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Lower Extremity Neuromuscular Control Immediately After Fatiguing Hip-Abduction Exercise

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Context: Fatigue of the gluteus medius (GMed) muscle might be associated with decreases in postural control due to insufficient pelvic stabilization. Men and women might have different muscular recruitment patterns in response to GMed fatigue.

Objective: To compare postural control and quality of movement between men and women after a fatiguing hip-abduction exercise.

Design: Descriptive laboratory study.

Setting: Controlled laboratory.

Patients or Other Participants: Eighteen men (age = 22 ± 3.64 years, height = 183.37 ± 8.30 cm, mass = 87.02 ± 12.53 kg) and 18 women (age = 22 ± 3.14, height = 167.65 ± 5.80 cm, mass = 66.64 ± 10.49 kg) with no history of low back or lower extremity injury participated in our study.

Intervention(s): Participants followed a fatiguing protocol that involved a side-lying hip-abduction exercise performed until a 15% shift in electromyographic median frequency of the GMed was reached.

Main Outcome Measure(s): Baseline and postfatigue measurements of single-leg static balance, dynamic balance, and quality of movement assessed with center-of-pressure measurements, the Star Excursion Balance Test, and lateral step-down test, respectively, were recorded for the dominant lower extremity (as identified by the participant).

Results: We observed no differences in balance deficits between sexes ($P > .05$); however, we found main effects for time with all of our postfatigue outcome measures ($P \leq .05$).

Conclusions: Our findings suggest that postural control and quality of movement were affected negatively after a GMed-fatiguing exercise. At similar levels of local muscle fatigue, men and women had similar measurements of postural control.

Key Words: gluteus medius muscle, postural control, balance

Key Points

- An exercise that fatigued the gluteus medius negatively affected quality of movement and postural control as measured dynamically and statically.
- At similar levels of muscle fatigue, quality of movement and postural control were affected similarly for men and women.
- Impairments in quality of movement and postural control after a fatiguing hip exercise were not different between sexes.

Proper function and coordination of muscles that provide stability to the lumbar spine, hips, and pelvis (ie, the core) are important for providing optimal production, transfer, and control of forces and movement that occur throughout the body. Equalized muscle activation of the core is essential for stability and functional efficiency, which require control of strength, balance, and movement.[1] Weakness or insufficient coordination in core musculature can lead to aberrant movement patterns, compensatory movement patterns, strain, overuse, and injury.[2] Zazulak et al[3] reported that decreased neuromuscular control of the trunk and dynamic stability at the knee joint are related to increased risk of knee injury during high-speed athletic maneuvers.

Fatigue also might disrupt afferent nerve impulses, which would impair conscious joint awareness, slow neural transmission, decrease afferent signals needed to create compensatory contractions, and reduce joint control.[4–6] In a fatigued state, the conduction of the afferent signal is impaired, which might lead to slower propagation of efferent signals necessary to maintain posture.[7] Hunter[8] described sex differences in skeletal muscle fatigability. During sustained and intermittent isometric contractions, women are less fatigable than men because of differences in their neuromuscular systems that allow physiologic adjustments during a sustained fatiguing task.[8] The magnitude of sex differences in fatigability is specific to the task performed, the age of the person performing the task, and the muscle group involved during the fatiguing exercise.

Hip joint musculature is exceptionally important for adequate pelvic and trunk stabilization during ambulation.[9] The role of hip abduction and external rotation strength in core stability is important in the prevention of lower extremity injuries.[10] Gluteus medius (GMed) dysfunction is a common cause of insufficient hip abduction and external rotation strength that is often associated with decreases in postural control.[11,12]

Researchers[6,13] have examined the effect of hip and ankle fatigue on postural control; however, they did not specifically quantify the extent of muscle fatigue using electromyography (EMG). Furthermore, a discovery of different responses in men and women might help explain higher rates of knee injuries in female athletes.[14–16] Therefore, the purpose of our study was to compare postural control and quality of movement between men and women after a fatiguing hip-abduction exercise. We hypothesized that increases in fatigue of the GMed, as determined by a shift in median frequency, would cause immediate deterioration in postural control and quality of movement in healthy participants.

