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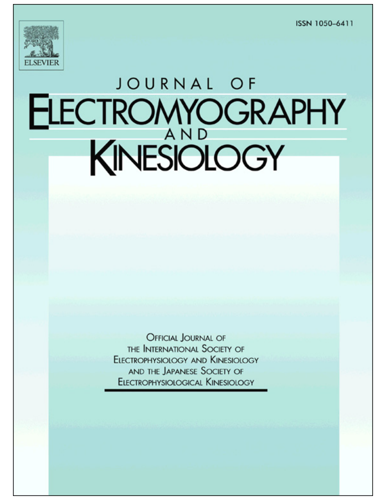

A comparison of gluteus medius, gluteus minimus and tensor facia latae muscle activation during gait in post-menopausal women with and without greater trochanteric pain syndrome

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Title: A comparison of gluteus medius, gluteus minimus and tensor facia latae muscle activation during gait in post-menopausal women with and without greater trochanteric pain syndrome.

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Keywords

tendinopathy; muscle activation; gluteal; electromyography; greater trochanteric pain syndrome

1. Introduction

Greater trochanteric pain syndrome (GTPS) is a degenerative condition of the gluteus medius (GMed) and minimus (GMin) tendons and the trochanteric/surrounding bursae that causes debilitating pain over the lateral aspect of the hip (Bird et al. , 2001, Oakley et al. , 1999, Woodley et al. , 2008). Despite limited epidemiological research, GTPS commonly affects post-menopausal women and the unilateral and bilateral prevalence of this condition is reported to be 15.0% and 8.5% respectively, in community-dwelling women between 50 and 79 years (Del Buono et al. , 2012, Lievense et al. , 2005). Clinically, these women complain of pain lying on their side, ascending and descending stairs, walking, and moving from a sitting to standing position (Collee et al. , 1990, Gordon, 1961, Karpinski and Piggott, 1985, Lequesne et al. , 2008, Schapira et al. , 1986, Shbeeb et al. , 1996, Spear and Lipscomb, 1952, Tortolani et al. , 2002, Woodley, Nicholson, 2008).

The GMed and GMin muscles are crucial for the lateral stability of the hip joint and pelvis, particularly in unilateral stance. Deficits in these stabilising muscles exist in GTPS (Allison et al. , 2016a), including GMin and GMed (Woodley, Nicholson, 2008), however the detailed activation of these muscles is unknown. Using ultrasound, GMin has been shown to activate earlier in subjects with chronic hip pain during a step down function task (Dieterich et al. , 2016), however there is no way of investigating amplitude of activation using this method. In the GTPS population, there is a lack of research into gluteal muscle activation during gait, despite walking being a common aggravator of lateral hip pain. Identification of differences in hip stabilising muscle activation during gait, between GTPS and control groups, may facilitate targeted rehabilitation programs to address muscle impairments and dysfunction, and enable gait phase-specific interventions.

Fine wire electromyography (EMG) research suggests that anterior and posterior portions within GMin and anterior, middle and posterior portions within GMed have unique activation properties across the gait cycle (Semciw et al. , 2014, Semciw et al. , 2013c). In healthy young adults, posterior GMin has its greatest burst of activation early in the gait cycle, while anterior GMin has its greatest burst in mid to late stance (Semciw, Green, 2014). This functional differentiation facilitates pelvic and femoral head stability across the entire range of movement. It is important then to consider segmental gluteal muscle activation in GTPS where hip muscle function is thought to be impaired.

Similarly, variability in muscle activation in this population is unknown. It has been reported that in other chronic conditions, variability of movement patterns and/or muscle activation is reduced (Edwards et al. , 2016, Heiderscheit et al. , 2002, Miller et al. , 2008, Seay et al. , 2011, Selles et al. , 2001). Implications of this may include chronic overload of the musculo-tendinous unit, thus associated pain and injury.

The aim of this research was to investigate, quantify and compare temporal and amplitude, measures of muscle activation in the anterior and posterior portions of GMin and the anterior, middle and posterior portions of GMed and tensor fascia latae (TFL) during gait, in post-menopausal women with and without GTPS. A secondary aim was to assess if differences in muscle activation variability existed between control and GTPS groups.

2. Methods:

2.1 Participants

Eight post-menopausal women with GTPS (mean age 58.9, SD 3.3) and 10 control post-menopausal women (mean age 60.2, SD 2.6) participated in this study. Post-menopausal status was determined by >12 months of amenorrhea as per the Australasian Menopause Society guidelines (Australasian Menopause Society, 2008), or recorded as of the date of hysterectomy. Control participants had no history of congenital hip disease, hip or back surgery, hip trauma, or any lower limb or lumbar spine pain or injury in the last 6-months. Post-menopausal women with GTPS were included if they scored <80 points on the VISA-G questionnaire (Fearon et al. , 2015) and had lateral hip pain reproduction on 3 of 5 clinical tests (Trendelenburg test (Lequesne, Mathieu, 2008), palpation of the greater trochanter (Dennison and Beverland, 2002), Patrick-faber test (Mitchell et al. , 2003) standard and/or modified resisted external derotation test (Lequesne, Mathieu, 2008)). Participants who reported signs or symptoms consistent with intra-articular hip pathology or osteoarthritis (locking or catching in the joint, range of movement restriction, difficulty manipulating shoes and socks) were excluded (Fearon et al. , 2013). Ethical approval was granted by the La Trobe University Human Ethics Committee (UHEC 14-056), and all participants provided written informed consent.

