal hop landing). The non-dominant leg had significantly greater knee valgus angles and lower balance performance than the dominant leg in all tasks. No significant correlations were found between balance and knee valgus tests in all tasks ($P \geq 0.05$). However, there are significant differences found between the dominant and non-dominant limbs for all tests ($P \leq 0.05$). No correlations were found between balance performance and knee valgus angle. Differences were found between the dominant and non-dominant limbs, the dominant had better outcome measures in all tests. More attention should be considered for the non-dominant limb during rehabilitation to balance its performance with the dominant.



## 1. INTRODUCTION

Injuries to the knee and ankle are common in athletes and are most seen in cutting and jumping sporting tasks such as volleyball, football, and basketball [1], [2]. Although these injuries are usually occurred as a result of direct contact, non-contact episodes such as landing from a jump also seen frequently [1], [2]. [2] for example found that 58% of all injuries in female basketball players happened during landing from a jump. Similarly, [1] reported that 63% of all injuries were associated with jump landing tasks during volleyball competition, totaling 61% of knee injuries. Proper landing from a jump requires stability, strength, and balance, which are also seems critical to prevent lower limb injuries. Therefore, it is possible that the rate of injuries mentioned above was a result of impaired stability or strength deficits.

Neuromuscular control plays a main role in dynamic joint stability and the body's inherent prevention from injury [3- 5]. Time to stabilization (TTS) is a measure of neuromuscular control that integrates both sensory and mechanical systems to control the complex of a jump landing task [6]. Moreover, TTS can be considered as a more functional task that is used currently to measure postural stability [6].

Poor limb alignment, especially an increased knee valgus during single-leg squat and single-leg hop landing has been correlated with patellofemoral pain (PFP) [7]. Patellofemoral pain is one of the most common dysfunctions and disorders of the lower extremities, mainly affecting young physically active female athletes [8]. The presence of PFP usually limits participation in sporting activities [9]. This disorder has been reported to develop of patellofemoral osteoarthritis [8], [10]. As the patella passes through the trochlear groove, it has been thought that abnormalities in lower limb biomechanics are claimed to negatively affect the alignment of the patella [11]. [11] reported that PFP patients had increased lateral patellar subluxation and tilting during squatting with the neutral aligned position knee. [12] found a significant relationship between lateral patella translation and knee abduction and external rotation when asymptomatic participants squatted with knees aligned in a valgus or neutral position. Abnormal distribution of the stresses on the patellofemoral joint will happen when the load-bearing surface areas are changed, with different patellar tracking [13]. This abnormal distribution of stresses is believed to have a strong relationship with patellar dysfunctions, such as osteoarthritis and chondromalacia [14]. [15] found that increased lateral patellar tilt being correlated with both increased stress on loading and decreased medial and lateral patella facet cartilage volumes. [7] reported that patients with PFP showed significant greater knee valgus angle on the affected limb during loading tasks than that reported in either their sound limb or in the asymptomatic control group. Therefore, the mechanisms of the lower limb altered mechanics are still not clearly understood, however, lower limb mechanics and the increase of knee valgus on loaded tasks are believed to play an important role in the development of knee disorders [16], and this could be affected by body balance or impaired stability during loaded tasks such as squatting and landing from a hop. However, this relationship between the body balance and knee valgus angle has still not yet been investigated. Therefore, the aim of this study being to found if balance tasks including time to stabilization and sway area would have an effect on knee valgus angle during single-leg squat and single-leg horizontal hop for distance tasks in healthy participants. Moreover, this study investigated if there are differences found between the dominant and non-dominant limb in all tasks.

## 2. Materials and Methods

### *2.1 Experimental subjects*

Twenty-eight healthy male participants (mean age 31.4 ± 4.3 year, range 21–38 year, height mean 174 ± 3.9 cm, range 167–181 cm, and weight mean 78.4 ± 6.1 kg, range 67.5–89.5 kg) were recruited from sport clubs throughout official invitations and distributed posters. All participants were recreationally athletes participated at least 3 hours of sporting activity per week. A written informed consent was obtained from all subjects and the project was approved by the University of Najran Research Ethics Committee with approval number (10 – 05 -02 – 2020 EC).