METHODS

Our descriptive laboratory study included a pretest-posttest repeated-measures design with static groups comparison. The independent variables were sex (female, male) and time (prefatigue, postfatigue). Main outcome variables included static balance, dynamic balance, and lateral step-down test (LSDT) performance.

Participants

Eighteen men (age = 22 ± 3.64 years, height = 183.37 ± 8.30 cm, mass = 87.02 ± 12.53 kg) and 18 women (age = 22 ± 3.14, height = 167.65 ± 5.80 cm, mass = 66.64 ± 10.49 kg) volunteered to participate in the study. All volunteers had at least a moderately active lifestyle, defined by the US Department of Health and Human Services[17] as participating in 150 to 300 minutes of physical activity per week. Exclusion criteria included a history of lower extremity or low back surgery, joint injury in the 6 months before the study, or low back pain or concussion in the 6 months before the study and included a positive Trendelenburg test on the *dominant leg*, which was defined as the leg with which the participant would kick a ball. Participants provided written informed consent, and the University of Virginia Institutional Review Board for Health Sciences Research approved the study.

Instrumentation

A general spine and lower extremity medical questionnaire was used to screen participants for exclusion criteria. An AccuSway Plus force plate (AMTI, Watertown, MA) was used to quantify center-of-pressure (COP) excursion data during static balance, and signals were collected at 50 Hz. A tape measure was secured to the floor for the Star Excursion Balance Test (SEBT). Gluteus medius muscle activity was measured using surface EMG. Signals were amplified at a gain of 1000 from disposable, gelled, 10-mm silver chloride electrodes, digitized with a 16-bit data acquisition system (MP150; BIOPAC Systems, Inc, Santa Barbara, CA), and sampled at 1000 Hz.

Testing Procedures

The EMG electrodes were placed parallel to the muscle fiber orientation, approximately 2 cm apart, between the iliac crest and greater trochanter on an area superficial to the GMed muscle, which was verified with isolated hip-abduction. We also placed EMG electrodes over the vastus lateralis during the fatiguing hip-abduction exercise as a potential confounder to our outcome measures. Electrodes were placed approximately 10 cm proximal to the patellar base and parallel to the muscle fiber orientation of the vastus lateralis. A ground electrode was placed on the anterior aspect of the medial malleolus on the nontesting limb. Before electrode placement, the skin was shaved if needed, debrided via light rubbing with a coarse surface, and cleansed with isopropyl alcohol to minimize skin impedance.

For baseline measurements, each participant performed single-limb static balance on a force plate, dynamic balance was measured with the SEBT, and quality of movement was measured with the LSDT. These measurements were counterbalanced and repeated in the same order for the posttest.

Single-Limb Static Balance

Participants performed static balance testing while standing barefoot on the dominant limb, remaining as still as possible, and with their eyes open. They were instructed to maintain a single-legged stance on the test leg with their eyes open while concentrating on a picture at eye level on the wall in front of them and holding the nonstance limb at approximately 45° of knee flexion and 30° of hip flexion.[18–20] Participants performed 4 15-second trials; they performed 2 trials before and 2 trials after the fatiguing task and rested 15 seconds between trials. Measurements of static balance included the COP velocity, COP area, standard deviation (SD) in the anteroposterior direction, and SD in the mediolateral direction. The means of the 2 pretrials and the 2 posttrials served as the dependent variable. Intraclass correlation coefficients have been reported to range from 0.41 to 0.79 for measures of velocity, range, and variability.[19] A trial was considered unsuccessful if the contralateral foot touched the force plate, ground, or testing limb; the participant fell off or hopped on the force plate; or the participant lifted the heel of the testing limb.[21]

Data were sampled at a rate of 50 Hz, and COP data were filtered with a fourth-order, zero-lag, low-pass filter with a cutoff frequency of 5 Hz. The COP area, COP velocity, and SDs in the anteroposterior and mediolateral directions were calculated with Balance Clinic software (AMTI).

