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The Indirect Role of Gluteus Medius Muscle in Knee Joint Stability during Unilateral Vertical Jump and Landing on Unstable Surface in Young Trained Males

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Abstract: (1) In the present investigation, we tested the hypothesis that unilateral countermovement jump performance is associated with knee joint stabilization ability during unilateral landing on unstable surface. (2) Twenty-five male sport students were tested for dynamometric knee extension and flexion, and hip abduction isometric strength. Myolectric activity of vastus lateralis and medialis, gluteus medius, and biceps femoris muscles were measured during unilateral countermovement vertical jump performed on a force plate, and during unilateral landing on unstable surface. (3) Vertical jump impulse negatively correlated with biceps femoris activation at landing. Participants with greater hip abduction force performed greater vertical jump impulse, and activated the biceps femoris less when landing on unstable surface. Furthermore, participants with smaller knee flexion/extension torque ratio increased biceps femoris/vastus medialis activation ratio at landing. (4) We conclude that hip abduction strength is an important contributor to unilateral vertical jump performance. Because biceps femoris is considered the synergist of the anterior cruciate ligament, we also propose that hip abductors are primary frontal plane protectors of the knee joint by reducing knee valgus and stress, allowing for smaller biceps femoris co-activation (secondary protection) at landing on unstable surface.

Keywords: hip abduction; knee extension; knee flexion; co-activation; knee valgus; trained males

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1. Introduction

Unilateral lower extremity jumps and landings are very common in ground-contact sports [1,2]. Because of increased load and reduced stability, mechanical stress on the knee joints increases with such movement modalities, augmenting the risk of injuries. For example, single-leg jumps applied in plyometric exercise training experiment evoked as high as 6.2 N/kg vertical ground reaction force [3], and knee joint is stressed by 8.5 N/kg reaction force when volleyball players perform their take-offs [4]. In addition, Tibiofemoral joint contact force can increase to more than ten times the bodyweight when landing from as low as 30 cm [5].

Knee joint stabilization is often studied by using different landing tasks [6–9], and the role of knee extensor and flexor muscles to protect passive tissue damage during landings is well understood [10]. The knee flexor co-activation as well as flexor to extensor strength ratio, known as knee joint stability indicators, have been considered important contributors to knee joint protection during unilateral landings on unstable surface [11]. An important limitation, however, is that researchers focused mainly on sagittal plane dynamics, while the dynamic control of knee valgus, which is a frontal plane kinematical phenomenon in the knee, has also been shown to relate to knee ligament injuries [12]. The gluteus medius muscle interests physiotherapists because it functions as a hip abductor, suggesting a potential role in knee valgus control [13–15]. The closest to the focus of the present work is a study by Moisan et al. [9], in which individuals with chronic ankle instability demonstrated smaller gluteus medius activation during landing on unstable surface, compared to healthy controls. Therefore, despite the fact that the gluteus medius is a pelvic muscle, its strength and/or activation seems to be important in the indirect stabilization of the knee joint during landings as it prevents excessive knee valgus.

In addition to the aforementioned stabilization roles, knee extensor and flexor strength have been shown to contribute to countermovement jump (CMJ) height [16], an important measure of athletic performance, which has been extensively studied [17–19]. In addition, both knee extensor and flexor activation were found greater when landings were performed unilaterally versus bilaterally [6]. Based on the above pieces of evidence, therefore, it seems reasonable to assume that knee joint stabilization ability and CMJ performance are related. Furthermore, extensive knee valgus may deteriorate CMJ performance through biomechanically disadvantageous force exertion; therefore, it is important to investigate hip abduction strength contribution to CMJ performance. The latter assumption derives from previous evidence showing that gluteus medius malfunction, for example, alters ankle joint kinematics, which is a compensation strategy to maintain posture during a single-leg forward jump [20].

