Title:

Gluteal tendinopathy and hip osteoarthritis: different pathologies, different hip biomechanics

Authors & Affiliations:

Kim Allison^a, Michelle Hall^a, Paul W. Hodges^b, Tim V. Wrigley^a, Bill Vicenzino^b, Yong-Hao Pua, Ben Metcalf^c, Alison Grimaldi^b, and Kim L. Bennell^a

^a Centre for Health, Exercise and Sports Medicine, Department of Physiotherapy, University of Melbourne, Parkville, Australia

Email: kim.allison@unimelb.edu.au, hallm@unimelb.edu.au, timw@unimelb.edu.au, k.bennell@unimelb.edu.au, b.metcalf@unimelb.edu.au

^b School of Health & Rehabilitation Sciences, University of Queensland, St Lucia

Email: p.hodges@uq.edu.au, b.vicenzino@uq.edu.au, info@dralisongrimaldi.com

^c Department of Physiotherapy, Singapore General Hospital, Singapore

Email: puayonghao@gmail.com

Corresponding Author

Dr Kim Allison, PhD, Bachelor of Physiotherapy (BPhty)

Centre for Health, Exercise and Sports Medicine, Department of Physiotherapy, University of Melbourne

161 Barry St Parkville, VIC 3010 Australia

Ph: +61 3 9035 4860 Fax: +61 3 8344 4188

Email: kim.allison@unimelb.edu.au

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Highlights

- A greater external hip adduction moment is associated with GT than hip OA
- Reduced hip sagittal excursion is associated with hip osteoarthritis
- Greater pelvic obliquity is associated with gluteal tendinopathy

ABSTRACT

Background: Gluteal tendinopathy (GT) and hip osteoarthritis (OA) are the most common causes of hip pain and associated disability in older adults. Pain and altered walking biomechanics are common to both conditions. This study aimed to compare three-dimensional walking biomechanics between individuals with unilateral, symptomatic GT and HOA.

Methods: Sixty individuals with symptomatic unilateral GT confirmed by magnetic-resonance-imaging and 73 individuals with symptomatic unilateral HOA (Kellgren-Lawrence Grade ≥ 2) underwent three-dimensional gait analysis. Maximum and minimum values of the external hip flexion moment, first peak, second peak and mid-stance minimum of the hip adduction moment (HAM), sagittal plane hip excursion and hip joint angles, pelvic obliquity and trunk lean, at the three HAM time points during stance phase of walking were compared between groups using an analysis of covariance.

Results: Compared to individuals with HOA, those with GT exhibited a greater hip peak extension moment ($P < 0.001$) and greater HAM throughout the stance phase of walking ($P = 0.01 - P < 0.001$), greater hip adduction ($P < 0.001$) and internal rotation ($P < 0.01 - P < 0.001$) angles and lower hip flexion angles and excursion ($P = 0.02 - P < 0.001$). Individuals with HOA exhibited a greater forward trunk lean ($P \leq 0.001$) throughout stance, and greater ipsilateral trunk lean in the frontal plane ($P < 0.001$) than those with GT.

Conclusion: Despite presence of pain in both conditions, hip kinematics and kinetics differ between individuals with symptomatic unilateral GT and those with symptomatic unilateral HOA. These condition-specific impairments may be targets for optimization of management of HOA and GT.

1. Introduction

Individuals with chronic gluteal tendinopathy (GT) experience high levels of hip pain and disability, comparable to those reported by individuals with end stage hip osteoarthritis (HOA) [1]. Both conditions are common over the age of 40 years [2-4] and can be difficult to differentially diagnose clinically [5, 6]. Notably both groups report hip pain aggravated during walking [7, 8] with significant effects on quality of life [3]. Unlike HOA, where evidence-based guidelines have been developed to guide exercise and gait modification in conservative management [9], little evidence exists to guide management of GT. Although walking provokes symptoms in both conditions [7], it is unlikely that the same interventions would be appropriate as it would be expected that walking biomechanics would differ between individuals with GT and HOA as a consequence of differences in the underlying pathology (i.e., tendon versus articular) and disease-specific impairments (e.g. joint/capsular stiffness associated with HOA [10, 11]). Such differences would be expected to have unique relevance for development and/or progression of each condition. Understanding differences in gait biomechanics between GT and HOA may help to direct assessment and to inform condition-specific treatment approaches.

HOA is an *intra*-articular hip pathology characterized by joint stiffness and reduced passive range of movement which is associated with reduced hip joint excursion in the sagittal plane during walking [10, 11]. Conversely, GT is an *extra*-articular hip pathology characterized by lateral hip pain and sensitivity to palpation over the greater trochanter [12]. Common to GT and HOA are evidence of: i) hip abductor muscle weakness (compared to controls, deficits of 32% and 31% are reported for individuals with GT [13] and HOA [14], respectively), ii) a relationship between hip abductor weakness and pelvic control during single leg loading [8, 15] and ii) altered walking hip biomechanics [10, 16-19], but with unique elements. Compared

to controls, GT is characterized by altered walking biomechanics in the frontal plane, such as *greater* contralateral pelvic drop [16] and a *greater* external hip adduction moment (HAM) [16]. In contrast HOA involves *lower* frontal [10, 20, 21] and sagittal [10, 18] plane moments and *lower* external sagittal plane hip excursion [18, 19, 22].