### *2.2 Procedures*

For each participant, the measurements of their performance during all tests were taken for both legs individually (the dominant and non-dominant limbs), the dominant limb was known as the limb that is used to kick the ball. The participants were asked to remove any clothes that restricted their lower limbs movement such as socks, jeans, or tight trousers, and were also be asked to wear loose shorts to allow the placed markers to be clear during filming the tasks. For all the mentioned tests there were practice trials (from three to five trials maximum), to make sure that the participants become familiar with the tests. Three successful trials for each test were recorded from each subject, then the mean value over the three trials was calculated and reported for data analysis.

#### *2.2.1 Balance Tests*

These tests were performed using a portable Kistler Force Plate, 600 mm x 400 mm, Type 9286AA (Kistler, Winterthur, Switzerland) which is interfaced with a laptop computer with force time data collected using Bioware software. There were three different balance tests, two static tests to measure the sway area and one dynamic test to measure TTS. Bioware software was downloaded to a laptop which was connected to the force plate; this software was set by the researcher for the two different methods. For the static tests (sway area), the duration force-time data was collected for 10-s at a frequency of 50 Hz. For the dynamic test (TTS), the duration force-time data was collected for 6-s at a frequency of 1000 Hz. The detailed procedures of the three tests are explained below.

##### *2.2.1.1 Straight Leg Static Balance Test (Sway Area)*

Static balance was measured during standing in a straight leg position on the force plate on one leg and remaining as motionless as possible for 10-s until the participant is instructed to relax. Participants kept their eyes open, hands on hips and the non-weight bearing leg was slightly flexed at the hip and knee. The foot position is placed in a neutral position pointed straight forwards.

##### *2.2.1.2 Flexed Leg Static Balance Test (Sway Area)*

For this test, the procedure was the same as explained above, but the knee angle for the tested leg was in a flexed position at approximately 30° using a goniometer. The rationale for using 30° of knee flexion is because it has been reported that strain in the anterior cruciate ligament (ACL) during simultaneous hamstring and quadriceps activity is significantly high from full extension to 30° of flexion [17]. Static balance was measured during standing in a flexed leg position on the force plate on one leg and the participants remained as motionless as possible for 10-s until they are instructed to relax. Participants kept their eyes open and hands on hips, and the non-weight bearing leg was slightly flexed at the hip and knee. The foot position is placed in a neutral position pointed straight forward.

##### *2.2.1.3 Dynamic Balance Test (TTS)*

The participants applied a single-leg horizontal hop for distance test, the maximum (furthest) distance of the three trials was reported. Then 80% of the maximum hop distance value was calculated and recorded to be used as a distance hop from the starting point of the test to the middle point of the force plate. The rationale for using 80% as a test distance is to ensure that each participant was able to land and maintain their balance with their foot completely on the force plate; 80% of maximum distance is difficult and challenging but still achievable. Colored tape was used to mark the starting point for the hop-land trials after calculations. Finally, the participants hopped from the starting point and land on the force plate with one leg and remain as motionless as possible for 6-s until instructed to relax. After landing, they kept their eyes open and the non-weight-bearing leg slightly flexed at the hip and knee. The participants were free to move their arms as required to help in balancing following landing; once completely stabilized hands placed on hips.

Unsuccessful attempts were when the participants hopped and touched the ground with their non-weight bearing leg during landing or failed to hop with a proper distance.

### *2.2.2 Frontal Plane Projection Angle (Video Capture)*

The frontal plane projection angle (FPPA) was assessed using a camera, set at a standard sampling frequency of 30 fps, positioned on a tripod at a height of 80cm from the floor to the middle of the lens, and 2.5m away from an X-shaped marker which was placed as a reference for the central point on the floor. The zoom lens of the video camera was set at a standard 1x optical zoom throughout all trials in order to standardize the camera position between participants. The reason behind placing the camera on a tripod at a height of 80cm and 2.5m away is to ensure that the video included the lower limbs, trunk, and shoulders of the participants with different heights. Each participant was filmed, before starting any of the individual tests, using a calibration frame (1m ×1m) for 5-s. The calibration distance was set 2.5m away from a camera (frontal plane) just above the X mark which was placed on the floor. This calibration was used for data analysis.