Star Excursion Balance Test

Participants performed the SEBT by standing on the dominant limb and reaching with the contralateral limb as far as possible in the anterior, posteromedial, and posterolateral directions.[22] Researchers[22] have shown that practice trials decrease the learning effect of this test. Each participant performed 6 practice trials in each direction, followed by a 5-minute rest period. For baseline and postfatigue testing, the means of all 3 trials for each direction were used for analysis. A trial was considered successful if the participant bent his or her knees, used arm strategies to maintain balance, and looked in the direction in which he or she was reaching. The trial was deemed unsuccessful and was repeated if the participant lifted the heel of the testing leg, had a loss of balance that prevented a return to the starting position, did not hold the testing limb out long enough for the distance of the reach to be determined, pressed off the ground too hard, or used the reach limb to support the body during excursion. The average of 3 trials was normalized to the participant's leg length.[21]

Lateral Step-Down Test

The LSDT was used to assess quality of movements during a challenging task and has been reported to have an acceptable intertester reliability of 0.67.[23] Participants stood on the dominant limb on a platform 20 cm above the floor. With hands on hips, they lowered the heel of the nonstance limb and lightly touched the floor by bending at the knee of the dominant limb. Next, they extended the stance knee to return to the starting position. This was repeated 6 consecutive times and recorded on video for scoring at baseline and after the fatiguing protocol.

Fatigue Protocol

Participants performed repeated side-lying, eccentric hip-abduction contractions until the GMed was fatigued. We indexed the state of muscular fatigue using median frequency calculations from EMG data collected during the contractions. Positioning during the contractions was maintained with canvas belts, foam pads, the wall behind the treatment table, and oral encouragement (Figure A). Participants performed a maximal voluntary isometric contraction before the fatiguing protocol and before any practice trials or testing. This contraction served as the participant's baseline median frequency.

Participants were instructed to abduct the hip to 15° with the knees slightly flexed, then lower it back to neutral (Figure). Concentric contractions lasted less than 2 seconds, during which time the participants actively abducted the hip to 15°. This position was verified by using a canvas belt that limited hip joint motion to the desired range. Eccentric contractions lasted 5 seconds. Timing was verified by oral feedback from the tester (K.L.M.) while participants slowly lowered the abducted hip back to the starting position. With every fifth contraction, participants performed a 2-second isometric contraction against the canvas belt (ie, at 15° of hip abduction), and a 1-second clip of GMed EMG was recorded during the middle 1.0 second of the contraction. Median frequency was calculated immediately in real time (Figure B). The participant continued this process until successfully reaching a 15% downward shift in median frequency compared with a baseline measure of median frequency established before the fatiguing exercise.

After a 15% downward shift in GMed EMG was reached, participants performed their first bouts of postfatigue testing. They performed static balance, SEBT, or LSDT, as described. Next, participants performed additional hip-abduction exercises until they reestablished a 15% downward shift in median frequency, displaying sustained GMed fatigue. This was repeated for the third postfatigue measurement. The order of postfatigue measures was counterbalanced.

Data Processing

During the LSDT, the participant was given a score from 0 to 6 based on 5 evaluation criteria: arm strategy, trunk movement, pelvis plane, knee position, and maintenance of steady unilateral stance.[23] A lower score on the LSDT is an indicator of a person's ability to efficiently control the quality of movement, as displayed by successful dynamic postural control. Total scores of 0 to 1 classify the participant as having *good quality of movement;* 2 to 3, *moderate quality of movement;* or 4 or more, *poor quality of movement*.[23] The mean from the 6 trials was the dependent measure. Points for the LSDT are awarded as follows: 1 point is given if the participant attempts to maintain or recover balance by positioning his or her arms,