2.2 Instrumentation and electrode insertions

Eligible participants attended one EMG testing session that involved the application of intramuscular electrodes into five muscle segments: anterior and posterior segments of the GMin muscle, and anterior, middle and posterior segments of GMed and one surface electrode onto TFL. Stainless-steel Teflon® coated bipolar fine-wire intramuscular electrodes were prepared with a 1mm conductive tip, and inserted under real-time ultrasound guidance (HDI 3000; Advanced Technology Laboratories, USA) using previously described procedures (Semciw et al. , 2013a, Semciw et al. , 2013b). In brief, five insertion sites were marked on the stance dominant leg (testing leg) of control participants and the symptomatic leg of GTPS participants, with reference to major surface landmarks (Semciw, Pizzari, 2013b). Leg dominance was assessed using three previously described tests: stamp out an imaginary fire, kick a ball and step up onto a block (Bullock-Saxton et al. , 2001). The skill-dominant leg was the leg that completed at least 2/3 tasks and the contralateral leg, the stance limb. Where participants had GTPS bilaterally, participants were asked to select their 'most symptomatic leg'. TFL surface electrode application and placement was completed using the recommendations of Basmajian and De Luca (1985).

Footswitches (Model: 402, Interlink Electronics, USA) were positioned bilaterally on the plantar aspect of the heel and interphalangeal joint of the hallux, and used to record temporal aspects (phases) of the gait cycle (Semciw, Pizzari, 2013c).

Raw signals from the footswitches, surface and intramuscular electrodes were received by a Delsys Trigno^{TM} Wireless EMG system (Delsys Inc., Boston, USA). This device samples EMG signals with 16 bits.

2.3 Experimental Protocol:

Prior to the commencement, participants were instructed to complete a three minute warm up to familiarise themselves with the walking trial protocol. The experimental protocol involved two components: walking trials to determine muscle activation patterns during gait, and isometric muscle strength testing to evaluate strength differences, between GTPS and control participants.

Six walking trials were completed at a comfortable self-selected walking speed (Latt et al. , 2008) along a 10m walkway (Semciw, Green, 2014). Trials were timed with a stop-watch and were repeated if the average walking speed increased or decreased by >5% (established during warm-up).

Isometric strength measures were undertaken during testing leg hip abduction in side-lie and hip internal/external rotation in sitting according to the methods described in Thorborg et al (2010), and hip ER in clam position (45° hip flexion and 90° knee flexion). All strength measures were completed using a hand-held dynamometer secured with a seat belt for standardisation (Table 2). This ensured consistent and sustained resistance to the participant force. Each isometric trial was performed three times for 3 s, with a 3-min respite between each trial to reduce fatigue effects. The standardised encouragement given by the examiner was ‘‘go ahead push-push-push-push and relax’’(Thorborg, Petersen, 2010).

After the series of walking trials, and after each isometric strength test, participants were asked to rate their level of discomfort by placing a mark on a 10cm visual analogue scale (VAS) where 0cm = no discomfort and 10cm = maximum possible discomfort. Self-reported activation was assessed using the Minnesota Leisure Time Physical Activation Questionnaire (Taylor et al. , 1978).

2.4 Data processing

Raw signals collected by the Delsys EMGworks Acquisition software (CMRR >80 dB at 60Hz; gain of 1000; band pass filtered 20-900 Hz) were sampled at 2000Hz. Intramuscular EMG signals from GMed and GMin were high pass filtered (4^{th} order Butterworth, 50Hz cut-off) to reduce low frequency movement artefact (Semciw, Pizzari, 2013c). The surface electrode (TFL) was high pass filtered at 10Hz. All data were then full wave rectified and further processed with a low pass filter (4^{th} order Butterworth) at a cut off frequency of 6Hz to generate linear envelopes. Electromyographic signals for each muscle were amplitude normalised to the respective peak muscle activation recorded during the gait cycle (Yang and Winter, 1984), and time normalised to 100-points (% of the gait cycle). It has previously been considered that normalising to maximum voluntary isometric contraction (MVIC) is inaccurate in people with pain (Sims et al. , 2002). Normalising to peak muscle activity within the gait cycle is an alternative normalisation method that has greater intra-subject reliability than MVIC methods (Suydam et al. , 2016). Data processing and analysis was completed by one investigator (blinded to group allocation), based on previously validated procedures (high intra-rater reliability: $ICC_{2,1}$ 0.965-1.000) (Semciw, Green, 2014).

The first and last walking trials were excluded to reduce learning and fatigue effects. Two consecutive strides, representing the two middle strides of each of the four walking trials were processed for analysis (8 strides per participant). This ensured consistent walking velocity between the trials by excluding acceleration and deceleration periods. For each participant, an ensemble of average muscle activation across eight strides was generated. This was summed and averaged across all participants within each group (GTPS and control) to generate a grand ensemble curve across the gait cycle. Average level of muscle activation across all participants was calculated to produce a grand ensemble for each muscle segment (anterior GMin, posterior GMin, anterior GMed, middle GMed, posterior GMed and TFL). Similarly, walking trial discomfort data and isometric strength measures were averaged across participants.

Previous research in young healthy subjects divided analyses of gait into distinct bursts of activation (Rutherford and Hubley-Kozey, 2009, Semciw, Green, 2014, Semciw, Pizzari, 2013c). Ensembles indicated two distinct bursts of activation, during early stance (0-30% gait cycle) and late stance (30% to toe off). Therefore data were acquired for 4 phases in total: 0-30% and 30%-toe off, total stance (0% to toe off) and swing (toe off to end of the gait cycle).

Delsys EMGworks 4.0 signal analysis software was used to acquire the dependant variables of peak amplitude (% peak muscle activation), average amplitude (% peak muscle activation) and time to peak (TTP, % of gait cycle) for each muscle segment from each phase of the gait cycle, established from the linear envelopes of each participant's trials. Variability of muscle activation was calculated using the mean coefficient of variation (CV) across the eight strides within each participant (Kiss et al. , 2012). These were determined using values from each one percent increment of the gait cycle and averaged within each phase (0-30%, 30-60%, 0-TO and entire gait cycle). The CV for each participant within each phase was summed and averaged within each group (GTPS vs. control).

Strength measures (Newtons), were multiplied by the lever arm to calculate peak torque and normalised to body mass (Jaric et al. , 2005). This normalisation method (Table 2) is used to account for differences in available muscle mass with increasing body size (Jaric, Mirkov, 2005).

