Gluteal muscle activation during running in females with and without patellofemoral pain syndrome

John D. Willson a,⁎, Thomas W. Kernozek a, Rebecca L. Arndt b, Daniel A. Reznick b, J. Scott Straker b

a La Crosse Institute for Movement Science, Department of Health Professions, Physical Therapy Program, University of Wisconsin — La Crosse, 1725 State Street, LaCrosse, WI, 54601, USA
b Gundersen Lutheran, Sports Medicine, 311 Gundersen Drive, Onalaska, WI, 54650, USA

Article history:
Received 10 October 2010
Accepted 17 February 2011

Abstract

Background: Hip and knee joint motion in the transverse and frontal plane during running may increase patellofemoral joint stress and contribute to the etiology of patellofemoral joint pain. We evaluated the association between these kinematics and the magnitude and timing of gluteus medius and maximus activity during running in females with patellofemoral pain. We also compared the magnitude and timing of gluteal muscle activity during running between females with and without patellofemoral pain.

Methods: Twenty females with patellofemoral pain and twenty females without knee pain participated in this study. Three-dimensional running kinematics, gluteus medius and maximus onset time, activation duration, mean activation level, and peak activation level were recorded simultaneously. Gluteal muscle timing and activation level were compared between groups using independent t-tests. The association of gluteal muscle activation parameters running kinematics in females with patellofemoral pain was quantified using Pearson correlation coefficients.

Findings: Females with patellofemoral pain demonstrated delayed (P = 0.028, effect size = 0.76) and shorter (P = 0.01, effect size = 0.88) gluteus medius activation than females without knee pain during running. The magnitude and timing of gluteus maximus activation was not different between groups. Greater hip adduction and internal rotation excursion was correlated with later gluteus medius and gluteus maximus onset, respectively.

Interpretation: Neuromuscular control differences of the gluteal muscles appear to exist among females with patellofemoral pain during running. Interventions to facilitate earlier activation of these muscles may be warranted among females with patellofemoral pain who demonstrate altered running kinematics.

⁎ Corresponding author at: 4075 Health Science Center, Department of Health Professions — Physical Therapy Program, University of Wisconsin — La Crosse, 1725 State Street, La Crosse, WI 54601, USA.
E-mail address: willson.john@uwlaux.edu (J.D. Willson).

1. Introduction

Running is a popular activity with levels of participation ranging from recreational jogging to amateur and professional competitive racing. An estimated 35.9 million Americans run as a recreational pursuit with 10.5 million running at least 100 days per year (USA Track & Field, 2003). Unfortunately, up to 80% of runners may experience an overuse injury sometime during their running career (Kerner and D’Amico, 1983; Lysholm and Wiklander, 1987; McQuade, 1986). Patellofemoral pain (PFPS) is a commonly cited lower extremity overuse injury, estimated to account for over 20% of all visits to an outpatient sports medicine center (Taunton et al., 2002). Recent studies also suggest that a gender bias exists for PFPS with females being two times more likely to develop PFPS than males (Boling et al., 2009, Taunton et al., 2002).

Individuals with PFPS have been found to demonstrate altered hip joint kinematics during a wide variety of activities. Most notably, a three-dimensional motion analysis of females with PFPS revealed increased hip internal rotation (femur motion relative to pelvis) during single leg squat, running, and jumping compared to females without PFPS (Souza and Powers, 2009a). Using dynamic magnetic resonance imaging (MRI), these same authors reported that females with PFPS displayed increased femoral internal rotation (femur motion relative to MRI field of view) during a single leg squat (Souza et al., 2010). Females with PFPS have also been found to display greater hip adduction during single leg squats, running, and jumping compared to a group of females without PFPS (Willson and Davis, 2008). Increased hip adduction and knee abduction during walking have been observed among females with PFPS with the most pain as reported on a visual analog pain scale (Salsich and Long-Rossi, 2010). These transverse and frontal plane rotations are believed to reduce patellofemoral contact area, increase patellofemoral joint stress, and provoke PFPS symptoms (Besier et al., 2008; Huberti and Hayes 1984; Lee et al., 2003; Salsich and Perman, 2007).

