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ORIGINAL RESEARCH

Altered tensor fasciae latae activation during functional movements in women with patellofemoral pain

Dave Clark[1], Sarah Martinez-Sepanski[2], Jennifer Caputo[1], Kelton Mehls[3], Sandra Stevens[4], John Coons[2]

[1] Department of Health and Human Performance, Middle Tennessee State University, Murfreesboro, TN, USA. [2] Department of Human Performance and Sport Sciences, Tennessee State University, Nashville, TN, USA. [3] Department of Athletic Training, Duquesne University, Pittsburgh, PA, USA. [4] Department of Occupational Therapy, Belmont University Nashville, TN, USA.

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Abstract

Patellofemoral pain syndrome (PFP) is a chronic injury seen in both the athletic and clinical setting. Because the cause of PFP is multifactorial, health professionals need to consider muscle activity differences in women with PFP compared to healthy controls to better diagnose, prevent, and rehabilitate this injury. Therefore, the aim of this study was to examine muscle activity differences during functional movements in women ($N = 21$) with PFP and their pain-free counterparts. Surface electromyography (sEMG) of the musculus gluteus medius (GMED), musculus gluteus maximus (GMAX), musculus abductor longus (AL), and the musculus tensor fasciae latae (TFL) in women diagnosed with PFP ($n = 9$; Age = 25.99 ± 8.4 years) and pain-free controls ($n = 12$; Age = 23.5 ± 6.5 years) during the forward lunge, lateral step down, and single leg squat. Peak muscle activity of the GMED, GMAX, and AL were not significantly different between groups for any movement; however, peak TFL activity was significantly higher in the PFP group during the descent phase ($p = .015$), and ascent phase ($p = .010$) of the forward lunge. In addition, peak TFL activity was significantly higher in the PFP group during the descent phase of the lateral step down ($p = .042$) and the ascent phase ($p = .046$) of the single leg squat. Women with PFP demonstrated higher peak TFL activity during functional movements. The results of this study provide critical information for healthcare and fitness professionals that can guide clinical assessments and treatment outcomes for individuals with PFP.

Introduction

Patellofemoral pain (PFP) is described as generalized knee pain located behind the patella or along its medial and/or lateral borders (Brechter & Powers, 2002), usually during squatting and stair ambulation (Crossley et al., 2019). The etiology of PFP is not fully understood, but it is hypothesized that lack of strength and neuromuscular control causes excessive hip abduction and internal rotation, which are associated with PFP (Ferreira et al., 2018; Selkowitz et al., 2022). Many researchers have compared muscle activity patterns of the gluteal and quadricep muscles in persons with and without PFP, but results are conflicting depending on the movement investigated.

Multiple studies indicate alterations in muscle activation within the lower extremity musculature of individuals with PFP. Mirzaie et al. (2019) reported that males with PFP exhibited altered activation patterns of the musculus gluteus medius (GMED) and musculus vastus medialis (VM) during the single-leg squat, as well

✉ Sarah Martinez-Sepanski, E-mail: smarti59@tnstate.edu
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as altered activation of the musculus vastus lateralis (VL) during the single-leg squat stance. However, no differences were seen in musculus gluteus maximus (GMAX) activity in either task when compared to a control group. Another study by Glaviano and Saliba (2022) found that females with PFP demonstrated lower GMED and GMAX activity during a single leg squat and step-up task, greater musculus vastus medialis obliques (VMO) activity during a step-down, step-up, and lunge, and greater VL activity during the step-up and single leg squat compared to women without PFP. Contrary to these studies, Martinez et al. (2021) found no significant differences between peak muscle activities in the musculus adductor longus (AL), musculus Tensor Fascia Lata (TFL), GMED, and GMAX in women with PFP compared to women without during a 10m walk. It is reasonable to propose that alterations in hip muscle activation patterns during movements that replicate squatting and stair ambulation tasks may be associated with patellofemoral pain syndrome. However, the inconsistency of the above results suggests the effect altered neuromuscular control on PFP pathology is not fully understood.

Furthermore, a recent systematic review and meta-analysis looking at neuromuscular influence on PFP etiology concluded, with caution of interpretation due to differences in methodology, that neuromuscular differences in PFP compared to healthy controls was only found in the GMED (Rodrigues et al., 2022). Another recent systematic review by Besomi et al. (2020) investigating TFL muscle activation effect on lower limb musculoskeletal conditions concluded that the role of the TFL on lower limb injury is not well investigated, with contradictory findings. This further adds to the inconclusive outcomes of muscle hip muscle activity's role in PFP.