In the present study we tested the hypothesis that CMJ performance is associated with the ability of knee joint stabilization at landing. We addressed this question through measuring and correlating CMJ impulse and knee extension, knee flexion, and hip abduction torque, as well as the activation of the involved muscles (joint stabilization markers) during unilateral CMJ and landing on unstable surface. If CMJ impulse is a significant predictor of knee joint stabilization ability, then physiotherapists and strength specialists could evaluate knee injury risks with simple CMJ tests.

2. Materials and Methods

2.1. Participants

Twenty-five healthy male physical education students (age = 20.4 ± 1.9 years, body mass = 78.6 ± 7.7 kg, height = 182.7 ± 5.6 cm) participated in the study. Apart from their regular curricular sport courses (4.54 ± 2.65 h/week), participants were involved in ground-contact sports for an additional 4.5 ± 2.7 h/week, while none of them were elite athletes. The only inclusion criterion was that they had at least one year experience in plyometric exercise training. Exclusion criteria were current injuries in the ankle, knee, hip, or spine, previous surgeries in these joints, vestibular abnormalities, or acute pain originating from orthopaedic abnormalities that could have prevented the participant from maximal lower extremity force exertion. Subjects gave written informed consent according to the Declaration of Helsinki after receiving both a verbal and a written explanation of the experimental protocol and its potential risks. The University Ethics Committee approved the protocol (approval number: 7961-PTE2019).

2.2. Experimental Protocol

Participants attended one familiarization, and one laboratory test session with two days in between. Before both familiarization and testing, participants warmed-up by riding a cycle ergometer for 5 min at a self-selected speed and by stretching, with special emphasis on the lower extremity muscles. This was followed by maximal isometric voluntary contractions (MVC) in knee extension, knee flexion, and hip abduction. After this, unilateral countermovement jumps, and landings on unstable surface were performed. Only the dominant leg was tested for every participant.

2.3. MVC Testing

Unilateral isometric knee extension and flexion MVCs were performed by using a Multicont II isokinetic device (Mediagnost, Budapest and Mechatronic Ltd., Szeged, Hungary, sampling frequency: 1000 Hz). Participants were seated on the dynamometer's padded seat, and performed full effort trials of knee extension and flexion at 70° and 20° of knee joint position, respectively (0° = full extension). The peak torque was determined and used for statistics. Knee flexion/extension torque ratios (Mf/Me) were also determined. For testing hip abduction MVC, participants laid on the side with the tested leg upwards. A hand-held dynamometer (C.I.T. Technics, Haren, The Netherlands) was placed and fixed 5 cm above the external malleolus, and participants were instructed to perform the isometric hip abduction at 0° hip joint angle with maximum effort. Hip abduction strength was expressed in Newton. In every MVC test, the torque/force achieved during the best attempt was normalized to participants' body weight and was considered for data analysis. There were three trials in each MVC task, and two-minute rests were allowed among trials. Before any testing, two submaximal warm-up trials were also executed.

2.4. Unilateral CMJ Testing

Participants stood on a force plate (Tenzi, Pilisvorosvar, Hungary) with one leg, and with the other leg slightly flexed. Three unilateral CMJs were executed with one minute rest between trials. During jumps, it was required to keep the hands on the hips to avoid arm-swing contribution. Subjects were instructed to jump as high as possible, but no instructions were given on jump strategy. During CMJs, vertical ground reaction force was measured with respect to time (sampling frequency: 420 Hz), and from the force-time curve the propulsive impulse was calculated as follows:

$$\vec{J} = \int_{t_1}^{t_2} \vec{F} dt$$

where $\vec{J}$ = propulsive impulse, $\vec{F}$ = force acting on the body over a time interval from t_1 to t_2. Values were then normalized to kg body mass of the participant. The best CMJ trial was considered for statistics.

2.5. Unilateral Landing on Unstable Surface

For this test, we followed the procedure described previously by Shultz et al. [7]. Participants stood on a box, and performed drops on the back (flat side) of a TOGU® Jumper (Figure 1). The flat side was used in order to selectively challenge knee joint stability, and to reduce the role of ankle stabilization during the landings. Instructions were given to participants to perform the drops similarly to a drop jump, and to land on the back of the equipment and maintain balance for three seconds. If balance was lost, the trial was repeated. After three warm-up trials, four successful test trials were performed.