One of the most consistent published findings among individuals with PFPS is decreased hip strength (Prins and van der Wurff, 2009).

See this article on the journal's website.
Clinicians and researchers intuitively link findings of decreased hip abduction, external rotation, and extension strength with altered hip joint kinematics among people with PFPS. Experimentally, however, the association between hip strength and hip joint kinematics appears to be rather weak (Dierks et al., 2008; Souza and Powers, 2009b; Willson and Davis, 2009). This suggests that hip strength deficits alone may not adequately account for differences in lower extremity kinematics frequently observed in females with PFPS during weight bearing activities.

Altered neuromuscular control of muscles resisting hip adduction or internal rotation may contribute to the observed kinematic differences during running between females with and without PFPS. Delayed activation of the hip abductors may reduce frontal plane hip joint stiffness and increase hip and knee joint excursions during weight bearing activities (Chaudhari and Andriacchi, 2006). Interestingly, during stair ascent, females with PFPS demonstrated delayed gluteus medius (GMED) onset relative to females without PFPS (Boling et al., 2006; Brindle et al., 2003; Cowan et al., 2009). However, to our knowledge, GMED and gluteus maximus (GMAX) timing parameters during running have not been examined in this population. Further, the association of these GMED and GMAX activation parameters with hip and knee frontal and transverse plane rotations among females with PFPS during running has not been reported.

A greater understanding of gluteal muscle activation patterns during running in females with PFPS may facilitate development of clinical interventions to improve altered running mechanics in these individuals. Therefore, the purpose of this study was to examine the magnitude and timing of GMED and GMAX activities among females with and without PFPS during running. In addition, this study examined the association between the magnitude and timing of GMED and GMAX activation and transverse and frontal plane hip and knee joint excursions during running that may contribute to the etiology or exacerbation of PFPS. Based on limited previous studies, we hypothesized that females with PFPS would demonstrate delayed GMED and GMAX activation of shorter duration but in higher magnitude than healthy controls during running. We further hypothesized that a delayed onset, shorter duration, and increased magnitude of GMED and GMAX activation would be associated with and without PFPS. During testing in order to reduce variability that may be caused by different shoe absorption properties.

### 2. Methods

The study protocol was approved by the university institutional review board and all subjects provided informed consent prior to participation. Using an alpha level of 0.05, a beta level of 0.2, and estimates of gluteal muscle activation variability from previous literature and pilot data, 19 participants per group were calculated to be necessary to identify between-group differences with effect sizes greater than 0.8 (Souza and Powers, 2009a). Participants were recruited from three area universities and two community fitness centers. All participants were female runners, 18–35 years old, who ran at least 10 miles per week and reported their activity level as greater than or equal to 5 out of 10 on the Tegner activity scale (a measure of regular participation in recreational sports activities that require running or jumping) (Tegner and Lysholm, 1985) (Table 1). All subjects who were pregnant, reported known cardiovascular pathology, or trauma resulting in injury or surgery to either lower extremity in the last 12 months were excluded from participation. Control group subjects had to be free of lower extremity symptoms for the last two years.

Forty two potential participants with complaints of knee pain during running were screened by a licensed physical therapist for specific criteria to be included in the PFPS group. These criteria included a verbal pain score of at least a 3 (moderate) on a 10 point verbal pain scale during running and squatting, prolonged sitting, ascending or descending stairs, or jumping. Potential participants must have also described pain behind or adjacent to the patella and not solely at the iliotibial band, patellar tendon, or knee-joint line. Knee symptoms were required to be of insidious onset and present for at least 2 months in duration. Participants with PFPS had to report that their symptoms were exacerbated with manual compression of the patella into the trochlear groove with the knee in 15° of flexion or with palpation of the medial or lateral patellar retinaculum against the posterior patellar surface. Lastly, participants with PFPS were required to score less than 85/100 on the Anterior Knee Pain Scale (Kujala et al., 1993). Fifteen points on this scale have been determined to be the minimum clinically important difference from healthy controls (Watson et al., 2005). Potential participants were excluded if they presented for screening tests with signs and symptoms of meniscus or ligament pathology, were currently receiving supervised treatment for PFPS, or reported symptoms in either foot, ankle, hip or low back that were exacerbated by running.