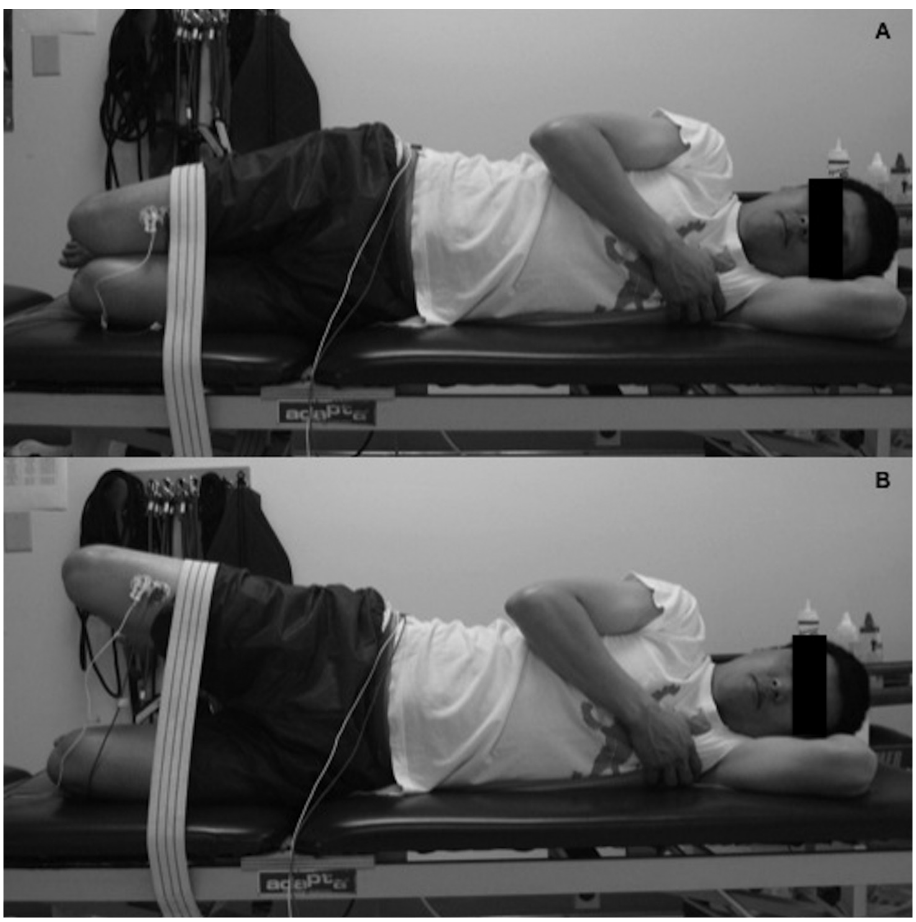

Figure. Gluteus medius eccentric fatiguing exercise. A, In the starting position, the participant concentrically contracts the hip abductors. B, The participant eccentrically contracts the hip abductors to abduct the hip to 15°.

trunk, or pelvis in a position other than the starting position or in neutral, 1 point is given if the knee deviates medially and the tibial tuberosity crosses over the second toe, 2 points are given if the knee crosses over the medial border of the foot, and 1 point is given if the nontesting limb bears any weight or if the testing limb becomes visibly unsteady and wavers.[23]

Electromyographic signals were collected in 1-second increments during each sampled contraction, band-pass filtered at 10 to 500 Hz, and transformed into the frequency domain using a fast Fourier transformation (padding with zeroes) to obtain the EMG power spectrum. We calculated the median frequency value from each isometric contraction as an index of muscular fatigue. To expedite real-time data processing, we used a custom-written macro program (Macro Magic; iolo technologies, LLC, Los Angeles, CA) that could calculate the necessary information in less than 10 seconds, providing quick feedback about the state of muscle fatigue during the fatiguing exercise. All processing was performed with Acq*Knowledge* software (version 3.7.3; BIOPAC Systems, Inc).

Statistical Analysis

An a priori sample size calculation was performed based on previously published data showing deteriorated dynamic balance after lower extremity fatigue.[24] Assuming an average 2% reduction in normalized anterior reach excursion during the SEBT and an SD of excursions of ±2%, we estimated that 34 participants (17 men and 17 women) would be adequate to find a difference in dynamic balance after GMed fatigue at an α level of .05 and power exceeding 80%.