The tensor fasciae latae (TFL) is considered to function as both a hip medial rotator and an abductor. The TFL distal insertion point into the iliotibial (IT) band allows this muscle to also produce lateral glide of the patella (Daros et al., 2023). High activity of the TFL may cause excessive internal rotation of the femur, and IT band tension can affect patellofemoral kinematics and cause stress around the patellofemoral joint (Daros et al., 2023; Merican & Amis, 2008). As such, desired rehabilitative exercises focus on high GMAX and GMED activity, while minimizing TFL activity (Slekowtiz et al., 2024). Selkowtiz et al. (2022) compared muscle activity of the hip in persons with and without PFP during 11 exercises. Interestingly, Selkowtiz found that individuals with PFP demonstrated significantly higher TFL muscle activity in every exercise. Another recent study by Daros et al., (2023) found similar results when comparing muscle activity of females with and without PFP during multiple body weight exercises, observing that women with PFP showed greater activation in the TFL compared to their healthy counterparts. The complex role of the TFL may contribute to the etiology of PFP, especially in females who are more prone to hip internal rotation and knee valgus (Shultz, 2008).

Females have been reported to be at greater risk for PFP compared to men (Boling, 2010) due to differences in trunk and hip neuromuscular control and biomechanics in all planes of motion, increasing stress placed on the knee joint in females (Hewett, 2016). Poor lower limb alignment, specifically during weight-bearing tasks, due to increased knee valgus has been related with PFP (Rodriquez et al., 2022; Souza et al., 2010). Taking into consideration the above studies, further investigation is needed on the role of neuromuscular activation role in PFP pathology, especially for painful movements that can occur in one's daily life. As such, the purpose of this study was to determine whether women with PFP exhibited a difference in muscle activity patterns of the AL, TFL, GMED, and GMAX during functional movements when compared to a control group. The authors hypothesized that women with PFP would exhibit altered muscle activity patterns when compared to non-painful controls.

Methods

Participants attended one session. The independent variables were group: women diagnosed with PFP compared to pain-free controls. Surface electromyography (sEMG) of the GMED, GMAX, AL, and the TFL were the dependent variables.

Participants

A total of 21 adult females were recruited from the local community. Participants were excluded from the study if they had a history of patellofemoral joint surgery or patellar dislocation or if they exhibited signs or symptoms of collateral or cruciate ligament involvement, meniscal or articular pathology, iliotibial band or pes anserine tendon tenderness, patellar tendonitis, patellar apprehension sign, back pain, hip pain, sacroiliac joint pain, or knee joint effusion (Cichanowski et al., 2007; Crossley et al., 2002). For inclusion in the PFP group (n = 9; age: 25.99 ± 8.4 years; height: 167.4 ± 5.3 cm; body mass: 71.1 ± 12.2 kg), participants had to have self-reported anterior or retro-patellar pain during at least two of the following activities: kneeling, prolonged sitting, squatting, ascending stairs, descending stairs, jumping, hopping, or running. The onset of symptoms had to be unrelated to an injury or trauma and present for at least four weeks. Additional criteria to be included in the PFP group included pain provoked during a 20.3-cm step descent, during a double-legged squat, or with palpation of the patellar facets (Baldon et al., 2009; Crossley et al., 2002). For inclusion in the control group (n = 12; age: 23.5 ± 6.5 years; height: 161.5 ± 11.4 cm; body mass: 67.7 ± 10.3 kg), participants had to have no self-reported anterior or retro-patellar pain. In addition, each experimental group participant was to be matched with a control group participant with respect to age (+/- 2.5 years). This university's Institutional Review Board approved this study, and all participants signed an informed consent document prior to data collection.

Procedures

Upon arrival, participants were informed of the benefits and risks of the testing protocol and signed the informed consent document. Participants were then screened for inclusion criteria and age was recorded. Inclusion criteria were assessed using the Visual Analogue Scale (VAS; Crossley et al., 2004) self-report of pain symptoms with functional activities, which has been deemed a valid and reliable test for persons with PFP (Crossley et al., 2004). If a participant had a score higher than 0 on the VAS, the participant performed a counterbalanced screening to confirm presence of PFP during which the researcher assessed pain in the symptomatic knee with a step-down task, during a squat, and with palpation of the medial and lateral patellar facets (Crossley et al., 2002). Following completion of all inclusion criteria screening and testing, participant height was assessed to the nearest 0.1 cm using a stadiometer (SECA Corporation, Model 222, Hamburg, Germany) and body mass was measured to the nearest 0.1 kg using a digital scale (Tanita Corporation, Model BF-522, Arlington Heights, IL).

