



GLUTEAL ACTIVATION AND INCREASED FRONTAL PLANE PROJECTION ANGLE DURING A STEP-DOWN TEST IN YOUNG WOMEN

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original paper

DOI: <https://doi.org/10.5114/hm.2018.73614>

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ABSTRACT

Purpose. To investigate how the activation of gluteus maximus and gluteus medius interacts with different frontal plane projection angles (FPPA) in healthy young women presenting dynamic knee valgus in one limb while performing the step-down test.

Methods. The total of 18 young women presenting FPPA > 15° during the step-down test in one limb (dynamic knee valgus) were assessed. The other limb should present less than 15° for comparisons. The amplitude of muscle activation was assessed through surface electromyography of gluteus medius and gluteus maximus during 8 subsequent weight bearing step-down tests.

Results. FPPA was positively correlated with gluteus maximus activation and with the assessed side showing FPPA > 15°, which also revealed increased activation of gluteus maximus. No differences were noted for gluteus medius. The principal component analysis explained 73% of the variance in 2 components, with gluteus maximus explaining 48% of the variance on the 1st component. Gluteus medius explained 25% on the 2nd component.

Conclusions. Gluteus maximus seems to be a major component to explain dynamic knee valgus in women without symptoms of patellofemoral pain, probably owing to weakness and lack of stabilization of other proximal muscles of the hip-knee complex during the task.

Key words: assessment, knee, hip, valgus, electromyography

Introduction

Gluteal weakness is often associated with abnormal femoral movements in internal rotation associated to adduction of the hip, leading the knee to move medially on the frontal plane [1]. The misalignment may change the knee kinematics, increasing lateral forces acting on the patella and the occurrence of patellofemoral pain (PFP) [2]. Young women (18–35-year-old) are more affected and show greater changes in lower limb kinematics than age-matched men [3–7]. A systematic review noticed increased dynamic valgus of the knee and increased joint load in women compared with

men during landing and pivoting movements [8]. During weight bearing activities, excessive dynamic knee valgus seems to be controlled by increased strength and activation of muscles that oppose the internal rotation associated with the adduction of the femur [9]. A study [10] assessed kinematic variables of the hip and the level of activation of hip muscles while running and landing from a jump, as well as during a step-down test. The results showed decreased hip muscle activation in females with PFP compared with pain-free controls.

The frontal plane projection angle (FPPA) is a two-dimensional measurement often used to assess knee

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Received: September 21, 2017

Accepted for publication: December 8, 2017

Citation: Barbosa AC, Vieira ER, Barbosa MA, Fernandes I, DamázioM, Badaró B. Gluteal activation and increased frontal plane projection angle during a step-down test in young women. Hum Mov. 2018;19(1):64–70; doi: <https://doi.org/10.5114/hm.2018.73614>.

kinematics during closed kinetic chain activities [11]. FPPA is related to knee pain severity [12], the prediction of PFP [13], and the interaction between hip abductor isometric torque [14]. Also, passive hip internal rotation range of movement predicts the occurrence of high FPPA during single leg squatting [14].

Surface electromyography (sEMG) can assess hip muscles activation during dynamic knee valgus, highlighting the important role of the gluteus medius to lower limb kinematics [1, 15]. However, no association was observed between the FPPA of the knee and strength of posterolateral hip muscles in a sample with PFP [11]. In a recent study, deficits of strength (28%, approximately) were observed on hip extensors in women with PFP compared with the control group [11]. Another study suggested an association between gluteus maximus weakness and PFP [12]. Additionally, a systematic review with meta-analysis showed inconclusive outcomes to determine whether deficits in hip muscle strength are predisposing factors or a consequence of PFP [16]. The gluteus maximus muscle is a powerful hip extensor and lateral rotator [17], acting in synergy with gluteus medius to dynamically stabilize the hip-knee complex [18]. Souza and Powers [10] showed increased activation of gluteus maximus as an attempt to stabilize the hip joint in subjects with PFP and compensate gluteal weakness during weight bearing activities.

