ORIGINAL ARTICLE

Association between Muscle Activation and Knee Flexion Angles during Landing from Broad Jump

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ABSTRACT

Background: Greater knee flexion angles have been reported to facilitate a more effective attenuation strategy for the impact forces experienced during landing. This study sought to analyze the correlation between knee flexion angles and electromyography of the lower extremity muscles during landing from broad jump.

Methods: Eight male and 9 female healthy recreational athletes (age: 26.00 ± 3.55 years; height: 1.67 ± 0.05 m; weight: 67.05 ± 10.66 kg) participated in this study. Participants performed 4 trials of broad jump. Peak knee flexion angles and electromyography of gluteus maximus, quadriceps, hamstring were evaluated during the landing phase. Pearson (r) correlation was performed to determine the relationship between the knee flexion angles and lower extremity muscle activation. Also, regression analysis was conducted to determine the predictors of the knee flexion angle.

Results: A significant strong negative correlation was found between gluteus maximus and peak knee flexion angles (r = - 0.64, p = 0.003); whereas quadriceps exhibited a significant moderate negative correlation with peak knee flexion angles during landing from broad jump (r = - 0.45, p = 0.03). Regression analysis revealed that gluteus maximus was the only significant predictor for knee flexion angle ($R^2 = 0.410$, p = 0.006) (Knee flexion = 146.09 + (-0.92 * Glut max)).

Conclusion: The gluteus maximus accounted for approximately 41% of the variation in knee flexion angles. Greater knee flexion angles (soft landing technique) were correlated with decreased activation of gluteus maximus and quadriceps muscles. Soft landing technique may assist athletes in dissipating the impact forces experienced during landing.

Keywords: Gluteus maximus; quadriceps; knee flexion angles; landing.

INTRODUCTION

Lower extremity injuries frequently occur in individuals participating in sports activities that involve a wide range of dynamic athletic maneuvers, accounting for approximately 60 % of sport-related injuries [1-3]. In the sports medicine literature, factors associated with risk of lower extremity injuries have been classified as modifiable and nonmodifiable factors [4]. Hence, in an attempt to reduce lower extremity injuries, significant efforts have been dedicated to evaluating modifiable factors such as biomechanical variables during jumping and landing. An increasing amount of evidence suggests that landing from a jump might be attributed to increasing the lower extremity injuries risk such as ligament tear and cartilage lesions [5-8]. Therefore, several researchers have evaluated landing from a jump to identify potential factors that may elevate the risk of lower extremity injuries.

The body experiences greater impact ground reaction forces (GRF) that need to be efficiently attenuated by the lower extremity joints during the ground contact phase. Attenuation of the impact forces may be influenced by the landing technique that athletes utilize during landing. Previous researchers have identified two landing techniques (stiff and soft landings) based on the sagittal-plane knee kinematics during landing [9, 10]. In opposition to stiff landing, soft landing which promotes a more flexed knee position is widely emphasized in the literature as essential for efficient attenuation of impact forces during landing [9-12]. Therefore, athletes are encouraged to adopt this landing technique (i.e. increase knee flexion angles) in an effort to lower the external impact forces which may potentially decrease the lower extremity injuries risk.

Previous investigators have reported that the amount of flexion angles of the knee joint might be greatly affected by the activation of the muscles around the knee and hip joints during dynamic maneuvers such as landing [13]. Increased activation of hamstrings muscles (concentrically) may increase knee flexion angles during landing (soft landing technique) [13]. On the other hand, greater activation of gluteus maximus and quadriceps muscles (eccentrically) may decrease knee flexion angles during landing (stiff landing technique) [13]. In a cross-sectional study, the researchers found a negative correlation between vastus medialis oblique, vastus lateralis, and gluteus maximus and peak knee flexion angles during single leg landing [13]. These findings indicate the influence of muscle activation (both gluteus maximus and quadriceps) on knee flexion angles during landing. Specifically, during the deceleration phase of landing, the researchers reported that quadriceps demonstrated the greatest influence on knee flexion angles.