Peak muscle activity and kinematic data were measured using a Trigno wireless sEMG system (Delsys; Natick, MA). Trigno Flex sEMG sensors were affixed with double-sided adhesive tape to the skin over the mid-muscle belly of the GMED, GMAX, AL, and TFL (Hermens et al., 1999). Digital goniometers (Biometrics, Newport, UK) were affixed to the lateral side of the body for measurement of hip and knee joint angles to determine ascending and descending phases of each functional movement. Alignment landmarks were consistent with landmarks used for manual goniometry (Clarkson, 2000). For hip joint angle measurement, the proximal goniometer sensor was affixed over the lateral midline of the trunk. The distal measurement sensor was affixed over the lateral midline of the thigh, determined by a line drawn from the greater trochanter to the lateral femoral condyle. For knee joint angle measurement, the proximal goniometer sensor was affixed over the lateral midline of the thigh, and the distal goniometer sensor was affixed over the lateral tibia, determined by a line drawn from the fibular head to the lateral malleolus (Piriyaprasarth et al., 2008). Prior to sEMG and electronic goniometer placement, if necessary, hair was shaved from all areas underlying sensor placement with a safety razor and then exfoliated with Redux paste. The sensors were then reinforced with stretch adhesive covering. Location and procedures for placement of sensors on the GMED, GMAX, and TFL muscles were implemented in accordance with the SENIAM project guidelines (*SENIAM Group)*. Sensor placement for the adductor longus was based on previously established positioning (Lovell et al., 2012).

Prior to performing functional movements, participants performed three trials of maximal voluntary isometric contractions (MVIC). For each MVIC, participants were positioned to allow for maximal generation of force (Kendall et al., 1993). External resisting force was provided by the researcher. Participants performed one practice trial, followed by three MVIC trials for each movement. Instruction was given to the participant to build to a maximal level of force over a period of two to three seconds, after which time she was told to hold this maximal force against the external pressure for five seconds. A 30-second rest was given between trials. Peak sEMG data recorded during each functional movement were normalized to the sEMG MVIC of the respective muscle/muscle groups (Bolgla & Uhl, 2007).

Functional Movements

Prior to each test, participants practiced each functional movement until the movement was performed in a stable, controlled fashion. For each test, participants were instructed to perform at least five repetitions, with a 1 min rest period between repetitions to prevent fatigue. A digital metronome with a beat frequency of 60 beats per minute was used to establish a consistent speed for each movement. An external trigger device (Delsys, Natick, MA) was used to initiate and terminate data collection.

Single-leg squat: Participants were instructed to stand with their feet shoulder width apart and hands on their hips. They were then told to assume a single-leg stance, flexing the non-tested knee to 90 degrees. Participants were instructed to perform a single-leg squat as far as comfortably possible while keeping their stance foot completely on the floor. They were instructed to slowly squat as far as possible over a two second period, then return from the squat to the original stance position over a two second period, using the digital metronome to establish consistency in speed of movement.

Lateral step-down: The lateral step-down was performed in a manner originally described by Piva et al. (2006). Participants were asked to stand on a 20.3 cm high step in a single-leg stance on the leg being tested, with hands on the waist and the knee straight. The non-symptomatic leg was positioned over the floor adjacent to the step, with the knee in extension. The participants were asked to bend the tested knee until the non-symptomatic foot gently contacted the floor and then re-extend the knee to the starting position.

Forward lunge: The forward lunge was performed with the tested leg forward. Participants were instructed to first stand with feet placed adjacent to each other and hands on their hips. Participants then stepped forward with the tested leg to a point that equaled the distance from the anterior superior iliac spine to medial malleolus of the ankle (Cook et al., 2014). Maintaining hands on their hips, the participant was then instructed to lunge downward as far as possible, pause, and then return to full knee extension of the forward leg, concluding by returning to the starting position (Distefano et al., 2009; Dwyer et al., 2010).