Preliminary evidence for preventive intervention could be provided by identifying the activation pattern on the main gluteal muscles in young women without PFP, who present dynamic knee valgus (FPPA > 15°). Future degenerative changes due to excessive retro-atellar overpressure could be prevented by focal assessments and interventions [19].

Therefore, the purpose of this study was to investigate how the activation of gluteus maximus and gluteus medius interacts with FPPA in healthy young women while performing the weight bearing step-down test.

Material and methods

Participants

This was a non-randomized cross-sectional study, developed at the facilities of the Department of Physical Therapy of the Federal University of Juiz de Fora – Campus Governador Valadares, Brazil. Sample selection was carried out by a public call in the city of Governador Valadares. The total of 18 adult female subjects (22 ± 2 years of age, 165 ± 6 cm, 58 ± 8 kg)

participated in the study. Inclusion criteria were to present with a FPPA greater than 15° during the step-down manoeuvre in one limb. The other limb should present less than 15° for comparisons. Among the exclusion criteria, there were pharmacological treatment for osteoarticular pathologies, presenting signals or medical diagnosis of intervertebral disc herniation, hip, or knee degenerative injuries, overweight or obesity, and history of lower limb surgery.

Knee angle assessment

All procedures were conducted in a well lit reserved room with a non-reflective background to allow privacy. A camera (Coolpix S2700 16 MP, Nikon, Tokyo, Japan) was fixed and levelled on a tripod 3 m away from the subject horizontally and 0.85 m above the floor. Digital images were acquired in the continuous mode. All images were analysed with the use of the PAS/SAPO software (<http://sapo.incubadora.fapesp.br>) [20]. A plumb line was fixed on the roof with green cylinders 1 m apart from each other to calibrate the software.

A trained examiner identified the following anatomical landmarks through palpation: the midpoint of the ankle malleoli, the midpoint of the femoral condyles, and 30 cm above the knee on the proximal thigh along with a line from the anterior superior iliac crest (ASIS) [21]. Adhesive hypoallergenic tapes with attached reflexive green cylinders were positioned on the body landmarks for subsequent angle calculation. Subjects were instructed to stand up at a 20-cm step pad parallel to the plumb line and perpendicular to the camera.

Both lower limbs were assessed. The starting position was standing on the step pad [22] with arms crossed against the chest. The subjects were asked to step down, touch their toe to the ground, and return to the starting position. The test was standardized: 2 seconds for the descent phase, 1 second to touch the ground, and 2 seconds to return [11]. A chronometer was used to control the procedure. The first two trials were performed as familiarization and the obtained mean values from the last 8 trials were used for statistical analysis. The subjects did not present any sign of imbalance that could impair the analysis or cause any episode of falling. The offline FPPA was measured between the line from the marker on the midpoint of the ankle malleoli to the midpoint of the femoral condyles and the line from the proximal thigh along with a line from the ASIS to approximately 30 cm above the knee, at the

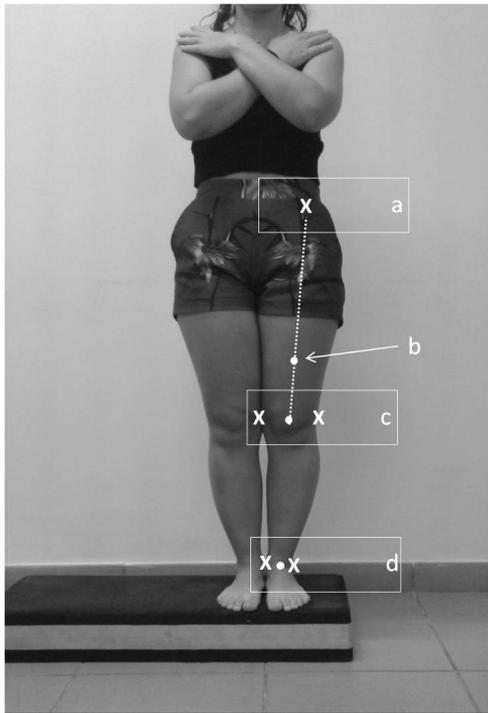


Figure 1. Landmarks position:
 a. the anterior superior iliac crest (ASIS);
 b. 30 cm above the knee on the proximal thigh along with a line from the ASIS;
 c. the midpoint of the femoral condyles;
 d. the midpoint of the ankle malleoli