We performed 4 2×2 (time by sex) repeated-measures multivariate analyses of variance (MANOVAs) to compare COP excursion data collected during dominant-limb static stance between sexes and over time. These measures included COP velocity, COP area, SD in the anteroposterior direction, and SD in the mediolateral direction. We also performed 2×2 repeated-measures MANOVAs for normalized reach distance in each direction of the SEBT and for the LSDT score. We performed post hoc *t* tests if necessary. We also used independent-samples *t* tests to compare sexes at baseline for all data. Finally, we compared prefatigue-postfatigue median frequency of the GMed and quadriceps, represented by EMG recorded from the vastus lateralis, to determine whether this muscle experienced fatigue during the exercise protocol. Cohen d effect measures were determined by calculating the mean difference between groups (prefatigue, postfatigue) with the pooled SD serving as the denominator. The strength of the effect size was determined as small (≤0.4), moderate (0.41–0.7), and large (≥0.71). The α level was set a priori at .05. All statistical comparisons were performed with SPSS (version 17.0; SPSS Inc, Chicago, IL).

RESULTS

The average shift in median frequency of the GMed was 20.5 ± 4.8 Hz. This was a reduction in median frequency for men ($t_{17}=10.8$, $P<.001$) and women ($t_{17}=9.20$, $P<.001$). However, median frequency of the quadriceps muscle group measured concurrently was not different for men ($t_{17}=0.05$, $P=.96$) or women ($t_{17}=-0.86$, $P=.40$).

After the fatiguing protocol, both groups displayed a decrease in dynamic postural control, as demonstrated by shorter reach distances on the SEBT ($F_{3,32}=30.3$, $P<.001$), but we found no group-by-time interactions ($F_{3,32}=0.41$, $P=.75$) after the exercise. We observed a multivariate main effect for group ($F_{3,32}=2.9$, $P=.05$) but no univariate main effects for group (Table 1). When men and women were pooled, we observed decreases in the anterior ($F_{1,34}=70.7$, $P<.001$), posteromedial ($F_{1,34}=57.9$, $P<.001$), and posterolateral ($F_{1,34}=54.4$, $P<.001$) reach directions.

We found a multivariate main effect for time ($F_{6,29}=4.5$, $P=.003$) but not for group ($F_{6,29}=0.63$, $P=.70$) for COP excursion data. When male and female scores were pooled, we observed increases in COP velocity ($F_{1,34}=4.6$, $P=.04$), COP excursion area ($F_{1,34}=13.7$, $P=.001$), SD in the mediolateral direction ($F_{1,34}=16.4$, $P<.001$), and SD in the anteroposterior direction ($F_{1,34}=7.8$, $P=.008$) after GMed fatigue (Table 2).

We found no group ($F_{1,34}=1.56$, $P=.22$) or time-by-group ($F_{1,34}=0.75$, $P=.391$) interactions for the LSDT after exercise. The LSDT decreased postfatigue for both sexes ($F_{1,34}=60.80$, $P<.001$). Female participants presented with higher baseline values than male participants, but the ability to control the quality of movement after GMed fatigue deteriorated comparably between sexes (Table 3).

DISCUSSION

We induced localized fatigue of the GMed, which we hypothesized would result in reduced ability to provide stability to the lumbo-pelvic-hip complex. We observed that, after an eccentric fatiguing protocol of the GMed, participants had impairments in postural control and the quality of their movements. These findings were not different between men and women. Researchers[25,26] have evaluated the effects of concentric fatigue of the GMed and have observed increases in knee valgus angles in females and increased peak knee joint displacement in the frontal plane among males and females. However, eccentric fatigue of the GMed might be a better indicator of what functional effects the GMed might experience during a prolonged bout of exercise. The changes we observed in postfatigue measurements of quality of movement and postural control indicate the importance of the GMed in lower extremity stabilization.