Screening of potential PFPS participants continued until 20 females with PFPS and 20 healthy females were identified and agreed to participate in this investigation. Ten of the 20 PFPS participants reported bilateral symptoms. For these participants, the most symptomatic lower extremity was chosen for analysis. The right lower extremity of the healthy control group subjects was used for analysis. All participants wore the same type of shoe (model 629, New Balance, Boston, MA, USA) during testing in order to reduce variability that may be caused by different shoe absorption properties.

#### 2.1. Procedure

Participants were prepared for electromyography assessment by a light abrasion and cleansing of the skin with isopropyl alcohol for the application of surface electrodes. The electrode for the gluteus medius was applied superior to the greater trochanter on a line to the most lateral aspect of the iliac crest. The electrode for the gluteus maximus was applied half the distance between the greater trochanter and the sacrum on an oblique angle (Cram et al., 1998). Preamplified single differential surface electrodes (DE-2.1, DelSys Inc., Boston, MA, USA) with an interelectrode distance of 10 mm and a common mode rejection ratio of 92 dB were used to record activity of each muscle. The signal to noise ratio for each electrode was visually inspected during resisted hip abduction and hip extension and then taped down to reduce movement based artifact. In addition, all subjects wore compression shorts over the electrodes to limit the potential for movement artifact and increase the likelihood of skin contact during testing.

Single adhesive ground electrode was placed over the medial malleolus. The electrode for the gluteus medius was applied superior to the greater trochanter on a line to the most lateral aspect of the iliac crest. The electrode for the gluteus maximus was applied half the distance between the greater trochanter and the sacrum on an oblique angle (Cram et al., 1998). Preamplified single differential surface electrodes (DE-2.1, DelSys Inc., Boston, MA, USA) with an interelectrode distance of 10 mm and a common mode rejection ratio of 92 dB were used to record activity of each muscle. The signal to noise ratio for each electrode was visually inspected during resisted hip abduction and hip extension and then taped down to reduce movement based artifact. In addition, all subjects wore compression shorts over the electrodes to limit the potential for movement artifact and increase the likelihood of skin contact during testing. A single adhesive ground electrode was placed over the clavicle. The surface electrodes were sampled at 1080 Hz and were interfaced with an amplifier (Bagnoli-4, DelSys Inc., Boston, MA, USA) with 20–450 Hz band-pass filter and an overall gain of 10,000. The EMG signals were digitized through a 12-bit A/D board synchronized with a force platform and motion analysis data.

The muscle activity data during running were normalized to a maximum voluntary isometric contraction (MVIC) recorded for each muscle just prior to the running trials. The gluteus medius MVIC was recorded with the participant side-lying with their involved knee straight and their hip in zero degrees of flexion, abduction, and external rotation. An adjustable nylon strap (length = 210 cm, width = 4.5 cm) was placed around the distal thigh and examination table to resist hip abduction (Orthopedic Physical Therapy Products, product number 635, Minneapolis, MN, USA). The gluteus maximus

### Table 1

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age [yrs]</th>
<th>Weight [kg]</th>
<th>Height [m]</th>
<th>Miles run/week</th>
<th>Running experience [yrs]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td>21.6 (4.5)</td>
<td>62.1 (8.9)</td>
<td>1.69 (0.09)</td>
<td>21.1 (12.2)</td>
<td>5.0 (3.6)</td>
</tr>
<tr>
<td>PFPS</td>
<td>21.3 (2.6)</td>
<td>62.9 (7.7)</td>
<td>1.68 (0.06)</td>
<td>15.6 (8.1)</td>
<td>4.1 (3.1)</td>
</tr>
</tbody>
</table>

#### Subjects

- **Healthy**: 20 females
- **PFPS**: 20 females

#### Note

- The table presents average (SD) subject demographics for females with patellofemoral pain (PFPS) and without (Healthy).