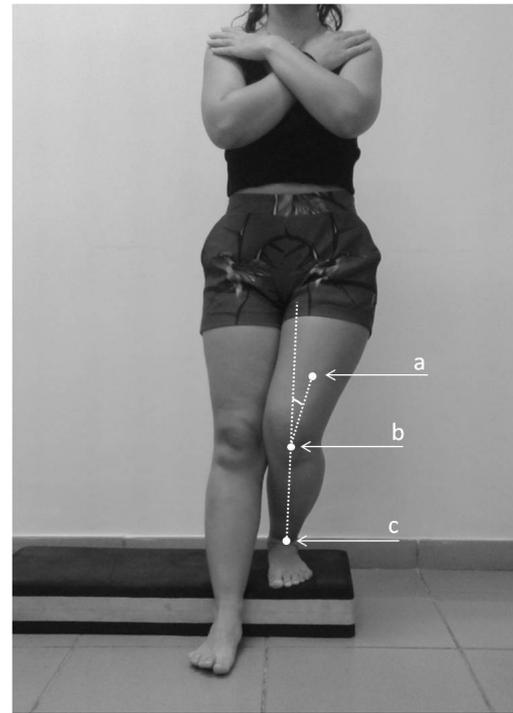


Figure 2. The frontal plane projection angle (FPPA): measured between the line from marker 'c' (on the midpoint of the ankle malleoli) to the midpoint of marker 'b' (on the midpoint of the femoral condyles) and the line from marker 'a' (on the proximal thigh along with a line from the ASIS to approximately 30 cm above the knee) to marker 'b'. The frame that corresponded to the point of maximum knee flexion was used to measure the FPPA

frame that corresponded to the point of maximum knee flexion (Figures 1 and 2). Positive FPPA values above 15° denoted knee valgus and negative FPPA values pointed at knee varus [23].

Muscle activation recording

A biological signal acquisition module with 8 analogue channels was used (Miotec®, Biomedical Equipment, Porto Alegre, RS, Brazil) to continuously record muscle activation during concentric and eccentric phases. The conversion from analogue to digital signals was performed by an A/D board with 16-bit resolution input range, the sampling frequency of 2 kHz, common rejection module greater than 100 dB, signal-noise ratio less than 03 µV root mean square and impedance of 109 Ω. The sEMG signals were recorded in root mean square in µV with surface Meditrace® (Ludlow Technical Products, Gananoque, Canada) Ag/AgCl electrodes with the diameter of 2 cm and centre-to-centre distance of 2 cm, applied in a transverse orientation parallel to the underlying fibres on a muscle site. A ref-

erence electrode was placed on the left lateral humeral epicondyle. The sEMG signals were amplified and filtered (Butterworth fourth-order, 20–450 Hz bandpass filter, 60 Hz notch filter). All pieces of information were recorded and processed with the Miotec Suite® software (Miotec Biomedical Equipment, Porto Alegre, RS, Brazil). Prior to sEMG electrode placement, the skin was cleaned with 70% alcohol to eliminate residual fat, which was followed by an exfoliation with specific sandpaper for skin and the second cleaning with alcohol. Gluteus maximus electrodes were placed over the muscle belly, midway between the second sacral vertebra and the greater trochanter [10]. Gluteus medius (posterior fibres) electrodes were placed 33% of the distance between the posterior ilium and the greater trochanter [24, 25].