Frontal plane moments are considered to be particularly relevant for both gluteal (abductor) tendon and hip joint loading and pathology, given that (1) the external HAM is inferred to require a balancing internal hip abductor moment contributed to by tension within the hip abductor muscles [23, 24] implicated in GT and (2) the external HAM and the external flexion moment are considered indicators of hip joint loads [25]. Despite the similarity of some features of GT and HOA clinical presentations, condition-specific features of frontal and sagittal plane moments, the latter yet to be investigated in GT, may provide guidance for optimizing management for HOA and GT. Given that the position of the trunk and pelvis in the frontal plane influences HAM magnitude [16, 26], investigation of their contribution to kinematics during walking is critical.

Comparison of spatiotemporal gait variables between these clinical groups has identified no differences between walking speed and step length during a clinical 10 meter walk test [7], but no study has directly compared kinematics and kinetics during walking between individuals with GT and HOA. Use of sophisticated three-dimensional gait analysis to compare walking spatiotemporal variables, as well as gait kinematic and kinetics is likely to provide biomechanical data specific to GT and HOA that could form a foundation to inform individualized management approaches.

This study aimed to address the following research questions:

1. Is the external HAM or hip flexion moment different between individuals with symptomatic unilateral GT and symptomatic unilateral HOA?
2. Are there differences in hip, pelvic and trunk kinematics occurring throughout stance phase at the time of the first peak, mid-stance and second peak hip abduction moments, or hip joint excursion in the sagittal plane during walking in individuals with symptomatic, unilateral GT and HOA?

2. Methods

2.1 Participants

Participants in this study were a sample of convenience from a database of three studies that completed at the University of Melbourne. Participants in the GT group (n=60) were recruited at baseline from a randomized controlled trial (RCT) [27] of which 40 participants were included in a cross sectional study [16]. Inclusion criteria for GT participants were: (1) a primary report of unilateral hip pain at the greater trochanter for ≥ 3 months with an average intensity of ≥ 4 on an 11-point numeric rating scale (NRS) ('0' no pain; '10' worst pain imaginable); (2) aged 35–70 years; (3) a clinical diagnosis of GT made by a physiotherapist and defined as tenderness to palpation of the greater trochanter and at least one of six pain provocative tests for GT [28], and (4) a primary diagnosis of GT made by magnetic resonance imaging (MRI) [29]. To exclude intra-articular hip pathology, the following exclusion criteria were applied: (1) a primary complaint of groin pain, (2) passive hip flexion range <90 degrees or (3) evidence of HOA on plain X-ray defined as Kellgren-Lawrence Grade 2 or above [30]. Additional exclusion criteria were applied to exclude the presence of other conditions that could affect gait and relevant to intervention arms of the RCT (Appendix 1).

Participants in the HOA group (n = 73) were recruited at baseline from two studies performed

at the University of Melbourne between 2006 and 2012 [n=48 from a cross-sectional study (unpublished Thesis) and n=25 from a RCT [31]]. All participants had HOA according to the American College of Rheumatology classification criteria of pain and radiographic changes [32] and femoral or acetabular osteophytes along with joint space narrowing $\geq$ Grade 2 on standing x-ray; ii) hip or groin pain on most day of the past month. Exclusion criteria were applied to exclude other conditions that could affect gait and those specific to elements of the RCT (Appendix 1).

Ethics approval was obtained from the University of Melbourne Health Ethics Committee and all participants provided written informed consent.

2.2 Walking analysis

Participants underwent three-dimensional gait analysis whilst walking barefoot along a 10-m walkway at their self-selected comfortable speed. Participants reported pain experienced during walking on the NRS. Reflective markers were placed in accordance with the Plug-in-Gait configuration (Vicon Systems Ltd, 2010). Kinematic data were recorded at 120Hz using a 12-camera (MXF20/F40) Vicon motion capture system (Vicon, Oxford, UK). Ground reaction force data were collected at 1200Hz from two force plates (Advanced Mechanical Technology Inc., Watertown, MA). Marker trajectory data were filtered using a Woltring quintic spline filter. Hip joint angles and moments were calculated using the Plug-in-Gait model, with external moments calculated using inverse dynamics and expressed in the distal (thigh) co-ordinate system. Hip angles (sagittal, frontal, and transverse plane) were calculated for each trial, along with step length and velocity. A trunk segment was defined with the sagittal and frontal plane angle of the trunk in relation to the laboratory coordinate system [33] and pelvic angles determined using a rotation-obliquity-tilt Cardan sequence [34].