Surface EMG was recorded for the GMed and quadriceps muscle group. After data collection, median frequency was analyzed for the quadriceps to ensure that the eccentric fatiguing exercise did not cause a shift in median frequency for the quadriceps muscle group; measurement of quadriceps median frequency revealed that the eccentric exercise we used did not cause a shift in quadriceps median frequency. Therefore, impairments in postural control after the fatiguing exercise and the quality of movement as measured with the LSDT can be attributed to physiologic changes to the GMed.

Our results demonstrate that, at the same level of GMed fatigue in both sexes, postural control and quality of movement were affected equally for men and women. We possibly did not find differences in postural control between men and women after our fatiguing protocol because we had similar thresholds for defining fatigue for both groups. Therefore, men and women experienced shifts in median frequency of similar magnitude, resulting in lower extremity postural control responses of similar magnitude. Researchers[27,28] have produced comparable results with the SEBT, finding no difference in normalized reach distances between men and women. Although other researchers[29,30] have found variances in neuromuscular recruitment patterns between sexes, we found men and women adapted similarly at the same level of local muscle fatigue.

Table 1. Univariate Statistical Results (Mean ± SD) for the Star Excursion Balance Test From Prefatigue to Postfatigue of the Gluteus Medius Muscle

	Men (n = 18)			Women (n = 18)			*P* Value			Total (N = 36)
Reach Direction	Prefatigue	Postfatigue	Effect Size (95% Confidence Interval)	Prefatigue	Postfatigue	Effect Size (95% Confidence Interval)	Time	Group	Group x Time	Effect Size (95% Confidence Interval)
Anterior reach	67.1 ± 5.0	60.9 ± 5.3	1.22 (0.51, 1.93)	69.4 ± 5.8	64.4 ± 5.0	0.93 (0.24, 1.61)	<.001[a]	.08	.36	1.04 (0.34, 1.74)
Posteromedial	84.1 ± 11.3	77.6 ± 11.1	0.58 (–0.09, 1.24)	80.6 ± 7.6	75.5 ± 7.2	0.69 (0.02, 1.37)	<.001[a]	.37	.84	0.62 (–0.05, 1.28)
Posterolateral	79.9 ± 13.3	73.4 ± 13.3	0.49 (–0.18, 1.15)	77.4 ± 8.7	71.8 ± 8.7	0.65 (–0.02, 1.32)	<.001[a]	.32	.27	0.54 (–0.12, 1.21)

[a] Indicates main effect of time (*P* < .05).

Table 2. Univariate Statistical Results (Mean ± SD) for Center of Pressure From Prefatigue to Postfatigue of the Gluteus Medius Muscle

	Men (n = 18)			Women (n = 18)			*P* Value			Total (N = 36)
Measure	Prefatigue (cm/s)	Postfatigue (cm/s)	Effect Size (95% Confidence Interval)	Prefatigue (cm/s)	Postfatigue (cm/s)	Effect Size (95% Confidence Interval)	Time	Group	Group x Time	Effect Size (95% Confidence Interval)
SD mediolateral	0.47 ± 0.08	0.56 ± 0.14	–0.82 (–1.51, –0.14)	0.49 ± 0.09	0.54 ± 0.13	–0.36 (–1.02, 0.30)	<.001[a]	.96	.13	–0.59 (–1.27, 0.07)
SD anteroposterior	0.68 ± 0.2	0.85 ± 0.37	–0.57 (–1.22, 0.11)	0.70 ± 0.19	0.77 ± 0.23	–0.34 (–1.00, 0.32)	.008[a]	.69	.27	–0.38 (–1.04, 0.28)
Center-of-pressure velocity	3.68 ± 0.88	4.32 ± 1.32	–0.6 (–1.27, 0.06)	3.53 ± 0.92	4.43 ± 3.44	–0.36 (–1.02, 0.30)	.04[a]	.97	.73	–0.41 (–1.07, 0.26)
Center-of-pressure excursion area	6.63 ± 2.49	9.72 ± 4.69	–0.82 (–1.50, –0.14)	5.76 ± 2.45	7.66 ± 5.10	–0.48 (–1.14, 0.19)	.001[a]	.78	.38	–0.64 (–1.31, 0.03)

[a] Indicates main effect of time (*P* < .05).