While the influence of muscle activation on the amount of knee flexion angles during single-legged landing has been previously examined, there is still a lack of research evaluating the relationship between sagittal-plane knee kinematics and activation of lower extremity muscles during bilateral landing from broad jump. Understanding the influence of lower extremity muscles on knee flexion angles during landing may provide important information for designing more effective injury prevention programs. Thus, this study sought to evaluate the relationship between peak knee flexion angles and muscle activation of the lower extremity (gluteus maximus, quadriceps, and hamstrings muscles) during bilateral landing from broad jump. It was hypothesized that peak knee flexion angles would have a negative correlation with gluteus maximus and quadriceps muscles; whereas hamstrings muscles would have a positive correlation with peak knee flexion angles during landing form broad jump.

METHODS

Design: A cross-sectional observational study was conducted to analyze the relationship between peak knee flexion angles and muscle activation of the lower extremity (gluteus maximus, quadriceps, and hamstrings muscles) during bilateral landing from broad jump. Participants performed 4 trials of broad jumps in a controlled laboratory setting. The study was approved by the institutional review board of Majmaah University and an informed consent was obtained from each participant.

Participants: Using convenience sampling, 8 male and 9 female healthy recreational athletes (age: 26.00 ± 3.55 years; height: 1.67 ± 0.05 m; weight: 67.05 ± 10.66 kg) participated in this investigation. Participants were included if they were able to execute a broad jumping task and currently participating at recreational level in soccer, basketball, and volleyball. Participants were excluded if they had surgery of low back or other lower extremity, lower extremity injury within the 6 months prior to study enrollment, and other ligament injuries of the lower extremity.

Instrumentation and data reduction: A surface electromyography (EMG) system (Delsys, Inc. Boston, MA) was used to quantify muscle activation of gluteus maximus, quadriceps, and hamstrings. Twelve wireless electrodes were attached to each muscle of both limbs based on the recommendations of Cram et al [14]. Specifically, electrodes were secured bilaterally (using hypoallergic adhesive tape) over lateral and medial hamstrings, vastus lateralis, rectus femoris, vastus medialis, and gluteus maximus. Isopropyl alcohol was utilized to clean the skin before placing the electrodes.

Polygon software (Vicon Motion Systems) was used to analyze EMG data that were time-synchronized with kinematic data. The EMG signals were analyzed during the landing phase. Dynamic normalization procedure was selected to normalize EMG data for each muscle in this investigation. This procedure has been previously utilized by several researchers to normalize EMG data during different dynamic maneuvers [15-21]. The average values of rectus femoris and vastus lateralis and medialis were calculated to constitute the quadriceps musculature; whereas the average values of the lateral and medical hamstrings constituted the hamstring musculature. For each muscle, the average of both limbs was calculated for each participant.

A motion capture system (Vicon Motion System Inc, Denver, CO), containing 8 cameras, was utilized to collect flexion angles of the knee joint while 4 force platforms (AMTI, Watertown, MA) were utilized to identify the landing phase which was operationally defined as the time interval between foot contact and bilateral maximum knee flexion. This time interval was selected in this study as it represents the time of greatest knee loading [22]. Force plates and kinematic data were sampled at 1920 and 240 Hz, respectively. Calibration of the motion capture system and the force plates was executed before the start of each data collection, as described by the manufacturer's recommendations. Using Plug-in gait model, 15 retro-reflective markers were placed on the second sacral vertebra, both anterior superior iliac spines, and on the following locations of both limbs: second metatarsophalangeal joints, calcaneal tuberosities, lateral malleoli, middle distance between lateral malleoli and lateral femoral epicondyles, thighs, and lateral femoral epicondyles. Flexion angles of the knee joint were analyzed using Vicon Nexus software (Vicon Motion System). The average of knee flexion angles of both limbs was calculated for each participant. A fourth-order no-lag Butterworth filter was utilized to smooth video data with a frequency of 10 Hz.