Data Processing

Surface EMG data were initially processed using a 2nd order Butterworth band-pass filter at frequencies of 20Hz and 450Hz. These data were then smoothed using a root-mean-square (RMS) filter with a 125 ms window. All data processing was performed using EMGworks analysis software (Delsys, Model SC-S08-4.5.3, Natick, MA) and exported to Microsoft Excel (2016). Peak muscle activity was obtained during five repetitions of each functional movement and averaged to obtain a mean peak surface EMG signal for each movement. These averages were normalized to the previously obtained MVIC values. Goniometer data was used to mark and differentiate directional phases (descending and ascending) during the forward lunge and single-leg squat.

Data Analysis

The IBM© SPSS© Statistics (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp) was used for the statistical analysis. Independent samples *t* tests were used to compare normalized average peak muscle activity of the GMAX, GMED, TFL, and AL between the groups. An alpha level of .05 was used for all statistical procedures. Effect sizes for all analyses were calculated using Hedge's *g*.

Results

Peak muscle activity of the TFL was higher in females with PFP when compared to females without PFP during the descent phase ($p = .02$, $g = -1.13$) and ascent phase ($p = .01$, $g = -1.22$) in the forward lunge (see Table 1). Similar results were seen during the ascent phase of the lateral step-down and forward lunge. Peak TFL activity was higher in females with PFP when compared to females without PFP during the ascent phase ($p = .04$, $g = -0.93$) of the lateral step-down (see Table 2). Peak TFL activity was also higher in females with PFP when compared to females without PFP during the ascent phase ($p = .05$, $g = -0.90$) of the single-leg squat (see Table 3). During the forward lunge, lateral step down and single leg squat there was no significant difference in peak muscle activity of the GMED, GMAX, or AL during either the descent phase or ascent phase.

Table 1. Peak muscle activity during the forward lunge (Mean ± SD).

Muscle Tested	PFP Group	Control	*t*	*p*	*g*
AL (D)	1.01 ± 0.43	1.15 ± 0.75	0.50	.62	0.21
AL (A)	0.95 ± 0.43	1.21 ± 0.71	0.99	.33	0.42
TFL (D)	0.67 ± 0.25	0.40 ± 0.22	-2.66	.02*	-1.13
TFL (A)	0.65 ± 0.20	0.41 ± 0.19	-2.88	.01*	-1.22
GMED (D)	0.48 ± 0.55	0.29 ± 0.17	-1.14	.27	-0.48
GMED (A)	0.71 ± 0.89	0.35 ± 0.20	-1.36	.19	-0.58
GMAX (D)	0.27 ± 0.19	0.24 ± 0.13	-0.32	.75	-0.14
GMAX (A)	0.39 ± 0.20	0.33 ± 0.17	-0.73	.47	-0.31

*AL: Adductor longus; TFL: Tensor fasciae latae; GMED: Gluteus medius; GMAX; Gluteus maximus; D: Descent phase; A: Ascent phase. * $p < .05$; df: 19.*

Table 2. Peak muscle activity during the lateral step down (Mean ± SD).

Muscle Tested	PFP Group	Control	t	p	g
AL (D)	1.05 ± 0.38	1.64 ± 0.18	1.61	.13	0.60
AL (A)	1.19 ± 0.44	1.79 ± 0.13	1.51	.15	0.64
TFL (D)	0.61 ± 0.18	0.42 ± 0.21	-2.19	.04*	-0.93
TFL (A)	0.65 ± 0.23	0.49 ± 0.20	-1.71	.10	-0.72
GMED (D)	0.48 ± 0.50	0.29 ± 0.17	-1.20	.27	-0.48
GMED (A)	1.15 ± 0.54	0.43 ± 0.24	-1.38	.20	-0.68
GMAX (D)	0.22 ± 0.18	0.21 ± 0.13	-0.27	.79	-0.12
GMAX (A)	0.38 ± 0.25	0.31 ± 0.19	-0.75	.46	-0.32

*AL: Adductor longus; TFL: Tensor fasciae latae; GMED; Gluteus medius; GMAX; Gluteus maximus; D: Descent phase; A: Ascent phase. * $p < .05$; df: 19.*

Table 3. Peak Muscle Activity During the Single Leg Squat (Mean ± SD).