---

J.D. Willson et al. / Clinical Biomechanics 26 (2011) 735–740
DVIC was recorded with the participant in a prone position on an examination table with their hip in 0° of flexion and their knee in 90° of flexion. A nylon strap over the posterior thigh resisted hip extension. Participants performed two practice trials prior to collection of a single 5-second MVIC trial for each muscle.

After completion of the MVIC trials, subjects were prepared for 3D motion analysis testing. Reflective markers were placed on the leg and pelvis of the involved limb (PFPS group) or right limb (control group). The three-dimensional coordinates of these markers were used to track the motion of the pelvis, femur, shank, and foot, each modeled as a rigid body. Anatomical markers used to establish the segmental-coordinate systems were placed over each ilac crest, the greater trochanters, medial and lateral femoral condyles, medial and lateral proximal tibia, medial and lateral malleoli, the first and fifth metatarsal heads, and the tip of the shoe. Tracking markers, which remained in place for all of the running trials, were positioned as a cluster of 3 markers on the rearfoot of the shoe, a cluster of 4 markers on the posterior shank, a cluster of 4 markers on the lateral thigh, and 3 markers for the pelvis on each anterior superior iliac spine and at the LS-S1 interspace. The knee and ankle joint centers were computed as the midpoint of a line between the femoral condyles and malleoli markers, respectively. The hip joint center was identified using the Newton iterative spherical fitting algorithm on data recorded during a standing trial where the instrumented leg was moved in a prescribed fashion prior to the running trials (Hicks and Richards, 2005). During this trial, participants stood on their contralateral leg while moving their free leg through two arcs of approximately 80° hip flexion and two arcs of 50° hip abduction. Following both the standing calibration trial and hip center movement trial, each of the anatomical markers was removed.

Next, all participants were asked to run along a 20 meter runway between 3.52 and 3.89 m/s as indicated by the forward velocity of the runway. Marker trajectories were digitally filtered using a bi-directional 4th order Butterworth filter. All lower extremity joint angles during the stance phase of each running trial were calculated with Visual 3D software (C-Motion Inc., Rockville, MD, USA) using a Cardan sequence of rotations which first calculated hip and knee flexion–extension, followed by abduction–adduction, and internal–external rotation, respectively. Joint kinematic conventions were defined using the right hand rule. Hip and knee frontal and transverse plane joint excursions were calculated from the time of initial contact with the force plate to the time of peak vertical ground reaction force for each running trial using custom software (LabView 8.6, National Instruments, Austin, TX, USA). Kinematic data were not normalized to the static neutral trial. In other words, zero degrees corresponded to an erect posture at the hip and knee.

All EMG data (MVIC trials and running trials) were high pass filtered using a bi-directional, 4th order Butterworth filter with a cutoff frequency of 30 Hz, then full-wave rectified and low-pass filtered using a bi-directional 4th order Butterworth filter with a cutoff frequency of 6 Hz, and normalized to peak activity recorded during the MVIC trial (Besier, et al., 2003). The normalized, processed EMG data were analyzed with custom software (LabView 8.6, National Instruments, Austin, TX, USA) to determine four variables of interest during the running trials: muscle activation onset time relative to foot contact, muscle activation duration, peak activation level, and average activation level. Gluteus medius and gluteus maximus onset activation were determined by examining a 500 ms window prior to foot contact with the force platform during the running trials. A 10 N threshold was used to determine foot contact based on the onset of the vertical ground reaction force. The threshold voltage required for muscle activation onset was calculated based on five standard deviations above the resting mean activation at baseline. Muscle activation onset relative to foot contact was defined as the time that the muscle activation remained above this threshold for 25 consecutive milliseconds during each running trial (Brindle et al., 2003). Similarly, muscle activation was considered terminated when the activation level fell below this threshold for more than 25 ms during the running trial. The onset and termination of muscle activation were visually confirmed during data processing (Hodges and Bui, 1996). The time interval between these two events was defined as the muscle activation duration. The peak normalized value and the average activation level were also determined during this time interval. The reliability of each of these variables has been found to be acceptable in previous studies of lower extremity muscle activation during dynamic movements (ICC values 0.81–0.93) (Bolgla and Uhl, 2007; Bolgla et al., 2010; Cowan et al., 2001; Smoliga et al., 2010).