2.5 Statistical analysis

The temporal and amplitude gait variables from each segment in each phase were used for quantitative comparisons (peak amplitude, average amplitude and time to peak). Histograms and the Kolmogorov-Smirnov (K–S) test were used to explore assumptions of normality (Field, 2009). Independent samples t-tests were performed to identify differences in dependant variables (EMG data, peak torque, walking speed, discomfort ratings and mean CV) between groups. To estimate of the magnitude of difference (effect size) between groups, a standardised mean difference (SMD = mean difference/pooled SD) was calculated for all gait comparisons (Field, 2009). For non-parametric data, effect sizes were calculated by dividing the z-score of the Mann–Whitney U test by the square root of the total sample size (Field, 2009). An effect size threshold of 0.2, 0.5 and 0.8 was considered small, medium and large respectively(Cohen, 1988). All statistical analyses were performed in SPSS (version 21, IBM SPSS Inc., Chicago, IL, USA) using an alpha of 0.05.

3. Results

Participant baseline characteristics is outlined in Table 1. All intramuscular electrodes except one posterior GMin (GTPS participant) remained in situ for the entire testing session. One middle GMed intramuscular electrode signal (control participant) and one TFL surface electrode signal (control participant) were affected by artefact and could not be processed, and consequently discarded from analysis. The mean (SD) walking speed for was 0.74 (0.06) $m.s^{-1}$ for the control group and 0.90 (0.14) $m.s^{-1}$ for GTPS participants ($p=0.013$). Mean (SD) stride time was 1.01 (0.07) for control participants and 1.09 (0.10)s for GTPS participants ($p=0.057$). Level of discomfort (mean (SD)) for comfortable pace walking trials for control and GTPS participants was 2.12(1.46) cm and 4.96(1.61) cm respectively ($p=0.003$). The GTPS group had significantly less hip muscle peak torque during abduction and clam strength tests (Table 3) and significantly higher discomfort scores ($p=0.003$).

Table 4 presents quantitative comparisons of TFL and segmental gluteal amplitude and temporal EMG variables between control and GTPS participants, when normalised to percentage of peak muscle activation.

The ensemble curves for posterior GMin illustrate a large first burst of activation followed by a small burst, in both GTPS and control participants. There was significantly greater average and peak posterior GMin muscle activation, with large effect sizes, in GTPS participants during the first phase (0-30%), $<p=0.01$ and $p=0.04$ respectively. An earlier peak in GTPS group muscle activation in gluteus minimus posterior was found in the second burst (30%-TO), and also for the entire duration of stance phase.

The shape of the anterior GMin ensemble differs between GTPS and controls. For the GTPS group, the ensemble curve illustrates a larger first burst than the second, whereas the control group illustrates a smaller first burst compared with the second. GTPS participants had significantly greater average muscle activation, with large effect, in anterior GMin over the entirety of stance phase (0%-TO). Nil other significant differences existed between groups. The shape of the ensemble for all GMed segments are consistent between GTPS and control participants, however, the magnitude of activation differs. A large first burst was seen for both groups, however, a smaller second burst of activation is seen in the control group. During both the second burst of stance phase (30%-TO) and over entirety of stance (0%-TO), GTPS participants showed significantly higher average levels of anterior and middle GMed muscle activation, with moderate to large effects. Similarly more peak activation in the anterior and middle portions of GMed was seen during the second burst (30%-TO). An earlier peak in GTPS muscle activation in middle GMed during early stance (0-30%).

No differences were found for the duration of stance from 0-TO however significantly greater peak TFL muscle activation was again found in the GTPS group compared to control participants during swing phase.

Variability in muscle activation across the gait cycle was significantly greater in the control group compared to GTPS for anterior GMin and anterior GMed across stance phase, and more specifically 30-60% (late stance) of the gait cycle (ES>1.04, p<0.05; Table 5).

Table 1. Baseline Characteristics

	Control	GTPS	p-value
	Mean (SD)	Mean (SD)	
Age	60.20(2.74)	58.88(3.48)	0.379
Height	164.73(4.31)	164.89(4.55)	0.975
Weight	69.95(10.20)	87.21(53.68)	0.128
BMI	25.30(3.50)	31.38(9.50)	0.122
VISA-G Questionnaire	97.21(9.49)	55.00(6.46)	**<0.001**[a]
Minnesota Activity Questionnaire (kcal)	83.40(54.15)	42.55(37.92)	0.107

[a] non-parametric test (Mann-Whitney-U) **Bold** = significant result

Table 2: Method for measuring hip strength

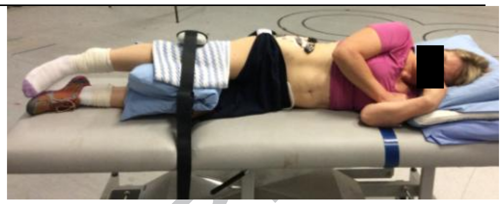
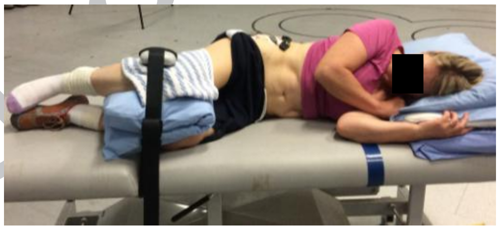
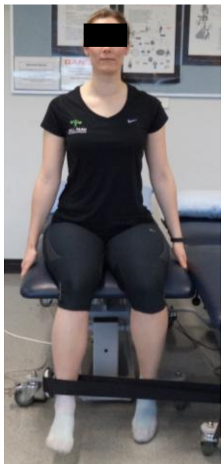
Action	Description	Lever arm and measurement	Illustration
Side-lie Hip Abduction	Performed in side-lying, pillow between knees, with hips and knees in neutral, the participant performs a maximal isometric hip abduction force against the dynamometer positioned 5 cm proximal to the lateral femoral condyle, secured with a seat belt.	Ipsilateral thigh segment Greater trochanter to the lateral femoral condyle	
Side-lie Clam	Performed in side-lying, pillow between knees, with 45° hip flexion and 90° knee flexion, the participant performs a maximal isometric hip external rotation force against the dynamometer positioned 5 cm proximal to the lateral femoral condyle, secured with a seat belt.	Ipsilateral thigh segment Greater trochanter to the lateral femoral condyle	
Seated Hip IR	Participant is seated with 90° hip and knee flexion and holding onto the table with both hands. The participant exerts a maximum hip internal rotation force against the dynamometer applied 5 cm proximal to the proximal edge of the medial malleolus.	Ipsilateral shank segment Fibular head to lateral malleolus	
Seated Hip ER	Participant is seated with 90° hip and knee flexion and holding onto the table with both hands. The participant exerts a maximum hip external rotation force against the dynamometer applied 5 cm proximal to the proximal edge of the lateral malleolus.	Ipsilateral shank segment Fibular head to lateral malleolus	