Figure 1. Landing task performed to the flat side of a TOGU® Jumper.

2.6. Surface Electromyography

EMG data were collected telemetrically during all MVC, CMJ, and landing tasks. The skin was carefully prepared by shaving and cleansing with alcohol. Dual Ag/AgCl surface electrodes (Noraxon, Scottsdale, AZ, USA) were positioned on vastus lateralis (VL) and medialis (VM), biceps femoris (BF), and gluteus medius (GM) muscles according to SENIAM recommendations (www.seniam.org; accessed on 1 May 2021), and were kept on their place throughout the performance tests. EMG signals were collected (Noraxon, Scottsdale, AZ, USA, sampling frequency: 2000 Hz), and the raw data were processed with the root mean square technique, using 50-ms moving window. After this, the peak EMG values were determined for every performance test trial. The peak EMG values for CMJ and landing task trials were considered in a pre-specified recording period (Figure 2). The onset of this period was manually marked by considering the time point, when legs were unweighted and muscles were seen relaxed on the EMG register. To determine the end point, the peak VL EMG activity was used as reference point, which was clearly identifiable in every recording. The end point of the measurement period was 500 ms after the peak of VL EMG activity in order to ensure that the entire movement (either CMJ or landing) is involved in the measurement. All CMJ and landing EMG data were normalized to those obtained during MVCs. The BF/VM activation ratio during the landing task was also determined.