The average muscle activation and kinematic variables of interest from all five running trials were calculated and used for analysis. Independent t-tests were used to test for differences in gluteus medius and gluteus maximus muscle onset time, activity duration, peak activation, and average activation between females with and without PFPS (alpha=0.05). The linear bivariate association of each muscle activation variable with hip and knee transverse and frontal plane joint excursions from initial contact to peak vertical ground reaction force among females with PFPS was evaluated using Pearson correlation coefficients. All statistical procedures were performed in SPSS (version 17, SPSS Inc., Chicago, IL, USA).

### Table 2

<table>
<thead>
<tr>
<th>Group</th>
<th>Peak activation [% MVIC]</th>
<th>Average activation [% MVIC]</th>
<th>Onset prior to foot contact [ms]</th>
<th>Activation duration [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gluteus medius</td>
<td>102.9 (52.5)</td>
<td>64.8 (30.9)</td>
<td>59.7 (32.6)</td>
<td>193.6 (38.7)</td>
</tr>
<tr>
<td>Healthy</td>
<td>112.4 (35.3)</td>
<td>81.4 (29.8)</td>
<td>35.2 (32.3)*</td>
<td>1512 (57.5)*</td>
</tr>
<tr>
<td>PFPS</td>
<td>76.4 (36.4)</td>
<td>51.6 (27.3)</td>
<td>60.9 (58.1)</td>
<td>185.6 (67.6)</td>
</tr>
</tbody>
</table>

However, gluteus medius activation prior to foot contact occurred 24 ms earlier among healthy females \( P=0.028 \), effect size = 0.76) and activation duration was 42 ms longer than females with PFPS \( P=0.01 \), effect size = 0.88). No differences in gluteus maximus activation timing or magnitude were identified between females with and without PFPS.

Hip joint excursion in the transverse and frontal plane was correlated with gluteus medius and gluteus maximus activation onset time (Table 3). Specifically, greater hip adduction excursion during running was moderately correlated with activation onset times closer to foot contact (later onset) for both the gluteus medius and gluteus maximus (Figs. 1 and 2). Greater hip internal rotation excursion was also moderately correlated with later gluteus maximus activation onset times (Fig. 3). No association between knee transverse or frontal plane joint excursion and gluteus medius or maximus activation parameters was found (Table 3).

### 3. Results

Peak and average gluteus medius activation during running were not different between female participants with and without PFPS (Table 2). However, gluteus medius activation prior to foot contact occurred 24 ms earlier among healthy females \( P=0.028 \), effect size = 0.76) and activation duration was 42 ms longer than females with PFPS \( P=0.01 \), effect size = 0.88). No differences in gluteus maximus activation timing or magnitude were identified between females with and without PFPS.

Hip joint excursion in the transverse and frontal plane was correlated with gluteus medius and gluteus maximus activation onset time (Table 3). Specifically, greater hip adduction excursion during running was moderately correlated with activation onset times closer to foot contact (later onset) for both the gluteus medius and gluteus maximus (Figs. 1 and 2). Greater hip internal rotation excursion was also moderately correlated with later gluteus maximus activation onset times (Fig. 3). No association between knee transverse or frontal plane joint excursion and gluteus medius or maximus activation parameters was found (Table 3).
variables during running for patellofemoral pain syndrome (PFPS) participants. *P<0.05.