Table 3. Comparison of discomfort and peak torque measures normalised to body mass

MVIC	Discomfort (VAS 0-10 scale)				Peak torque adjusted for body mass (Nm/kg)			
	Control Mean(SD)	GTPS Mean(SD)	Effect size	p-value	Control Mean(SD)	GTPS Mean(SD)	Effect size	p-value
Hip Abd in slide-lie	0.89(1.34)	4.8(3.02)	1.67	**0.00**	1.07(0.07)	0.75(0.08)	-4.09	**0.01**
Clam	1.03(1.10)	4.06(2.69)	1.49	**0.01**	2.44(1.39)	0.71(0.07)	-1.58	0.28
Hip ER in sitting	1.26(1.57)	2.84(2.65)	0.71	0.14	0.50(0.06)	0.42(0.04)	-1.46	0.33
Hip IR in sitting	1.33(1.42)	2.84(2.66)	0.70	0.14	0.62(0.05)	0.51(0.07)	-1.76	0.19

ER = external rotation; IR = internal rotation; **Bold** = significant result

Table 4. Comparison of muscle segments across the gait cycle between control and GTPS groups

Muscle segment	Phase		Average (% peak muscle activity)				Peak (% peak muscle activity)				Time to Peak (% of gait cycle)			
			Mean(SD)		Effect size	p-value	Mean(SD)		Effect size	p-value	Mean(SD)		Effect size	p-value
			Control	GTPS			Control	GTPS			Control	GTPS		
Anterior GMin	Stance	0-30	45.13(18.61)	58.05(12.14)	0.76	0.11	78.29(27.69)	90.52(17.06)	0.38	0.12[a]	16.58(6.13)	17.93(2.61)	0.26	0.57
		30-TO	49.86(7.77)	51.43(13.12)	0.06	0.83[a]	88.70(15.37)	83.32(17.82)	-0.31	0.50	11.06(5.19)	9.44(3.56)	-0.34	0.46
		0-TO	49.11(7.10)	55.55(4.93)	0.98	**<0.05**	100.00(0)	100.00(0)	0.00	1.00[a]	29.84(11.93)	25.45(10.76)	-0.37	0.43
	Swing		20.06(413.02)	17.63(11.78)	-0.01	0.69	39.47(24.71)	34.21(22.83)	-0.21	0.58				
Posterior GMin	Stance	0-30	52.24(11.42)	65.87(5.16)	0.75	**<0.01[a]**	88.02(14.06)	100.00(0)	1.04	**0.03**	16.49(3.60)	13.63(2.77)	-0.82	0.10
		30-TO	42.40(20.15)	35.99(6.66)	-0.38	0.39	72.58(33.59)	65.90(10.92)	-0.24	0.59	7.95(2.48)	4.46(1.53)	-1.54	**<0.01**
		0-TO	49.14(7.34)	52.20(3.20)	0.48	0.29	100.00(0)	100.00(0)	0.00	1.00[a]	25.44(9.58)	13.63(2.77)	-1.47	**<0.01**
	Swing		12.64(1.12)	9.09(9.08)	-0.58	0.38~	24.10(22.80)	19.87(16.84)	-0.19	0.73~				
Anterior GMed	Stance	0-30	58.48(5.50)	65.39(5.67)	1.18	**0.02**	100.00(0)	99.63(1.05)	-0.26	0.70[a]	14.87(1.90)	15.60(2.13)	0.35	0.45
		30-TO	21.88(10.34)	38.98(10.41)	1.57	**<0.01**	39.80(17.34)	63.90(11.86)	1.51	**<0.01**	9.08(3.95)	8.21(3.54)	-0.25	0.63~
		0-TO	43.41(4.04)	53.21(4.58)	2.18	**<0.01**	100.00(0)	100.00(0)	0.00	1.00[b]	15.19(2.10)	17.06(3.75)	0.35	0.20
	Swing		10.43(7.00)	17.37(18.21)	0.50	0.34	19.70(13.59)	33.62(34.57)	0.53	0.31				
Middle GMed	Stance	0-30	54.37(12.49)	66.64(7.16)	0.65	**<0.01[a]**	90.97(20.14)	99.72(0.59)	0.08	0.35~	13.84(2.80)	13.60(2.08)	-0.09	**0.04~**
		30-TO	21.15(12.15)	35.34(7.16)	1.29	**0.01**	41.64(22.16)	66.93(8.75)	1.33	**<0.01**	7.10(4.70)	4.67(2.27)	-0.59	0.29~
		0-TO	41.31(8.71)	52.36(5.16)	1.40	**<0.01**	95.46(13.61)	100.00(0)	0.23	0.74[a]	15.40(4.99)	14.34(2.64)	-0.09	0.73~
	Swing		20.95(24.06)	8.54(3.28)	-0.63	0.53~	38.31(39.97)	18.41(8.29)	-0.60	0.89[a]				
Posterior GMed	Stance	0-30	60.13(5.30)	65.63(5.00)	1.01	**<0.05**	99.32(1.65)	99.94(0.15)	0.22	0.52[a]	13.81(2.30)	14.39(2.06)	0.25	0.59
		30-TO	26.47(11.64)	32.58(7.81)	0.57	0.19	52.63(24.98)	63.32(12.70)	0.45	0.28	5.23(3.25)	4.63(2.13)	-0.20	0.66
		0-TO	46.12(5.54)	50.88(5.14)	0.82	0.08	100.00(0)	100.00(0)	0.00	1.00[a]	15.06(3.68)	14.91(3.01)	0.25	0.97~
	Swing		12.54(12.09)	10.72(10.53)	-0.15	0.61	22.51(118.40)	19.74(17.83)	-0.03	0.75				
TFL	Stance	0-30	43.03(25.30)	55.87(20.10)	0.53	0.27	65.95(34.80)	75.18(25.71)	0.28	0.41	16.85(3.50)	17.65(2.91)	0.23	0.62
		30-TO	48.39(14.93)	57.03(8.16)	0.67	0.17	82.96(23.33)	88.73(14.96)	0.28	0.50	15.07(3.57)	17.33(7.55)	0.37	0.54~
		0-TO	48.16(13.58)	57.55(9.95)	0.74	0.13	100.00(0)	90.73(17.01)	-0.41	0.20~	32.30(14.08)	32.99(16.03)	0.23	0.93~
	Swing		32.77(16.11)	45.44(11.79)	0.84	0.05~	37.97(20.71)	80.57(14.61)	2.23	**<0.01~**				