Table 3. Lateral Step-Down Test Scores[a] (Mean ± SD) From Prefatigue to Postfatigue of the Gluteus Medius Muscle

Men (n = 18)			Women (n = 18)			*P* Value			Total (N = 36)
Prefatigue	Postfatigue	Effect Size (95% Confidence Interval)	Prefatigue	Postfatigue	Effect Size (95% Confidence Interval)	Time	Group	Group x Time	Effect Size (95% Confidence Interval)
1.97 ± 0.73	2.84 ± 0.75	–1.01 (–1.70, –0.31)	2.36 ± 0.89	3.05 ± 0.70	–1.17 (–1.88, 0.47)	<.001[b]	.22	.391	–0.87 (–1.55, –0.18)

[a] Indicates scored on a 7-point scale, with scores of 0 to 1 indicating good-quality movement; 2 to 3, moderate-quality movement; and ≥4, poor-quality movement.
[b] Indicates main effect of time (*P* < .05).

Center-of-pressure velocity, COP area, and standard deviations (SDs) in the mediolateral and anteroposterior directions increased after GMed fatigue. An increase in COP velocity implies postural stability was impaired and suggests the COP was moving over a greater distance per unit of time. Postfatigue COP excursions occurred over a greater area of the foot, which was shown by the increase in COP area. Increases in the COP excursion might have been caused by a decrease in the efficiency of the GMed firing during single-limb stance after the fatiguing protocol, resulting in overcompensation to maintain the body's center of mass over the base of support.[6] The increase in SDs in the mediolateral and anteroposterior directions describes greater variability (ie, the COP excursions are farther away from the mean) in the mediolateral and anteroposterior directions, respectively. During the hip-abduction fatiguing task, EMG of the hip adductors was not recorded. Increases in SD in the anteroposterior direction could be attributed to the inability of the hip adductors to decelerate and control forward thrust of the body during the single-limb balancing task.[31]

Reach distances in all directions of the SEBT (anterior, posteromedial, posterolateral) decreased after the GMed-fatiguing exercise. Although the GMed most often is considered to greatly influence frontal-plane dynamics, GMed dysfunction greatly affected the anterior reach direction. This effect on dynamic balance is relative to the substantial contribution of the GMed to forward acceleration and support during single-legged stance. Anderson and Pandy[32] found that the posterior portion of the GMed acts as a stabilizer throughout early stance and the midstance phases of gait, and the anterior portion also acts as a stabilizer during midstance. As seen with the substantial decrease in the anterior reach direction of the SEBT, a deficit of the GMed greatly decreases the amount of stability achieved during any type of forward or sagittal-plane movement. Clinically, this is an important finding because it explains that the GMed contributes to postural stability in single-legged stance, which is a key component of almost all functional movements, including walking. Most often, the GMed is assessed as a frontal-plane mover and stabilizer, but we showed it contributes to stabilization during sagittal movement. Because the anterior reach direction is a quadriceps-dominant dynamic balance task,[33] it might present a potential confounding factor for the observed deteriorations in postural control. However, we verified via surface EMG that the quadriceps were not fatigued during the hip-abduction exercise. Other potential confounders to changes in static and dynamic balance that we did not investigate in our study, such as the vastus medialis oblique, gluteus maximus, tensor fascia latae, and hip-adductor muscles, might have been activated during the hip-abduction exercise and might have contributed to the outcomes of our study.