Procedure: After obtaining informed consent and explaining all procedures, anthropometric measures were taken and recorded from each participant. Then, participants were given a warm-up protocol that consisted of 5 min cycling, 5 continuous vertical jumps and 10 half squats. To determine participants maximum broad jump, participants performed three maximum broad jump and the average of these jumps was recorded. The landing task involved in this study required the participant to jump forward and land with both feet on the force plates. The distance between the participant's standing area and the force plates was equal to his maximum broad jump. Participants were given a demonstration of the landing task and allowed to perform two practice trials to become familiar with the study's instrumentation and procedures. Participants were then asked to successfully complete 4 landing trials. Landing with both feet completely on the force plates and returned to a standing position without losing balance was deemed as a successful trial. Arms movement was not restricted during the trials to facilitate natural landing.

Statistical Analysis: Kolmogorov-Smirnov test and box plots were utilized to evaluate the assumptions of normality and outliers for each variable. Also, the assumption of independent errors was checked using Durbin-Watson test, whereas variance inflation factor (VIF) was used to check the assumption of multicollinearity when the model included more than one predictor. Means, standard deviations (SD) and 95% confidence intervals were computed for each measure. Pearson correlation (r) was calculated to determine the relationship between knee flexion angles and each of the following muscles: gluteus maximus, quadriceps, and hamstring. The following criteria were used to interpret correlations: week relationship ($r < 0.30$), moderate relationship ($0.03 \leq r < 0.50$), strong relationship ($r \geq 0.50$) [23]. A muscle that has a significant correlation with knee flexion was selected to be included in forward multiple linear regression analyses to identify the predictors of knee flexion angles. Alpha was set at 0.05 to determine the statistical significance. All data analyses were conducted using SPSS 25 (SPSS Inc, Chicago, IL).

RESULTS

The data did not violate the assumptions of normality, outliers and independent errors. Mean, standard deviations and 95% confidence intervals for each variable are depicted in Table 1. The results demonstrated a significant strong negative correlation between Gluteus maximus and knee flexion angles (r = - 0.64, p = 0.003); whereas quadriceps exhibited a significant moderate negative correlation with knee flexion angles during landing from broad jump (r = - 0.45, p = 0.03) (Table 2). Regression analysis demonstrated that gluteus maximus was the only significant predictor for knee flexion angle (R^2 = 0.410, p = 0.006) (Knee flexion = 146.09 + (-0.92 * Glut max)) (Table 3). The gluteus maximus accounted for approximately 41% of the variation in knee flexion angles. Quadriceps was removed from this model because it did not add a significant change when it was included in the model (R^2 change = 0.087, p = 0.143). Multicollinearity was not an issue since there was only one predictor in this model.

Table 1. Means, Standard Deviations (SD), and 95% confidence interval for each variable

Variable	Mean ± SD	95% confidence Interval
Knee Flexion	81.51 ± 21.63	70.38 – 92.64
Gluteus maximus	69.76 ± 14.97	62.06 – 77.46
Quadriceps	84.95 ± 8.07	80.80 – 89.11
Hamstring	69.89 ± 13.93	62.72 – 77.05

Table 2. Correlations between knee flexion and muscle activation

	Maximum Knee Flexion Angles	
Muscle	r Value	p Value
Gluteus maximus	-0.64	0.003*
Quadriceps	-0.45	0.03*
Hamstring	-0.38	0.06

* Significant correlation at < 0.05

Table 3. Regression Model

	Unstandardized Coefficients		Standardized Coefficients			
Predictor	Beta	SE	Beta	P value	R^2	Model P value
Gluteus maximus	-0.926	0.287	-0.640	0.006	0.410	0.006

DISCUSSION

Based on previous studies investigating landing strategies, the relationship between knee flexion angles and muscle activation of the lower extremity during landing from broad jump has not been evaluated. This study sought to examine the relationship between peak knee flexion angles and muscle activation of the lower extremity (gluteus maximus, quadriceps, and hamstrings muscles) during bilateral landing from broad jump. The following findings of the present study included: (1) peak knee flexion angles demonstrated significant negative correlations with gluteus maximus and quadriceps, (2) gluteus maximus was the only significant predictor for peak knee flexion angles.