The maximal voluntary isometric contraction (MVIC) was used to normalize the sEMG signal. For the gluteus medius, the subject was positioned in side-lying with the test lower limb uppermost. The thigh and leg were extended and the lower limb in line with the trunk. The hip and knee of the untested limb were in flexion

to provide stability. The subject performed abduction about 30° from the midline, and the examiner resisted manually just above the malleolus. For the gluteus maximus, the subject was placed in the prone position with a pillow placed under the pelvis to provide hip flexion at approximately 10–15°. The subject extended the thigh with the knee flexed at 90° through the available hip-extension range of motion. The rater resisted manually at the distal thigh [26]. Verbal encouragement was given with each trial.

Statistical analysis

Normality was tested by the Shapiro-Wilk test. Correlation among normalized sEMG data, limb (right or left), and FPPA (> or < 15°) were analysed with Pearson's coefficient. The independent t test was used to assess differences between sides – classified using the FPPA (> or < 15°). Additionally, the multivariate test principal component analysis (PCA) was performed to assess the cumulative variance of the variables. Alpha levels were set at 0.05 for all tests. The SPSS for Windows software, version 18.0 (SPSS Inc., Chicago, USA) was applied in all statistical analysis.

Ethical approval

The research related to human use has been complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the authors' institutional review board or an equivalent committee.

The Federal University of Juiz de Fora Ethics Committee approved this study (CAAE44416315.1.0000.5147). The participants were informed about the study details and signed the informed consent form prior to participation.

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

None of the subjects reported any localized muscle pain during MVIC or while performing the step-down test. The FPPA was positively correlated with gluteus maximus activation ($r = 0.40$, $p = 0.008$) and with the limb's side ($r = 0.30$, $p = 0.04$). Also, a correlation was observed between the right and left gluteus maximus ($r = 0.65$, $p = 0.001$). Two components were extracted from PCA, explaining 73% of the variance. PCA showed

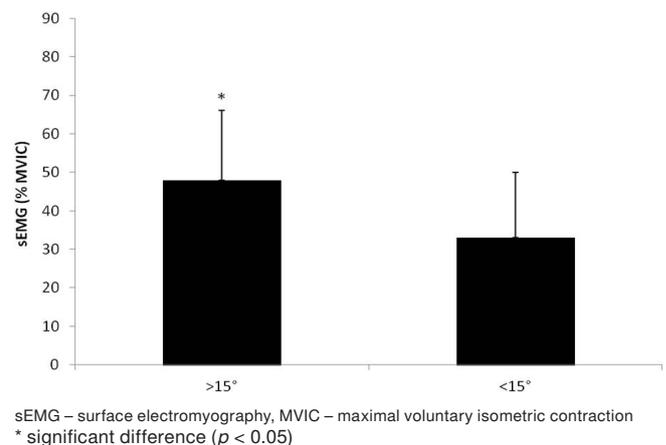


Figure 3. Comparison of the gluteus maximus activation by surface electromyography in individuals with frontal plane projection angle above and below 15°

the gluteus maximus (right, 0.95; left, 0.78) explaining 48% of the cumulative variance of the first component and the gluteus medius (right, 0.41; left, 0.77) explaining additional 25% of the variance of the second component. Differences in muscle activation were found when FPPA was an independent variable. The gluteus maximus activation was higher on the side with angles above 15° ($48 \pm 18\%$ vs. $33 \pm 17\%$; $p = 0.02$, Figure 3), with no difference for other comparisons.

Discussion

The results showed an increased activation of the gluteus maximus during the step-down test on the affected side, suggesting a decreased neuromuscular efficiency, as greater muscle recruitment is needed to perform the task. Biomechanical analysis showed posterior fibres of gluteus maximus acting as hip external rotators from 0 to 90° of flexion combined with posterior fibres of the gluteus medius [27], with both muscles stabilizing the knee-hip complex in the frontal plane [28]. The majority of studies target PFP symptomatic subjects, but some research has hypothesized that PFP is caused by altered kinematics during weight bearing activities [4], so the presence of increased hip adduction-internal rotation could be indicative of preliminary findings for PFP development.