In contrast to the gluteal activation timing parameters, this study did not identify a difference in GMED or GMAX activation level during running between females with and without PFPS. Souza and Powers (2009a) reported 91% greater average normalized GMAX activation among females with PFPS during running. Differences in methodology may help explain these conflicting results. The current study calculated average normalized gluteal EMG activation while the activation level exceeded a threshold value prior to and during foot contact. We chose this analysis technique based on pilot studies revealing that approximately 25% of the duration of gluteal muscle contractions during running occurred during the flight phase prior to foot contact. Indeed, among females with PFPS in this study, 23% and 32% of the duration of GMED and GMAX contractions occurred prior to stance phase, respectively. We also noticed during pilot testing that GMED and GMAX contractions typically end near 50% of stance phase while running and we did not wish to include the activity level of a resting muscle in our calculation of average muscle activity. Souza and Powers (2009a) calculated average normalized gluteal EMG activation during the stance phase of running. Therefore, the recording period in this previous study excluded anticipatory gluteal muscle activation prior to initial contact and included activation during the second half of stance phase, when muscle activity for our subjects was minimal. Although not statistically significant, it is worth noting that average GMED activation level among females with PPSS was substantially greater than females without PPSS. Specifically, GMED activation level was 25% greater among females with PPSS (effect size = 0.55), which is sufficient to speculate that a clinically meaningful difference exists and future studies with more participants seem justified. A post hoc power analysis using these data indicates that 53 subjects per group would be necessary for this difference to be statistically significant.

The second aim of this study was to examine the association of GMED and GMAX activation parameters with transverse and frontal plane hip and knee joint motion during running in females with PPSS. A moderate association was found between GMED onset time and hip

### 4. Discussion

The first aim of this study was to examine the timing and magnitude of GMED and GMAX EMG activation among females with and without PFPS during running. The PFPS group demonstrated a delayed GMED onset time and shorter GMED activation duration, but no differences in GMAX onset time or activation duration were found. Additionally, no statistically significant differences in peak or average GMED and GMAX activation were found among groups. Relative to the number of studies that have examined the hip strength in individuals with PFPS, there is a dearth of literature examining recruitment parameters of muscles that resist hip motion in the transverse and frontal planes. To our knowledge, this is the first investigation to measure GMAX and GMED activation onset time and duration in females with PPSS during running. Three previous studies have examined gluteus medius activation timing parameters during stair-stepping tasks in subjects with PPSS. Brindle et al. (2003) and Cowan et al. (2009) both identified a statistically significant delay in gluteus medius onset during stair climbing among subjects with PPSS compared with a healthy control group. Boling et al. (2006) also reported delayed gluteus medius onset among subjects with PPSS, but larger variability observed in their data diminished the statistical differences of their findings. Only a single investigation has compared GMED activation duration among subjects with and without PPSS. Brindle et al. (2003) reported that participants with PPSS demonstrated a shorter duration gluteus medius activation time during their stair stepping task. Therefore, our results appear to be consistent with Brindle et al. (2003) and Cowan et al. (2009) in that females with PPSS demonstrated delayed onset and shorter duration GMED activation during running. The fact that our results during running support the findings of previous studies during a stair climbing task it appears to suggest that altered neuromuscular recruitment of the GMED among females with PPSS may occur for relatively slow and dynamic movement activities alike.

### Table 3

Pearson correlation coefficients (r) and significance levels (P) between hip and knee kinematic measures (degrees) and gluteus medius (GMED) and gluteus maximus (GMAX) variables during running for patellofemoral pain syndrome (PFPS) participants. *P<0.05.