In order to examine the FPPA, three markers were placed directly on the participants' skin before starting the test using a black marker on the following points:

1. Anterior superior iliac spine (ASIS).
2. Midpoint of the knee joint (midpoint of the medial and lateral femoral epicondyles).
3. The middle of the ankle mortise anatomical landmark.

All markers were placed by the same experimenter, and the midpoints were determined using a standard tape measure. The analysis of the FPPA was undertaken in Quintic Biomechanics Software (v21, Quintic, Sutton Coldfield, UK) where FPPA was taken at the maximum knee flexion angle after landing from hop and squat (defined as the lowest point the pelvis reached).

#### *2.2.2.1 Single-Leg Squat Task*

Participants were instructed to stand on one leg, keep the other limb off the floor, with hands crossed behind their trunk in order to allow all markers to be visible. They were asked to squat down to 45° (estimated visually) but not greater than 60°, and then return to a normal position without losing their balance. During practice trials, knee flexion angle was checked using a standard goniometer (Gaiam-Pro) then observed by the examiner throughout all trials. There was an electronic counter used for each trial over 5-s period in which the first count starts the movement, the third shows the lowest point of the squat and the fifth shows the end. In order to control the degree of lower limb rotation during squatting, the participants were instructed to place their foot on the X-shaped marker, which is placed on the floor, with their foot pointing straight ahead. Acceptable trials were when participants maintained balance and squatted to the desired depth of approximately 45° of the knee joint.

#### *2.2.2.2 Single-Leg Horizontal Hop Landing Task*

The FPPA in this test was assessed during the single-leg horizontal hop for distance task. Participants were asked to perform a unilateral horizontal hop landing task as far as possible, and land with complete stabilization within the area of the X-shaped marker which was placed on the floor 2.5m far away from a camera (the hop was applied after adjusting the starting point). The participants hopped to the X-shaped marker (or nearby) from a starting point based on their individual hop distance achieved during the practice trials, to ensure that the landing was at a point ± 30 cm from the X-shaped marker, to accommodate the calibration.

After landing, the participants were free to move their arms as required and to help with balance following landing. Unsuccessful attempts were when the participant hopped and touched the ground with their non-weight bearing leg during landing, or failed to hop within the limited marked distance. The participants landed with their foot in line with the camera to ensure that the appropriate calculation of the FPPA was achieved. If the individual landed with their foot too abducted or adducted this trial was repeated as this will affect the measurement of the FPPA.

### *2.3 Data analysis*

All statistical analysis was conducted using SPSS for Windows version 25 (SPSS Inc., Chicago, IL). All data were tested for normality using a Shapiro-Wilk test to check whether the data were normally distributed or not (parametric or non-parametric); values were not normally distributed if they were equal to or less than ≤ 0.05. However, all the data was tested for normality and it was normally distributed. The mean value of the three measures (trials) for each test was calculated and then used to find correlations and differences. Pearson's correlation coefficient (r) was used for parametric data to explore the relationships between balance tests and knee valgus angle during single-leg squat and single-leg horizontal hop for distance tasks. Moreover, paired t-tests were used to evaluate specific differences between the dominant and non-dominant limbs with the Bonferroni correction ($\alpha = 0.0125$). The significance p-value was set at 0.05

## 3. Results

The mean, standard deviation, and the range of the values for balance tests which include the straight leg static balance test ($cm^2$), flexed leg static balance test ($cm^2$), and dynamic balance test (sec) for both limbs (the dominant and non-dominant) were as shown in Table 1, and for the knee valgus angle tests (˚) during both tasks (the single-leg squat and single-leg horizontal hop for distance) were as shown in Table 2.