The results support the hypothesis that peak knee flexion angles would have a significant negative correlation with gluteus maximus and quadriceps. This finding is consistent with previous researchers who reported that EMG activity of vastus medialis oblique, vastus lateralis, and gluteus maximus demonstrated significant negative correlations with peak flexion angles during a single-legged landing [13]. Smaller knee flexion angles may not allow lower extremity joints to adequately dissipate the external impact forces during the ground contact phase which might potentially increase the risk of lower extremity injuries [24]. This observation further supports the role of both gluteus maximus and quadriceps in modifying knee flexion angles during bilateral landing from broad jump.

Regression analysis was performed to determine which muscle has greater influence on knee flexion angles during landing. The results demonstrated that gluteus maximus was the only significant predictor for knee flexion angles during landing from broad jump. The final regression model revealed that gluteus maximus accounted for approximately 41% of the variation in knee flexion angles (R^2 = 0.410, p = 0.006). Previous researchers found that vastus medialis oblique accounted for approximately 47.1% of the variance in peak knee flexion during a single-legged landing in male and female recreationally active individuals (R^2 = 0.47, p < 0.01) [13]. The discrepancy between these findings could be due to the biomechanical differences between the two landing tasks. Although hip flexion angle was not evaluated in both studies, it is likely that bilateral broad jump resulted in a more horizontal jump which may have increased hip flexion angles (a more flexed position) compared with a more vertical jump during a single-legged drop landing (a more erect posture). Other authors have reported that landing with increased hip flexion angles is accompanied with greater knee flexion angles [25-27]. Greater hip flexion angles may increase the demand on hip extensors, in lieu of knee extensors (quadriceps), to attenuate impact forces during landing [28]. The results of the present investigation suggest that knee flexion is more influenced by gluteus maximus activity than activation of knee extensors during bilateral broad jump. Therefore, clinicians may consider teaching athletes to decrease activation of gluteus maximus in order to increase knee flexion angles during landing from bilateral broad jump. Individuals who land with a more flexed knee position may reduce the impact forces and therefore decrease the risk of sustaining lower extremity injuries [24]. However, previous researchers have reported that gluteus maximus acts eccentrically to control hip internal rotation, a key component of anterior cruciate ligament (ACL) injuries, during dynamic tasks [13, 29, 30]. Thus, it should be noted that decreased activation of gluteus maximus during landing may increase hip internal rotation and knee valgus, biomechanical factors implicated in the increased ACL loading [13].

This study provide support for the significant role of the gluteus maximus and quadriceps muscles on controlling the amount of knee flexion during landing. The results of the present investigation showed that gluteus maximus was the significant predictor of peak flexion angles as well as the significant correlations between increased peak knee flexion angles and decreased activation of gluteus maximus and quadriceps muscles. These findings have clinical implications for preventative training programs as decreased activation of both gluteus maximus and quadriceps muscles may increase knee flexion angles during landing from broad jump. Landing with greater knee flexion angles is theorized to decrease the impact forces on the joints during landing; therefore, may decrease the lower extremity injuries risk [24]. However, reduced gluteus maximus activity during landing may negatively alter hip rotation which may result in greater hip internal rotation and knee valgus, consequently increasing the loading on the ACL [13].

It is important to acknowledge a few limitations when interpreting the results of this study. The findings might not be generalizable to other population due to the participants' population that included only recreationally male individuals. Also, the sample size was too small to perform analyses for males and females separately in this investigation. Additionally, similar to most studies in controlled laboratory settings, the landing task may not closely imitate the landing tasks commonly performed during real sporting activities. Furthermore, the present investigation did not examine hip flexion angles, which might have influenced the results.

CONCLUSIONS

The findings of the present investigation revealed that smaller knee flexion angles (stiff-landing technique) were significantly correlated with greater activation of gluteus maximus and quadriceps muscles. Also, gluteus maximus was the only significant predictor for peak knee flexion angles, accounting for over 40% of the variation in sagittal-plane knee kinematics during bilateral landing from broad jump.

List of abbreviations: GRF: Ground Reaction Forces; EMG: Electromyography; VIF: Variance Inflation Factor; S.D: standard deviations; ACL: Anterior Cruciate Ligament.

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