<table>
<thead>
<tr>
<th>Variable</th>
<th>GMED</th>
<th>GMAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip adduction excursion [deg]</td>
<td>r 0.04, P 0.87</td>
<td>r 0.91, P 0.68</td>
</tr>
<tr>
<td>Hip internal rotation excursions [deg]</td>
<td>r -0.03, P 0.49</td>
<td>r 0.11, P 0.47</td>
</tr>
<tr>
<td>Knee adduction excursion [deg]</td>
<td>r 0.19, P 0.75</td>
<td>r 0.47, P 0.47</td>
</tr>
<tr>
<td>Knee internal rotation excursion [deg]</td>
<td>r 0.19, P 0.49</td>
<td>r 0.47, P 0.47</td>
</tr>
<tr>
<td>Variable GMED</td>
<td>Peak [%mvic] -0.49</td>
<td>Peak [%mvic] -0.39</td>
</tr>
<tr>
<td></td>
<td>Onset [ms] -0.22</td>
<td>Onset [ms] -0.39</td>
</tr>
<tr>
<td></td>
<td>Duration [ms] 0.38</td>
<td>Duration [ms] 0.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable GMAX</td>
<td>Peak [%mvic] 0.14</td>
<td>Peak [%mvic] 0.066</td>
</tr>
<tr>
<td></td>
<td>Average [%mvic] 0.17</td>
<td>Average [%mvic] 0.075</td>
</tr>
<tr>
<td></td>
<td>Onset [ms] -0.52</td>
<td>Onset [ms] 0.068</td>
</tr>
<tr>
<td></td>
<td>Duration [ms] -0.20</td>
<td>Duration [ms] 0.10</td>
</tr>
</tbody>
</table>

Fig. 1. Scatter plot of gluteus medius activation onset time relative to foot contact during running versus hip adduction excursion from foot contact to peak vertical ground reaction force. Positive values on the y-axis represent earlier activation. Positive values on the x-axis represent greater hip adduction excursion.

Fig. 2. Scatter plot of gluteus maximus activation onset time (ms) relative to foot contact during running versus hip adduction excursion (degrees) from foot contact to peak vertical ground reaction force. Positive values on the y-axis represent earlier activation. Positive values on the x-axis represent greater hip adduction excursion.
aduction excursion as well as between GMAX onset time and both hip adduction and hip internal rotation excursion. It has been proposed that delayed GMED recruitment may contribute to decreased frontal plane hip joint stiffness in the presence of vertical ground reaction forces (Chaudhari and Andriacchi, 2006). However, this association has not been previously observed in living subjects. While the correlations in this study are intriguing, it is worth noting that a considerable proportion of the variability in hip joint kinematics is not explained by gluteal activation timing variability. Without accounting for shared variance among gluteal activation parameters, delayed onset of GMED and GMAX accounted for 24% and 27% of the variability in hip adduction excursion, respectively. Delayed GMAX activation accounted for 23% of the variability in hip internal rotation excursion. However, the variance in hip kinematics explained by gluteal activation timing parameters is at least as large as that explained by hip strength alone in previous studies (Souza and Powers, 2009b; Willson and Davis, 2009). As such, these findings appear clinically meaningful and may suggest that interventions to improve altered lower extremity kinematics among female runners with PFPS should not focus on hip strengthening alone. Indeed, hip adduction and external rotation strengthening was not found to decrease hip adduction motion or result in changes in frontal plane hip or knee joint moments during running outside the range of potential measurement error (Snyder et al., 2009). Conversely, the addition of visual performance based feedback to a general lower extremity strengthening program elicited greater changes in frontal plane hip kinematics during jumping than a strengthening program alone (Herman et al., 2009). Together, these studies speak to the potential of neuromuscular training and movement based feedback for improving altered hip and knee kinematics.

The main findings of this study were delayed GMED onset activation and a moderate correlation of GMED and GMAX activation onset times with transverse and frontal plane hip joint excursion during running among females with PFPS. However, these data were collected after the participants developed PFPS. As such, it is impossible to discern whether these differences existed prior to development of PFPS or if they represent a response to PFPS. To our knowledge, anticipation of PFPS has not been reported to affect gluteal neuromuscular recruitment parameters. However, the expectation of pain has been found to affect anticipatory muscle recruitment in other regions, in people both with and without chronic pain. For example, among healthy subjects, Moseley et al. (2004) reported delayed activation of deep trunk muscles preceding voluntary arm movement when participants expected experimentally induced back pain. It is conceivable, therefore, that the anticipation of patellofemoral pain may have delayed the activation onset of gluteal musculature during the lower extremity movements associated with running. However, at this time it is unclear how such a response strategy would be beneficial for individuals with PFPS. Indeed, as stated above, delayed activation of hip abductor muscles may facilitate knee adduction excursion and knee alignment during weight bearing that is not thought to be beneficial to the patellofemoral joint (Besier et al., 2008; Lee et al., 2003).