[a] non-parametric test (Mann-Whitney-U); ~ log transformed; **Bold** = significant result; SD (standard deviation); TO (toe-off); GMin (gluteus minimus); GMed (gluteus medius)

Table 5. Variability (mean CV) in segmental muscle activation across the gait cycle between control and GTPS participants

Muscle	Phase	Control		GTPS			
		Mean CV	SD	Mean CV	SD	ES	p-value
Anterior GMin	Total GC	0.49	0.10	0.41	0.08	0.80	0.10
	0-TO	0.39	0.09	0.30	0.04	1.18	**0.02**
	0-30	0.37	0.16	0.29	0.11	0.56	0.23
	30-60	0.40	0.07	0.31	0.08	1.16	**0.02**
Posterior GMin	Total GC	0.49	0.15	0.43	0.05	0.49	0.26
	0-TO	0.41	0.15	0.34	0.07	0.62	0.21
	0-30	0.31	0.10	0.24	0.08	0.73	0.14
	30-60	0.52	0.26	0.44	0.07	0.40	0.42
Anterior GMed	Total GC	0.47	0.09	0.40	0.07	0.78	0.10
	0-TO	0.41	0.09	0.31	0.06	1.24	**0.01**
	0-30	0.27	0.10	0.22	0.07	0.60	0.20
	30-60	0.56	0.16	0.40	0.12	1.04	**0.03**
Middle GMed	Total GC	0.48	0.14	0.39	0.07	0.70	0.14
	0-TO	0.47	0.16	0.35	0.09	0.83	0.07
	0-30	0.37	0.20	0.22	0.09	0.93	0.06
	30-60	0.57	0.18	0.50	0.13	0.43	0.35
Posterior GMed	Total GC	0.43	0.06	0.44	0.10	0.18	0.70
	0-TO	0.41	0.07	0.38	0.13	0.28	0.54
	0-30	0.30	0.10	0.30	0.13	0.00	1.00
	30-60	0.53	0.14	0.47	0.16	0.38	0.41
TFL	Total GC	0.35	0.13	0.30	0.09	0.41	0.39
	0-TO	0.32	0.11	0.27	0.12	0.41	0.39
	0-30	0.30	0.12	0.26	0.11	0.30	0.53
	30-60	0.35	0.14	0.28	0.14	0.45	0.35

Bold = significant result; SD (standard deviation); ES (effect size); GC (gait cycle); TO (toe-off); GMin (gluteus minimus); GMed (gluteus medius)

[INSERT FIGURE 1]

Discussion

This study identified four key findings. Greater average muscle activation in all muscle segments was found in people with GTPS, compared to controls, however, the area that these segmental differences occurred varied across the gait cycle and were only significantly higher for anterior GMin and anterior and middle GMed during 0-TO, and posterior GMin and GMed during 0-30%. The EMG burst pattern of anterior GMin in participants with GTPS was reversed with a more dominant first burst early in stance when compared to control participants. Similarly, muscle activation in anterior GMin and anterior GMed was less variable in GTPS participants and they were significantly weaker than the control group during hip abduction.

Reduced hip abductor strength has previously been implicated in biomechanical differences present in people with GTPS (Allison, Vicenzino, 2016a, Grimaldi, 2011). The loss of the lateral stability mechanism (frontal plane femoropelvic alignment and medio-lateral stability in standing) in GTPS has been attributed to hip abductor weakness (Grimaldi, 2011) which may cause compression of the gluteal tendons over the greater trochanter of the femur, and result in lateral hip pain. Pain induced inhibition of activation may also negatively effect strength output, as there were significant between group differences in baseline VISA-G scores and a significant increase in discomfort scores in the GTPS group during strength testing.

In the GTPS group, greater average muscle activation in all muscle segments was found. The higher EMG amplitude may represent the need for greater motor unit recruitment given a submaximal functional task, when compared to the control group (Ling et al. , 2007). The reduction in muscle strength may drive the need for increased neuromotor effort. This compensatory response to muscle weakness has been previously been demonstrated in a hip osteoarthritis population during gait (Dwyer et al. , 2013). On a cortical level, higher amounts of local gluteal and TFL muscle activation in response to unilateral loading in the GTPS group may demonstrate an inability to modulate corticospinal pathway excitability and grading of muscle activation in response to task demands. Although, all may be plausible, based on experimental data, a causal link cannot be claimed.