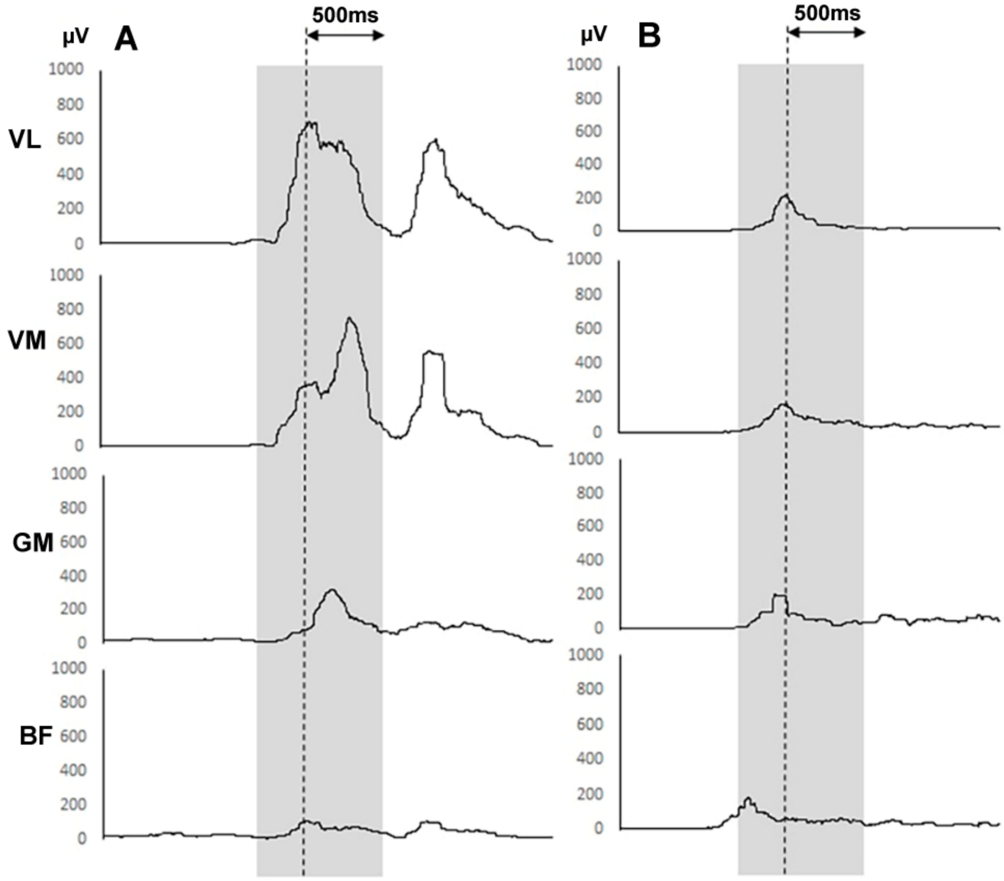

Figure 2. Processed EMG signals (RMS) and measurement periods for vastus lateralis (VL), vastus medialis (VM), gluteus medius (GM), and biceps femoris (BF) muscles during countermovement jump (**A**) and landing (**B**).

2.7. Statistical Analyses

Group means and standard deviations were computed for all measured and calculated variables. According to the Shapiro-Wilk test, all variables were normally distributed. Relative EMG activities of the muscles across tasks were compared with two-factorial ANOVA, using muscle (VM, VL, BF, GM) and task (CMJ, landing) as independent variables. Pearson product moment correlations were used to determine associations among all mechanical and EMG variables. The statistical significance was set at $p = 0.05$.

3. Results

3.1. Performance Measurements

Mean (± SD) values of the group performance measures are as follows: CMJ impulse = 2.83 (±0.26) $N \cdot s \cdot kg^{-1}$, knee extension torque = 3.70 (±0.62) $Nm \cdot kg^{-1}$, knee flexion torque = 1.97 (±0.39) $Nm \cdot kg^{-1}$, hip abduction force = $N \cdot kg^{-1}$, knee flexion/extension torque ratio = 0.53 (±0.09).

3.2. Muscle Activity

In EMG activity, there was significant main effect for task ($F = 17.1$, $p = 0.0001$) and muscle ($F = 15.7$, $p = 0.0001$), without task by muscle interaction. The post-hoc tests revealed that EMG activity was higher during CMJ versus landing ($p = 0.0001$), and that BF activity was lower than the activity of any other muscles ($p = 0.001$ or less) (Figure 3).

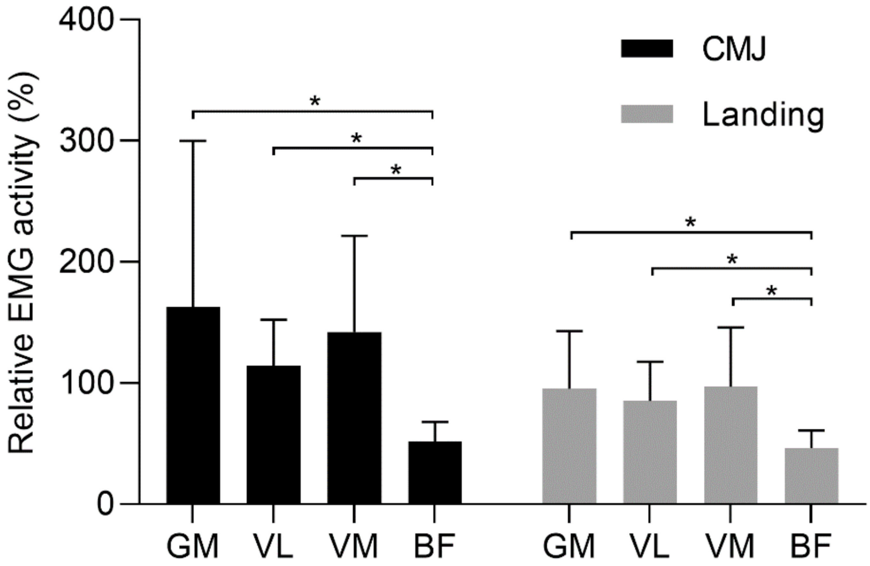

Figure 3. Relative peak EMG activities obtained from gluteus medius (GM), vastus lateralis (VL), vastest medialis (VM), and biceps femoris (BF) muscles during CMJ and landing tasks. * Represents significant difference at $p < 0.05$.