The associations between gluteal neuromuscular control and hip kinematics in this study do not imply a cause and effect relationship. However, two recent prospective studies provide some early evidence that hip neuromuscular control may contribute to the etiology of PFPS. Myer et al. (2010) determined that athletes who later developed PFPS demonstrated increased knee abduction moment at initial contact during drop landings. The authors postulated that these greater knee abduction moments may be a reflection of altered hip abductor recruitment prior to and during the drop landing performance. Boling et al. (2009) recently reported that increased peak hip internal rotation during a jump landing task was a significant predictor for PFPS development. Together, our results and these prospective studies suggest that future studies of the etiology of PFPS should consider including measures of gluteal activation parameters.

If subsequent studies support that earlier anticipatory GMED and GMAX activation during terminal swing decrease hip adduction and hip internal rotation excursion, these results may have relevance with respect to rehabilitation interventions for individuals PFPS who demonstrate altered hip kinematics during the loading phase of running. Previous studies suggest that clinical interventions may change the timing and amplitude of lower extremity anticipatory contractions during gait. For example, a 10 session, progressive perturbation training protocol has been reported to minimize high knee muscle cocontraction indexes during the terminal swing phase of gait among individuals after ACL injury (Chmielewski et al., 2005). Additionally, a progressive GMAX facilitation program including manual and visual facilitation techniques has been reported to decrease hamstring activation during the swing phase of running among an individual with exercise-associated cramping of the hamstrings (Wagner et al., 2010). It is conceivable that the intervention strategies used in these studies may be adapted to facilitate earlier GMED or GMAX activation during running and reduce altered hip joint kinematics that are detrimental to the patellofemoral joint.

Notable limitations exist for this study. Participants were female runners aged 18–35 years, and our findings may not generalize well to males or even females of different ages. It may be a limitation that all data for females without PFPS were collected using the right leg. Significant between-leg variability of hip and knee joint transverse and frontal plane kinematics has been reported (Zifchack and Davis, 2008). While this variability is expected to be random and should not systematically affect our results, future case–control studies should consider matching the side of PFPS subjects to control group subjects. Reflective markers placed on the skin and surface electrodes were to measure hip and knee kinematics and gluteal muscle activity, respectively. Skin movement may have influenced the location of the motion analysis markers during data collection. Skin movement over of the muscles of interest during running as well as other factors including ambient noise and motion artifact may have also influenced EMG measures of gluteal muscle activity during running. These errors were anticipated and included in the a priori sample size calculation on the assumption that the errors are random rather than systematic, which facilitates between-group comparisons. Finally, eight gluteal activation parameters were compared between groups and 32 correlation coefficients were tested against the null hypothesis, which raises concern over the family-wise Type I error rate for this study. Therefore, due to the large number of tests, readers are cautioned that some spurious statistically significant findings may exist in these results. However, in order to perform a Type I error, the null hypothesis needs to be true. In the absence of evidence to the contrary of these findings, there is little basis for drawing that conclusion. Future studies are necessary to cross-validate or refute these findings.

![Fig. 3. Scatter plot of gluteus maximus activation onset time (ms) relative to foot contact during running versus hip internal rotation excursion (degrees) from foot contact to peak vertical ground reaction force. Positive values on the y-axis represent earlier activation. Positive values on the x-axis represent greater hip internal rotation excursion.](image-url)
5. Conclusions

Females with PFPS demonstrated delayed onset and shorter duration GMED activation during running compared with females without PFPS. Delayed onset of both the GMED and GMAX was associated with increased hip adduction excursion and later onset time of GMAX was associated with increased hip internal rotation excursion during running in females with PFPS. Our research design prohibits a conclusion that delayed GMED and GMAX activation predisposes female runners with PFPS to hip adduction and hip internal rotation. However, these findings appear to suggest that one mechanism to improve altered lower extremity transverse and frontal plane running kinematics in females with PFPS may be to develop interventions promoting earlier GMED and GMAX activation.

References