The current study showed that the non-dominant leg had significantly greater knee valgus angles and lower balance performance (greater sway area in $cm^2$ and time to stabilization) than the dominant leg during all tasks (the dominant had better outcome measures than the non-dominant) as shown in Tables 1 and 2.

No significant correlations were found between balance tasks (sway area and time to stabilization) and knee valgus angle during single-leg squat and single-leg horizontal hop for distance tasks using Pearson's correlation coefficient for both the dominant and non-dominant limbs as shown in Tables 3 and 4.

It was found that there are differences between the dominant and non-dominant limbs using paired t-tests for the knee valgus angle tests during squatting ($P = 0.0001$, with the mean $-1.1 \pm 0.86$), and in the horizontal hop for distance tasks ($P = 0.0002$, with the mean $-1.2 \pm 1.06$). Moreover, similar differences were noted between the dominant and non-dominant limbs for balance tests in sway area with extended leg ($P = 0.0001$, with the mean $-0.063 \pm 0.07$), in sway area with bent knees 30˚ ($P = 0.0002$, with the mean $- 0.071 \pm 0.05$), and in time to stabilization tests ($P = 0.0001$, with the mean $-0.021 \pm 0.02$).

## 4. Discussion

The aim of this study was to investigate if balance tests including time to stabilization and sway area would have an effect on knee valgus angle during single-leg squat and single-leg horizontal hop for distance tasks in healthy participants. The additional aim was to investigate if there are differences between the dominant and non-dominant limbs during all tasks.

The current study showed that participants with non-dominant legs had significantly greater knee valgus angles and lower balance performance (greater sway area in cm2 and time to stabilization) than their dominant legs in all tasks, indicating that more control and better performance is found in the dominant limb. Some studies have reported similar findings between the dominant and non-dominant limbs but in different tasks, they found that the performance of a single-leg vertical hop from a standing position was significantly higher in the dominant leg than in the non-dominant leg [18,19]. Moreover, a similar phenomenon in the horizontal and lateral countermovement jumps was evaluated and found better outcomes for the dominant limbs [19]. It was also reported that professional basketball players jumped dramatically higher with the dominant leg than the non-dominant leg (12%) in a drop jump [20].

Regarding the greater knee valgus angles found in our study for the non-dominant limb in comparison to the dominant limb, [12] found a significant relationship between lateral patella translation and knee abduction and external rotation when asymptomatic participants squatted with knees aligned in a valgus or neutral position. Another study found that patients with patellofemoral pain (PFP) represented with greater knee valgus angle than what was found in either their asymptomatic limb or in the control group [21]. Therefore, to avoid such symptoms care should be taken when exercising and rehabilitating lower limbs extra attention should be considered for the non-dominant limb to balance its performance with the dominant especially with the measurements of the knee valgus angle.

The current study found no significant correlations between all balance tests (sway area and time to stabilization) and knee valgus angle tests during single-leg squat and single-leg horizontal hop for distance tasks for both the dominant and non-dominant limbs. Balance is an important element especially TTS, some authors have utilized it to evaluate the effects of fatigue [22], and others used it to investigate the variations in several tasks between healthy participants and patients with reconstructed ACL [23]. Our study would provide evidence that the body balance would not have a direct effect on knee valgus angles either in a static (sway area) or in a dynamic situation after landing from a hop which was recorded as TTS, other factors should be considered for the knee valgus angle during rehabilitation or exercise programs.

The current study reported better outcomes regarding the static balance (sway area) with bent knees than extended lower limbs as shown in Table 1, this would indicate that isometric muscle contractions with bent legs 30˚ provided better stability and play a big role in body balance. This was also similar to the previous findings which reported a significant implication of maximal isometric muscle strength for lower limbs and the Y-balance test [24]. Therefore, extra attention should be taken on isometric muscle strengthening during any rehabilitation or exercise programs to provide better outcomes for balance performance.

### *4.2 Directions for Future Research*

Regarding knee valgus angles other contributed factors should be considered and studied when evaluating knee valgus angles these might include strengthening the core and hip abductors, stretching the adductor of the hip, and biofeedback exercises in front of a mirror. Moreover, conducting research studies to investigate the relationships between isometric muscle strength of lower limbs and balance performance.