A reverse of the anterior GMin EMG burst pattern was found in participants with GTPS, when compared to control participants. The ensembles indicate a larger burst of GTPS anterior GMin activation in early stance (0-30%) and although not significant, the difference in average amplitude in the first burst is moderate to large (ES=0.76). Control group muscle activation patterns reflect that which occurs in the young healthy population (Semciw, Green, 2014) whereby anterior GMin EMG activation uniquely peaks in mid-to late stance (Semciw, Green, 2014). The larger second burst of activation for anterior GMin is thought to serve a synergistic role with iliopsoas, assisting with minimising anterior hip joint forces during mid to late stance (Lewis et al. , 2007) and stabilising the head of femur in the acetabulum. In normal healthy gait, terminal hip extension may act as a stimulus for increased anterior GMin muscle activation, as it acts to stabilise the anterior aspect of the hip joint and counteract the hip extension moment (Semciw, Green, 2014). Recent evidence suggests that women with GTPS have significantly reduced step length compared to controls (Allison et al. , 2016b), perhaps an adaptive strategy to relieve pain. An associated lack of terminal hip extension at toe off may play a role in altered muscle activation strategies during gait, through a reduced stimulus for anterior GMin to contract, resulting in a less dominant second burst of activation.

The reduced variability in the muscle recruitment in GTPS might result in an inability to adapt to dynamic environments (Hamill et al. , 1999) and change muscle recruitment in response to task demands (Stergiou et al. , 2006), and thus, may induce pathology. As the anterior portion of GMin and GMed are reported to be thinner than their posterior counterparts (Flack et al. , 2014) it is plausible that a lack of variability of movement may contribute to the pathology in this region. Decreased variability has been reported in several other musculoskeletal conditions (Edwards, Steele, 2016, Heiderscheit, Hamill, 2002, Miller, Meardon, 2008, Seay, Van Emmerik, 2011, Selles, Wagenaar, 2001) and is theorised to be a chronic motor adaptation to pain (Hodges & Tucker 2011). Low movement variability may be implicated in the recalcitrant nature of GTPS and may reflect central motor changes.

Differences in muscle activation, variability and strength measures identified between groups may help to guide the clinical management and further research of GTPS. The prescription of high load isometric exercises (Rio et al. , 2015) may assist in strengthening muscle tendon units and support function of the lateral stability mechanism, and further investigation of gait kinematics may help to identify potential gait retraining strategies for normalising anterior hip muscle activation, stability and variability.

Limitations

The small sample size may be a limitation in this study. To achieve the same large effect size for anterior GMin average activation during the first burst (ES=0.76) a post-hoc sample size calculation indicates a sample of 29 in each group (GTPS and control) is required to reach statistical significance (α=0.05 and a power of 0.80) (Faul et al. , 2007). There are inherent limitations for the use of surface electrode recordings, especially when recording from participants with a high BMI; this may account for some of the differences found between groups in TFL. As intramuscular EMG research in this age group and pathological group have not been researched previously, results may act as pilot data for further research in this area. As no biomechanical analysis was undertaken, the biomechanical factors that may be influencing muscle activation levels during gait can only be hypothesised. Matching legs between control and GTPS legs may have been more preferable, as we cannot assume that the stance leg or skill leg becomes symptomatic. An estimate of proximal femoral torsion in participants was not recorded. This may influence GMed EMG amplitude (Nyland et al. , 2004) and may confound the measurements. As the study was undertaken in post-menopausal older women (controls and GTPS), generalisability to other populations is limited.

Conclusion

Increased segmental gluteal muscle activation, decreased hip abduction strength, and reduced variability in muscle activation was found in post-menopausal women with GTPS, compared with controls – a combination that may lead to higher gluteal tendon load and result in pain. The inverse pattern in average anterior GMin muscle activation in the GTPS group may be inherently linked to altered gait characteristics. The larger burst of muscle activation seen in early gait during unilateral loading could influence the functioning of this segment as an anterior hip joint stabiliser in terminal extension. Further work needs to explore the mechanism of these changes, investigate targeted gait and rehabilitation strategies, and identify methods for increasing strength, reducing pain and normalising variability of muscle activation in GTPS.