Holden et al. [13] suggested that baseline measures of knee valgus displacement $\geq 10.6^\circ$ were predictive of PFP with high sensitivity (75%) and specificity (85%) in female adolescents. The increased activation of gluteus maximus was positively correlated with an increased FPPA, suggesting greater activation of gluteus maximus when higher dynamic knee valgus was ob-

served. The current results also indicate that the gluteus maximus is a major component to explain data variance when the task was performed and the dynamic knee valgus was perceived. Such combined data suggest the gluteus maximus activation as a predisposing factor to detect dynamic knee valgus and the development of PFP. Femoral internal rotation and adduction are thought to be controlled by gluteus maximus activation during unilateral tasks [29] and the current results suggest an increased activation of the muscle during step-down weight bearing to counteract the demand to maintain optimal alignment at the hip-knee complex. Similarly, Souza and Powers [10] reported increased activity of the gluteus maximus during the step-down task in females with PFP compared with the control group. Hollman et al. [30] showed the transverse-plane hip motion and hip extensor strength associated with frontal-plane knee kinematics during a jump-landing task. A systematic review noted females who presented PFP also showing deficits in hip extensor muscle strength [16], and a recent study found FPPA-peak values negatively correlated with the strength of hip abduction and posterolateral complex only for the group without PFP (FPPA-peak around 7°) [11]. The study assessed the relationship between the FPPA and hip and trunk muscle strength in women with and without PFP. However, individuals from PFP group with an average FPPA-peak smaller than 13° were considered, which impairs any comparisons with the present study. Another research proved gluteus maximus activation to be negatively correlated with knee valgus during a step-down test in healthy young women [29], but the knee valgus angle range was again lower (5.3–6.4°) than in the present study. Such differences in results may be explained by methodological issues concerning FPPA assessment and possible individual compensatory strategies during the step-down manoeuvre [11], such as lateral pelvic drop and the influence of external rotator muscles.

The results referring to gluteus medius were inconsistent with the presented outcomes: the muscle activation was not significantly correlated with FPPA, but the cumulative variance was explained by 25% at the second component. Such findings suggest a secondary role for gluteus medius during a single leg weight bearing task in women with increased FPPA and without PFP. A study assessed the activity of gluteus medius subdivisions [25] in healthy women presenting increased FPPA. The results showed that gluteus medius activation varied significantly across the subdivisions, with greater activation for mid and posterior subdivisions while performing a squat task [18]. Another study

assessed the gluteus medius and other muscles recruitment during 2 different types of squat, showing different patterns of muscle activation when the task was performed at the same relative intensity by female athletes [31]. Such studies noted different levels of muscle activation owing to task and assessment variations, proving that gluteus medius activation could change depending on external loads and demands in coordinating the biomechanical function to keep the hip-knee complex stable. We speculate that such differences tend to be more evident when biomechanical abnormalities are present, like increased FPPA, demanding more from other powerful muscles surrounding the joint complex.

An important limitation of the present study is the cross-sectional design, which does not allow cause-effect inferences. Although the current data support the argument of greater activation of gluteus maximus as an attempt to provide dynamic stabilization of the hip-knee complex and as a compensatory outcome of gluteus maximus weakness, knee-hip kinematics may be influenced by other factors, such as thigh muscles activation and joint coupling. Additional prospective studies are needed to provide definitive conclusions. Thus, it is possible that excessive FPPA subjects could benefit from exercises to modulate the activation of the gluteus maximus during weight bearing activities.

Conclusions

The present results provide preliminary evidence that young women with dynamic knee valgus exhibit increased gluteus maximus activation even before experiencing any usual symptoms of PFP, such as anterior knee pain. Additionally, gluteus maximus seems to be an important component to explain dynamic knee valgus in women without symptoms of PFP. We speculate that greater gluteus maximus activation is due to other muscle weakness and lower neuromuscular efficiency to stabilize the hip-knee complex in the frontal plane during a single leg weight bearing activity.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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