Muscle Tested	PFP Group	Control	*t*	*p*	*g*
AL (D)	1.13 ± 0.62	1.6 ± 1.02	1.22	.24	0.52
AL (A)	1.17 ± 0.58	1.43 ± 0.86	0.77	.45	0.33
TFL (D)	0.71 ± 0.35	0.48 ± 0.27	-1.74	.10	-0.74
TFL (A)	0.68 ± 0.35	0.42 ± 0.21	-2.14	.05*	-0.90
GMED (D)	0.64 ± 0.85	0.34 ± 0.17	-1.23	.23	-0.52
GMED (A)	1.04 ± 1.71	0.44 ± 0.26	-1.21	.24	-0.51
GMAX (D)	0.21 ± 0.14	0.21 ± 0.13	0.04	.97	0.02
GMAX (A)	0.29 ± 0.16	0.26 ± 0.18	-0.39	.70	-0.17

*AL: Adductor longus; TFL: Tensor fasciae latae; GMED; Gluteus medius; GMAX; Gluteus maximus; D: Descent phase; A: Ascent phase. * $p < .05$; df: 19.*

Discussion

The purpose of this study was to determine if hip muscle activity patterns in women with PFP differed from women without PFP during common functional movements that cause pain in persons with PFP. In the present study, women with PFP exhibited a significantly higher level of peak TFL activity during the descent and ascent phase of the forward lunge as well as the descent phase of the lateral step down and the ascent phase of the single leg squat. However, muscle activity for the AL, GMED, and GMAX were not different between women with and without PFP during the forward lunge, lateral step down, and single leg squat.

Current outcomes are similar to Selkowitz et al. (2022) who found TFL activity was significantly higher in persons with PFP when compared to controls during 11 different rehabilitative exercises. However, Selkowitz et al. also reported significantly lower GMax activity in individuals with PFP, which was not seen in the present study. To the authors' knowledge, only one other study has compared TFL muscle activity between individuals with PFP and controls without PFP (Martinez et al., 2021). Martinez et al. (2021) compared TFL muscle activity between females with and without PFP during a 10m walk, though it did not yield any significant muscle activity differences in the TFL.

The combined results of Selkowitz et al. (2022) and the present study, along with the lack of significant findings in TFL activity during a 10m walk between those with and without PFP (Martinez et al., 2021), suggest there may be increased TFL activation in motions that require larger range of movement. During larger movements, the TFL must serve as a stabilizer to compensate a non-stabilized knee joint caused by the weaker hip abductors and external rotators that have been noted in individuals with PFP. It is possible that PFP is associated with decreased stability and neuromuscular control of the external rotators and thus causes the TFL to become overactive. Higher peak muscle activity of the TFL in individuals with PFP may further increase the internal rotation of the femur which has been noted in individuals with PFP (Lio et al., 2015; Souza et al., 2009; Souza & Power, 2010).

The TFL is a complex muscle that can serve different purposes during open and closed kinetic chain movements (Neumann, 2010). In the open kinetic chain, the TFL functions as a hip flexor and abductor, whereas in the closed kinetic chain the primary function of the TFL is stabilization. For example, during the swing phase of gait, the TFL stabilizes the pelvic girdle and rotates the pelvis towards the weight bearing lower extremity when the contralateral lower extremity is unsupported (Gottschalk et al., 1989; Neumann, 2010). The TFL may act in this way to stabilize the femur by resisting external rotation during the stance phase of gait and the initial weight acceptance and deceleration phase of movement (Baker et al., 2018). However, due to the complex nature of the TFL, it may produce kinematic and kinetic effects that are beneficial in one plane but problematic in another. Over activation of the TFL during weight bearing movements may relate to the internal rotation associated with PFP, where excessive internal rotation has been known to increase patella cartilage stress in the knee in women with PFP (Liao et al., 2015).