Pearson product moment correlation results among the MVC, CMJ, and EMG variables are presented in Table 1.

Table 1. Pearson product moment correlations among all mechanical and EMG variables. * Significant at p = 0.05. ** Significant at p = 0.005.

							EMG at CMJ				EMG at Landing			
		I	M_{ext}	M_{flex}	F_{abd}	M_f/M_e	GM	VL	VM	BF	GM	VL	VM	BF
	M_{ext}	0.51 **												
	M_{flex}	0.48 *	0.59 **											
	F_{abd}	0.63 **	0.23	0.33										
	M_f/M_e	0.08	0.27	0.61 **	0.18									
EMG at CMJ	GM	0.12	0.24	0.11	0.17	−0.40								
	VL	0.24	−0.03	0.03	−0.02	0.03	−0.31							
	VM	−0.24	−0.35	0.06	−0.15	0.43 *	0.29	0.12						
	BF	−0.01	0.20	0.23	0.04	0.11	0.25	−0.08	−0.06					
EMG at landing	GM	0.11	0.07	−0.10	0.08	−0.16	0.44 *	−0.06	−0.13	0.19				
	VL	0.19	−0.20	−0.17	−0.10	−0.03	−0.05	0.56 **	0.19	−0.19	0.13			
	VM	−0.19	−0.53 **	−0.14	−0.24	0.33	−0.20	0.36	0.48 *	−0.23	0.07	0.51 *		
	BF	−0.62 **	−0.23	−0.39	−0.75 **	−0.27	−0.15	−0.12	0.03	0.19	−0.10	0.01	0.22	
	BF/VM	−0.12	0.42 *	0.07	0.06	−0.49 *	0.16	−0.53 **	−0.48 *	0.20	−0.08	−0.50 *	−0.77 **	0.29

CMJ = countermovement jump, I = countermovement jump propulsive impulse, M_{ext} = knee extension peak torque, M_{flex} = knee flexion peak torque, M_f/M_e = knee flexion/extension peak torque ratio, F_{abd} = hip abduction force, GM = gluteus medius, VL = vastus lateralis, VM = vastus medialis, BF = biceps femoris, BF/VM = biceps femoris/vastus medialis activation ratio.

4. Discussion

The present data show limited association among CMJ performance and knee joint stabilization; however, we propose an important muscle activation strategy during landing on unstable surface. The main finding is that participants with greater hip abduction force performed greater CMJ impulse, and activated the BF less when landed on unstable surface. Furthermore, participants with smaller M_f/M_e ratio increased BF/VM activation ratio at landing.

The lack of task by muscle interaction suggests that muscle activation strategies are similar in CMJ and landing, probably because both tasks require the same joint kinematics. This is confirmed by the moderate correlation in VL, VM, and GM activation between the two tasks. Regardless of task, BF was less activated than the vasti or the GM muscles, suggesting that its role is limited to knee joint stabilization [21]. In contrast, the vasti muscles, being primary movers (either eccentrically during landing or stretch-shorteninglike during CMJ) were highly activated. The role of GM has been investigated both during depth vertical jump [22] and landing [9], using EMG, musculoskeletal models and EMG-informed simulation techniques. GM functions as hip abductor, and the high GM activation indicates the importance of proper femur or/and pelvis positioning during both CMJ and landing on instable surface.

We found that CMJ impulse correlated with both knee extensor and hamstring torque. The contribution of knee extensor strength to vertical jump performance is well documented [23]. The role of hamstring in jump movements is rather limited to knee joint stabilization [21], but hamstring strengthening intervention can improve jump performance [24]. It is a novel finding in the present investigation that hip abduction force correlated with CMJ impulse. This confirms previous data showing positive relationship between hip abduction moment and vertical ground reaction force measured during drop vertical jump [22]. Hip abductor mal-function has been shown to contribute to dynamic knee valgus and pelvic tilt [25] and, therefore, the improper femur (valgus collapse) and pelvis positioning could be biomechanically disadvantageous in the direction of force production during CMJ. This is confirmed by studies showing that GM fatigue alters ankle joint kinematics [20], impairs postural control [26], and increases medial-lateral center of pressure displacement [27], contributing to uncertain balancing and reduced vertical ground-reaction force during unilateral CMJ.