Conflict of interest

Nil declared

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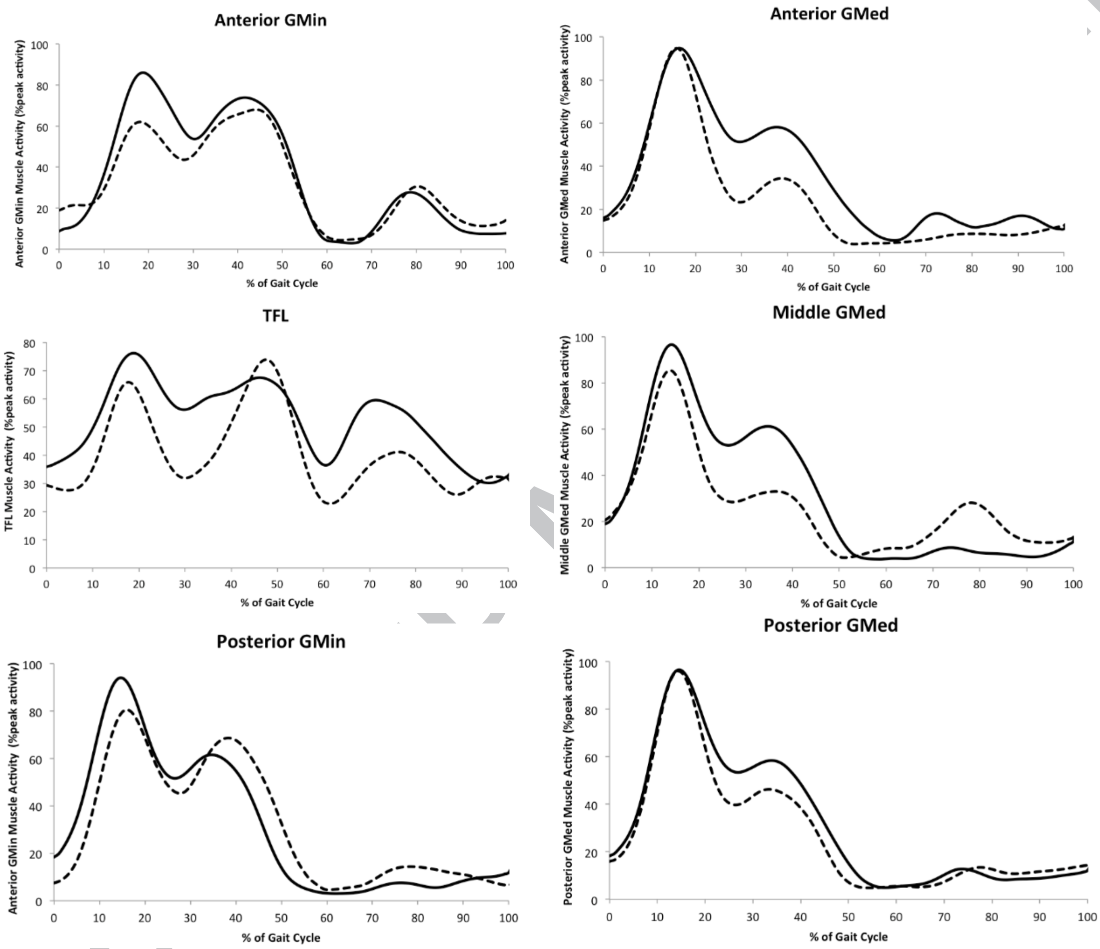
Figure 1: A comparison of GTPS and control muscle activity (normalised to a % of peak muscle activity) during the gait cycle



Grand ensemble EMG averages (GTPS participants = black solid lines; control participants = black dashed lines) for gluteus minimus anterior (anterior GMin) (10 control; 8 GTPS participants), gluteus minimus posterior (posterior GMin) (10 control; 7 GTPS participants), gluteus medius anterior (anterior GMed) (10 control; 8 GTPS participants), gluteus medius middle (middle GMed) (9 control; 8 GTPS participants), gluteus medius posterior (posterior GMed) (10 control; 8 GTPS participants) and TFL (9 control; 8 GTPS participants) across the gait cycle. Note, peak bursts in this figure represent mean peak activity within and across participants, therefore do not reflect absolute peak values of each burst in Table 3.

Table 1. Baseline Characteristics

	Control	GTPS	p-value
	Mean (SD)	Mean (SD)	
Age	60.20(2.74)	58.88(3.48)	0.379
Height	164.73(4.31)	164.89(4.55)	0.975
Weight	69.95(10.20)	87.21(53.68)	0.128
BMI	25.30(3.50)	31.38(9.50)	0.122
VISA-G Questionnaire	97.21(9.49)	55.00(6.46)	**<0.001**[a]
Minnesota Activity Questionnaire (kcal)	83.40(54.15)	42.55(37.92)	0.107

[a] non-parametric test (Mann-Whitney-U) **Bold** = significant result

Table 3. Comparison of discomfort and peak torque measures normalised to body mass

MVIC	Discomfort (VAS 0-10 scale)				Peak torque adjusted for body mass (Nm/kg)			
	Control Mean(SD)	GTPS Mean(SD)	Effect size	p-value	Control Mean(SD)	GTPS Mean(SD)	Effect size	p-value
Hip Abd in slide-lie	0.89(1.34)	4.8(3.02)	1.67	**0.00**	1.07(0.07)	0.75(0.08)	-4.09	**0.01**
Clam	1.03(1.10)	4.06(2.69)	1.49	**0.01**	2.44(1.39)	0.71(0.07)	-1.58	0.28
Hip ER in sitting	1.26(1.57)	2.84(2.65)	0.71	0.14	0.50(0.06)	0.42(0.04)	-1.46	0.33
Hip IR in sitting	1.33(1.42)	2.84(2.66)	0.70	0.14	0.62(0.05)	0.51(0.07)	-1.76	0.19

ER = external rotation; IR = internal rotation; **Bold** = significant result

Table 5. Variability (mean CV) in segmental muscle activation across the gait cycle between control and GTPS participants

Muscle	Phase	Control		GTPS			
		Mean CV	SD	Mean CV	SD	ES	p-value
Anterior GMin	Total GC	0.49	0.10	0.41	0.08	0.80	0.10
	0-TO	0.39	0.09	0.30	0.04	1.18	**0.02**
	0-30	0.37	0.16	0.29	0.11	0.56	0.23
	30-60	0.40	0.07	0.31	0.08	1.16	**0.02**
Posterior GMin	Total GC	0.49	0.15	0.43	0.05	0.49	0.26
	0-TO	0.41	0.15	0.34	0.07	0.62	0.21
	0-30	0.31	0.10	0.24	0.08	0.73	0.14
	30-60	0.52	0.26	0.44	0.07	0.40	0.42
Anterior GMed	Total GC	0.47	0.09	0.40	0.07	0.78	0.10
	0-TO	0.41	0.09	0.31	0.06	1.24	**0.01**
	0-30	0.27	0.10	0.22	0.07	0.60	0.20
	30-60	0.56	0.16	0.40	0.12	1.04	**0.03**
Middle GMed	Total GC	0.48	0.14	0.39	0.07	0.70	0.14
	0-TO	0.47	0.16	0.35	0.09	0.83	0.07
	0-30	0.37	0.20	0.22	0.09	0.93	0.06
	30-60	0.57	0.18	0.50	0.13	0.43	0.35
Posterior GMed	Total GC	0.43	0.06	0.44	0.10	0.18	0.70
	0-TO	0.41	0.07	0.38	0.13	0.28	0.54
	0-30	0.30	0.10	0.30	0.13	0.00	1.00
	30-60	0.53	0.14	0.47	0.16	0.38	0.41
TFL	Total GC	0.35	0.13	0.30	0.09	0.41	0.39
	0-TO	0.32	0.11	0.27	0.12	0.41	0.39
	0-30	0.30	0.12	0.26	0.11	0.30	0.53
	30-60	0.35	0.14	0.28	0.14	0.45	0.35