Interestingly, there were no significant differences in the GMED and the gluteus GMAX during the lunge, lateral step-down, or single leg squat when comparing women with and without PFP. It is possible that the current study did not find significant differences between the GMED and the GMAX in individuals with and without PFP due to the intricate interplay of various factors influencing muscle activation patterns. Differences in muscle activation across different exercises can be influenced by factors like movement specificity, compensatory mechanisms, muscle imbalances, pain responses, individual variability, and training history. The study's findings align with previous research by Daros et al. (2023), which also reported no significant differences in GMED activity between individuals with and without PFP during various exercises. Daros et al. (2023) did observe higher TFL activation in those with PFP and early GMED activation in individuals without PFP, highlighting the complexity of muscle activation patterns in the presence of PFP. Additionally, a recent study reported no significant differences in GMAX activity during the single leg squat between individuals with and without PFP (Mirzaie et al., 2019), further supporting the nuanced nature of muscle activation in individuals with PFP. Despite conflicting results from other studies that reported significantly lower GMED activity during specific exercises in individuals with PFP (Glaviano & Saliba, 2022; Selkowitz et al. (2022), there are some exercises observed in each study that showed no significant differences between GMED and GMAX muscle activation between individuals with and without PFP. Glaviano and Saliba (2022) did not observe any significant differences in GMED and GMAX activity during the lateral-step down, step-up, and lunge between females with and without PFP, similar to the present study for the lateral step-down and lunge. Seklowtiz et al. (2022) found that participants with PFP demonstrated lower GMED activity in only the hip abduction exercise, hip-hike, and step-up out of 11 exercises. These collective findings underscore the intricate variability in muscle activation patterns among individuals with and without PFP during functional movements, suggesting the need for further research to comprehensively understand the interplay of factors influencing muscle activity in individuals with PFP.

As evidenced, it is difficult to identify consistent muscle activity patterns in individuals with PFP across different movements. Thus, it is challenging to draw a conclusive manifestation of PFP. This study supports the idea that the cause of PFP is multifactorial and that increased TFL activation may be causing excessive internal rotation that is often noted in patients with PFP, however further research on muscle activity patterns in individuals with PFP is essential to validate the efficacy and implications of these findings. A limitation of the current study is in the criteria for determining PFP. Unlike pathologies such as osteoarthritis, chondromalacia, or meniscal tears, PFP is a condition that is difficult to quantify. Instead, the classification and diagnosis of the problem is reliant on the history of the individual and is often made once other potential problems are excluded. While the inclusion criteria for this study were similar to that of previous studies (Baldon et al., 2009; Crossley et al., 2002), the lack of criteria that definitively assesses and/or stratifies the severity of the condition creates potential variability within persons with PFP. Furthermore, the lack of objective measurements for femoral internal rotation or valgus during the movements executed makes it challenging to draw conclusions regarding the potential correlation between the onset of PFP symptoms and dynamic femoral valgus. Lastly, the authors acknowledge the lack of power analysis for this manuscript which could comprises the statical reliability of the results. The authors advise that future studies investigating EMG activity in patients PFP include a power analysis.

Overall, this study supports the idea that the TFL adopts an increased role in stabilization of the hip during the forward lunge, lateral step-down, and single-leg squat. Due to the complex action of the TFL, an increase in activity may have secondary deleterious effects in individuals with PFP. An increase in TFL activation could produce excessive internal rotation during large ranges of motion and especially upon weight acceptance. This could be indicative of increased use of the TFL to provide stability to the lower extremity during function, perhaps concurrent with decreased recruitment by other muscles that are also responsible for providing lower extremity stability. Therefore, it may be beneficial for healthcare and fitness professionals to strengthen the external rotators and stretch the TFL in clients with PFP.

Conclusion

The results of this study showed that muscle activity of the TFL is significantly higher in persons with PFP compared to healthy counterparts during closed-chain weight bearing functional tasks. Overactivation of the TFL may produce excessive internal rotation during large ranges of motion and especially upon weight acceptance in individuals with PFP. To improve symptomology in persons with PFP, it may be beneficial for healthcare professionals to strengthen the external rotators and stretch the TFL for clients with PFP. Future research investigating the outcome of rehabilitative protocols that focus on decreasing overactive TFL and increasing external rotators activity in individuals with PFP is encouraged.

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Authors' Contribution

Study Design: Clark, Coons, Caputo, Stevens; Data Collection: Clark, Martinez-Sepanski; Statistical Analysis: Mehls, Martinez-Sepanski, Clark, Coons; Manuscript Preparation: Mehls, Martinez-Sepanski, Clark, Coons, Stevens, Caputo. Funds Collection: N/A.

Ethical Approval

The study was approved by Middle Tennessee State University's Institutional Review Board (IRB) and it was carried out in accordance with the Code of Ethics of the World Medical Association also known as a declaration of Helsinki.

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Conflict of Interest

The authors hereby declare that there was no conflict of interest in conducting this research.

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