Countermovement jump impulse in the present study correlated with only one joint stabilization marker measured at landing: the BF activation (negative correlation), partly supporting our hypothesis. In addition, participants with less M_f/M_e ratio increased the BF/VM activation ratio at landing, and participants with less quadriceps torque activated the VM more at landing. Biceps femoris co-activation has been suggested to play an important role in most tasks that require strong knee joint stabilization [28]. Moreover, individuals with greater hamstring stiffness demonstrated smaller peak valgus during a controlled joint perturbation task, suggesting less ACL loading [29]. Based on our aforementioned findings and the fact that quadriceps and hamstring torque correlated with CMJ impulse (as shown in our results) in our participants, we suggest that individuals with smaller quadriceps and hamstring torque levels produce smaller jump performance, and that they compensate with higher VM activation and BF co-activation at landing on unstable surface to maintain knee joint stability. It seems realistic to assume that individuals with better jump performance feel more confident at landing and require less activation of the stabilizing muscles. This is in agreement with a previous study showing that individuals with greater hamstring strength produce softer landings quantified by measuring ground reaction forces [30]. In addition, jump performance has been shown to be associated with better static and dynamic balance [31], allowing more stable landing on unstable surface and requiring less activation in the involved muscles.

The present study provides an interesting finding regarding the role of hip abduction function in landing on unstable surface. We found strong negative correlation between hip abduction force and BF activation measured at landing. Hip abduction function has been shown to contribute to the magnitude of knee valgus [15], and increased knee valgus places higher stress on the ACL [29]. Based on our results and previous findings it seems that beside that BF activation has a direct role, the hip abductor strength has an indirect role in knee joint stabilization and the prevention of ACL injuries in unexpected landing situations. Namely, when an individual with less hip abduction strength lands on an unstable surface, the following mechanism is possible: (1) the lack of hip abduction strength allows greater knee valgus, (2) greater knee valgus places high stress on knee joint ligaments, (3) excessive stress on knee joint ligaments activates the BF. Therefore, hip abduction strength may indirectly prevent stress on knee joint by proper femur positioning, and this can be considered as a pro-active mechanism in ACL injury prevention. However, with less hip abduction strength, knee valgus may be produced, and BF is activated to directly reduce ACL stress. Though the latter can be considered as a reactive process, the exact neuromechanical mechanisms need to be clarified.

5. Limitations

Although in the present study in a large cohort we demonstrated strong negative correlation between hip abduction force and biceps femoris activation during landing, kinematic analyses are needed to provide direct evidence for quantifying the magnitude of knee valgus. Another important limitation is that we recruited only healthy moderately trained males and that the present data cannot be generalized to populations such as females, athletes or injured individuals.

6. Conclusions and Perspectives

In conclusion, the present study provides evidence that hip abduction strength contributes to unilateral vertical jump performance. Furthermore, we propose that hip abductors are primary frontal plane protectors of the knee by reducing valgus and joint stress. Biceps femoris is considered the synergist of the ACL (secondary protector), and sufficient hip abductor activation may diminish the role of biceps femoris co-activation as shown in our data when individuals land on unstable surface. Numerous studies demonstrated the effects of hamstring exercise interventions on reduced knee injury risks [32], however, strengthening the hip abductor muscles is also highly recommended for practitioners to provide a primary ACL protection in sports where unilateral jumps and landings are performed under unexpected situations. Understanding the protective behavior of the hamstring musculature in the prevention of ACL rupture is important. Therefore, future research investigating the time-specific activation of hamstring with respect to gluteus medius activation and frontal plane knee kinematics could provide useful insights on the proposed mechanism. The influence of health and training status as well as gender on the protective effect of the hamstring should also be studied.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of University of Pécs (approval number: 7961-PTE2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy rights of the subjects.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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