### *4.3 Limitations*

There are possible limitations with using a 2-D for motion analysis. Although 2-D analysis was reported previously to be an accurate in measuring several tasks, the accuracy and magnitude of 3-D lower limb motion analysis during any movement cannot be fully replicated by 2-D FPPA applications. However, in the absence of the 3-D methods 2-D analysis still can provide a reliable and valid measures for lower limb kinematics [25]. Another limitation is that the current study only included male participants, hence we need to investigate if different gender will enhance the overall findings.

## 5. Conclusions

No significant correlations were found between balance performance and knee valgus angle tests in all tasks.

Differences were found between the dominant and non-dominant limbs, the dominant had better outcome measures than the non-dominant in all tests. More attention and focus should be considered for the non-dominant limb during rehabilitation or exercise programs to balance its performance with the dominant limb.

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Author contribution
The author (Hussain Ghulam) has done all the work needed for this study.

Ethical considerations
A written informed consent was obtained from all subjects and the project was approved by the University of Najran Research Ethics Committee with approval number (10 – 05 -02 – 2020 EC).

Conflict of interest
The author has no conflicts of interest to report.

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**Table 1:** The mean, standard deviation, and the range of values for balance tests.

| Test | Straight Leg Static Balance ($cm^2$) | | | Flexed Leg Static Balance ($cm^2$) | | | Dynamic Balance (TTS) (sec) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Range | Mean | SD | Range | Mean | SD | Range |
| Dominant leg | 1.28 | 0.40 | 0.68-2.07 | 1.11 | 0.37 | 0.61-1.88 | 0.367 | 0.029 | 0.32-0.41 |
| Non-Dominant leg | 1.34 | 0.39 | 0.71-1.96 | 1.18 | 0.36 | 0.66-1.92 | 0.39 | 0.033 | 0.32-0.44 |

SD = Standard Deviation, TTS = Time to Stabilization, sec = Seconds

**Table 2:** The mean, standard deviation, and the range of values for knee valgus angle tests.

| Test | Single-Leg Squat (˚) | | | Single-Leg Horizontal Hop for Distance (˚) | | |
|---|---|---|---|---|---|---|
| | Mean | SD | Range | Mean | SD | Range |
| Dominant leg | 7.4° | 3.63° | 2.9-15.4° | 11.11° | 2.95° | 7.1-17.9° |
| Non-Dominant leg | 8.5° | 3.72° | 3.2-17.8° | 12.3° | 3.15° | 8-17.5° |

SD = Standard Deviation, ° = Degree

**Table 3:** Correlations between balance tests and knee valgus angle for the dominant limb.

| | **Knee Valgus Angle Tests** |
|---|---|

| Test | | | |
|---|---|---|---|
| | | **2D Squat**<br>**Dom Leg**<br>*r value (P value)* | **2D Horizontal Hop for Distance**<br>**Dom Leg**<br>*r value (P value)* |
| **Balance Tests** | **Sway Area with Extended Leg** | .160 (.417) | .107 (.588) |
| | **Sway Area with Bent Knee (30˚)** | .177 (.366) | .102 (.604) |
| | **TTS** | -.287 (.138) | -.212 (.280) |

2D: Two-dimensional, Dom: Dominant, TTS: Time to Stabilization

**Table 4:** Correlations between balance tests and knee valgus angle for the non-dominant limb.

| Test | | Knee Valgus Angle Tests | |
|---|---|---|---|
| | | **2D Squat**<br>**Non-dom Leg**<br>*r value (P value)* | **2D Horizontal Hop for Distance**<br>**Non-dom Leg**<br>*r value (P value)* |
| **Balance Tests** | **Sway Area with Extended Leg** | .212 (.278) | .056 (.776) |
| | **Sway Area with Bent Knee (30˚)** | .174 (.377) | .037 (.853) |
| | **TTS** | -.290 (.134) | -.165 (.401) |

2D: Two-dimensional, Non-dom: Non-dominant, TTS: Time to Stabilization