Bold = significant result; SD (standard deviation); ES (effect size); GC (gait cycle); TO (toe-off); GMin (gluteus minimus); GMed (gluteus medius)

Table 4. Comparison of muscle segments across the gait cycle between control and GTPS groups

Muscle segment	Phase		Average (% peak muscle activity)				Peak (% peak muscle activity)				Time to Peak (% of gait cycl		
			Mean(SD)		Effect size	p-value	Mean(SD)		Effect size	p-value	Mean(SD)		Effect
			Control	GTPS			Control	GTPS			Control	GTPS	
Anterior GMin	Stance	0-30	45.13(18.61)	58.05(12.14)	0.76	0.11	78.29(27.69)	90.52(17.06)	0.38	0.12[a]	16.58(6.13)	17.93(2.61)	0.26
		30-TO	49.86(7.77)	51.43(13.12)	0.06	0.83[a]	88.70(15.37)	83.32(17.82)	-0.31	0.50	11.06(5.19)	9.44(3.56)	-0.34
		0-TO	49.11(7.10)	55.55(4.93)	0.98	**<0.05**	100.00(0)	100.00(0)	0.00	1.00[a]	29.84(11.93)	25.45(10.76)	-0.37
	Swing		20.06(413.02)	17.63(11.78)	-0.01	0.69	39.47(24.71)	34.21(22.83)	-0.21	0.58			
Posterior GMin	Stance	0-30	52.24(11.42)	65.87(5.16)	0.75	**<0.01[a]**	88.02(14.06)	100.00(0)	1.04	**0.03**	16.49(3.60)	13.63(2.77)	-0.82
		30-TO	42.40(20.15)	35.99(6.66)	-0.38	0.39	72.58(33.59)	65.90(10.92)	-0.24	0.59	7.95(2.48)	4.46(1.53)	-1.54
		0-TO	49.14(7.34)	52.20(3.20)	0.48	0.29	100.00(0)	100.00(0)	0.00	1.00[a]	25.44(9.58)	13.63(2.77)	-1.47
	Swing		12.64(1.12)	9.09(9.08)	-0.58	0.38~	24.10(22.80)	19.87(16.84)	-0.19	0.73~			
Anterior GMed	Stance	0-30	58.48(5.50)	65.39(5.67)	1.18	**0.02**	100.00(0)	99.63(1.05)	-0.26	0.70[a]	14.87(1.90)	15.60(2.13)	0.35
		30-TO	21.88(10.34)	38.98(10.41)	1.57	**<0.01**	39.80(17.34)	63.90(11.86)	1.51	**<0.01**	9.08(3.95)	8.21(3.54)	-0.25
		0-TO	43.41(4.04)	53.21(4.58)	2.18	**<0.01**	100.00(0)	100.00(0)	0.00	1.00[b]	15.19(2.10)	17.06(3.75)	0.35
	Swing		10.43(7.00)	17.37(18.21)	0.50	0.34	19.70(13.59)	33.62(34.57)	0.53	0.31			
Middle GMed	Stance	0-30	54.37(12.49)	66.64(7.16)	0.65	**<0.01[a]**	90.97(20.14)	99.72(0.59)	0.08	0.35~	13.84(2.80)	13.60(2.08)	-0.09
		30-TO	21.15(12.15)	35.34(7.16)	1.29	**0.01**	41.64(22.16)	66.93(8.75)	1.33	**<0.01**	7.10(4.70)	4.67(2.27)	-0.59
		0-TO	41.31(8.71)	52.36(5.16)	1.40	**<0.01**	95.46(13.61)	100.00(0)	0.23	0.74[a]	15.40(4.99)	14.34(2.64)	-0.09
	Swing		20.95(24.06)	8.54(3.28)	-0.63	0.53~	38.31(39.97)	18.41(8.29)	-0.60	0.89[a]			
Posterior GMed	Stance	0-30	60.13(5.30)	65.63(5.00)	1.01	**<0.05**	99.32(1.65)	99.94(0.15)	0.22	0.52[a]	13.81(2.30)	14.39(2.06)	0.25
		30-TO	26.47(11.64)	32.58(7.81)	0.57	0.19	52.63(24.98)	63.32(12.70)	0.45	0.28	5.23(3.25)	4.63(2.13)	-0.20
		0-TO	46.12(5.54)	50.88(5.14)	0.82	0.08	100.00(0)	100.00(0)	0.00	1.00[a]	15.06(3.68)	14.91(3.01)	0.25
	Swing		12.54(12.09)	10.72(10.53)	-0.15	0.61	22.51(118.40)	19.74(17.83)	-0.03	0.75			
TFL	Stance	0-30	43.03(25.30)	55.87(20.10)	0.53	0.27	65.95(34.80)	75.18(25.71)	0.28	0.41	16.85(3.50)	17.65(2.91)	0.23
		30-TO	48.39(14.93)	57.03(8.16)	0.67	0.17	82.96(23.33)	88.73(14.96)	0.28	0.50	15.07(3.57)	17.33(7.55)	0.37
		0-TO	48.16(13.58)	57.55(9.95)	0.74	0.13	100.00(0)	90.73(17.01)	-0.41	0.20~	32.30(14.08)	32.99(16.03)	0.23
	Swing		32.77(16.11)	45.44(11.79)	0.84	0.05~	37.97(20.71)	80.57(14.61)	2.23	**<0.01~**			

[a] non-parametric test (Mann-Whitney-U); ~ log transformed; **Bold** = significant result; SD (standard deviation); TO (toe-off); GMin (gluteus minimus); GMed (gluteus medius)

groups

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Charlotte Ganderton

Tania Pizzari

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