Grading of the LSDT involves observation of maladaptive strategies that are performed during the challenge of a dynamic task. Researchers[34,35] have reported that such alterations commonly occur with lower extremity conditions. A larger number of alterations during the LSDT indicates poor quality of movement, which might be the result of poor core stability or an inability to control knee position during a dynamic task.[23] Efficient movement functions and the maintenance of balance during dynamic tasks are more complex than merely adequate force production from the muscles.[36] Dynamic stability of the body depends on neuromuscular control of the displacement of all contributing body segments during movement.[36] The glutei stabilize the trunk over the planted leg and provide power for forward leg movements; they also can be seen as a connection between the core and the lower extremity.[36] Therefore, fatigue of the GMed could cause a decline in postural control and impairments in the quality of movement, as we observed.

Baseline measurements of the LSDT displayed lower scores than postfatigue measurements for both sexes, indicating a reduction in the quality of movement during the task that might be caused by fatigue and the inability of the GMed to stabilize the pelvis during the LSDT. Although we found no main effect for sex, prefatigue scores were higher for women than men, suggesting women have less ability to maintain dynamic postural control. According to Zeller et al,[37] women present with greater knee adduction during a single-legged squatting maneuver than men, which might account for their higher baseline scores on the LSDT. Jacobs et al[38] also found that women commonly present with weaker GMeds than men and that a negative relationship between hip-abductor strength and valgus angles of the knee exists only in women. We acknowledge that the means presented for the LSDT are composite scores and reflect only the participants' overall performances, and they should be interpreted accordingly.

The hip musculature plays an important role in transferring forces from the lower extremity toward the spine; therefore, fatigue of the GMed might cause a decline in the quality of movement and disrupt the ability to perform dynamic tasks.[36] The increase in scores on the LSDT after GMed fatigue probably was the result of impaired femoral control due to GMed dysfunction. A deficit in the GMed decreases eccentric abduction force output and control, allowing undesired femoral internal rotation and adduction.[39,40] These proximal changes translated distally, causing dysfunction down the kinetic chain. Such changes place the lower extremity in a vulnerable position for injury, specifically increasing the amount of stress placed on the anterior cruciate ligament[11,25] and the risk of patellofemoral pain syndrome and other overuse injuries.[12]

Decreasing GMed fatigability might decrease the occurrence of undesirable lower extremity positions and will prevent greater valgus movement at the knee joint, reducing the amount of stress on the anterior cruciate ligament and decreasing the risk of injury.[11,25,41] With less activation from the GMed, the body experiences impaired postural control. Such impairment compromises the ability to perform voluntary motor skills and might limit specific movements and function.[42,43] We conclusively demonstrated that both postural control and quality of movement are compromised when the GMed is fatigued. Decreasing GMed fatigability might help encourage equalized muscle activation, allowing the body to produce functional movements while maintaining trunk stability.[1] Targeting the GMed in conditioning and rehabilitation of lower extremity injuries might reduce overuse conditions by improving dynamic hip stabilization and lower extremity kinematics.

A potential limitation of our study is that the rate of fatigue of the GMed between men and women was not considered in this model because all participants exercised until they reached the same level of spectral shifts in surface EMG. We did not monitor EMG of the GMed during the concentric phase of the exercise, so we do not know how the concentric phase of the exercise contributed to the fatigue that was induced in this study. We did not measure the amount of force during the fatiguing exercise; therefore, we cannot draw conclusions about the force-generating capabilities of the GMed. Finally, the results of the LSDT suggest participants used altered movement strategies while performing the challenging task; however, no data regarding the validity of this measure or the implications for injury risk in people with poorer scores are available.

Future investigators should implement a sex comparison of the fatigability of the GMed and a group comparison of healthy participants and participants with GMed weakness. Comparison of sexes during sport-specific activities might provide better insight into the functional involvement of the GMed. Additional studies in which investigators evaluate muscular activation patterns might help us better understand sex strategies and the importance of the GMed specific to men and women during more functional activities.

CONCLUSIONS

Postural control and quality of movement as measured dynamically with the SEBT and statically with COP were affected negatively after a GMed-fatiguing exercise. No sex differences were observed after the fatiguing task, which suggested that at similar levels of local muscle fatigue, men and women had similar measurements of postural control and quality of movement.

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