2.3 Outcome measures

External moments were normalized to body weight x height (Nm/BW.Ht%) to account for body size [35]. For each trial, maximum and minimum values of the external hip flexion moment and maximum values of the external HAM during 0-50% and 50-100% of stance phase, representing the first and second peaks respectively, and the minimum values between the peaks to represent the mid-stance moment [16] were determined. Data from each participant were visually inspected to confirm the presence of a bimodal HAM pattern. Maximum values of hip adduction, internal rotation, and flexion angles, contralateral pelvic drop and forward and ipsilateral trunk lean at the three HAM time points were calculated for each trial. Hip joint excursion in the sagittal plane during stance was also calculated. Values obtained for each of the five to six completed trials per participant were averaged.

2.4 Data analysis

Data analysis was performed using Statistical Packages for the Social Sciences version 22 (IBM, New York, USA). Data were explored for normality prior to analysis. Independent t-tests were used to compare descriptive characteristics and spatiotemporal variables between groups when data were normally distributed, and Mann Whitney-U tests when non-normally distributed. An analysis of covariance based on between-group differences in patient characteristics that were likely to have an influence on walking biomechanics (age [36], sex [37], symptom duration [16], walking velocity [38]) was used to compare biomechanical variables between groups with significance set at $P < 0.05$.

3. Results

3.1 Participant characteristics

Flow of participants in the study is shown in Figure 1. Participant characteristics are summarized in Table 1. The HOA group was significantly older, heavier, had a greater BMI and a greater duration of symptoms. Both the GT and HOA groups included more women than men. The predominance of women in the GT group (77%) is consistent with previous GT research [39, 40]. There were no differences between groups with respect to pain intensity reported during walking.

3.2 External moments during walking

Between-group differences were identified in the peak hip extension moment and at the first and second peak time-points of the HAM, with and without walking velocity, symptom duration, age and sex included as covariates (Table 2; Figure 1), and during mid-stance when no adjustments were made or when adjusting for velocity or age. Without any adjustments performed, individuals with HOA had a 35% lower peak extension moment when compared to individuals with GT ($p < 0.001$). Individuals with GT demonstrated an 18% greater first peak HAM, a 14% greater mid stance HAM, and 20% greater second peak HAM during the stance phase of walking compared to those with HOA.

3.3 Kinematics during walking

Between-group differences were identified in hip, pelvic and trunk kinematic variables (Table 2), irrespective of covariates. Without any adjustments performed, individuals with HOA demonstrated greater hip flexion angles (4.7 - 12.5 degrees), less excursion in the sagittal plane (11.3 degrees), and greater forward trunk lean (3.9 - 8.8 degrees) throughout stance compared to those with GT. Compared to individuals with HOA, individuals with GT exhibited greater hip adduction angles (3.6 – 5.0 degrees), and greater internal rotation angles (3.4 - 5.5 degrees) throughout stance. Individuals with GT exhibited marginally (< 2.5 degrees) greater

contralateral pelvic drop and contralateral trunk lean in the frontal plane at the three HAM moment time points than individuals with HOA. Based on sex-specific differences in walking kinematics in individuals with HOA [37] during walking, we performed a secondary analysis comparing men with GT with men with HOA, and women with GT to women with HOA (Supplementary Tables 1 and 2). All between-group differences persisted, apart from contralateral pelvic drop which did not differ between men with GT and those with HOA.

4. Discussion

This is the first direct comparison of walking biomechanics between GT and HOA. There were three main observations. First, compared to those with HOA, individuals with GT exhibited greater external HAM and a greater peak extension moment during the stance phase of walking. This infers greater demands on the hip abductor and flexor muscles and different loads on the femoro-acetabular joint. Second, differences in hip kinematics in all three planes were observed between groups. Individuals with GT walked in a more hip-adducted and internally rotated position, and those with HOA in a more flexed position. Third, individuals with HOA walked with greater forward trunk lean than those with GT. Together, these findings show that differences in walking biomechanics exist between individuals with GT and those with HOA.

The only previous study to compare walking characteristics between individuals with GT and those with HOA found no difference in walking speed or step length during a 10-meter walk test [7]. Although we also found no differences in walking speed, individuals with GT had a 4-cm greater step length than those with HOA. Less sensitive clinical measures used to assess step length in the previous study probably account for the between-study difference, but the clinical relevance of these small between-group spatiotemporal differences is questionable.

Consistent with previous evidence of a 9-33% greater HAM during walking in those with GT than condition-free controls [16], individuals with GT exhibited a 14-20% greater HAM than individuals with HOA and a 35% greater peak extension moment. The net external HAM is inferred to represent a net internal *adduction* moment contributed to by (1) the hip abductor muscles and (2) passive structures of the hip (and abductor mechanism) [23, 24], and the external extension moment an internal flexor moment, with a subsequent influence on joint loads. Although not conclusive in the absence of muscle activation data, these data provide some support for our contention that loads through the hip muscles (abductor and flexor) and hip joint differ during walking between those with GT and HOA. Albeit not assessed in the present study, individuals with HOA are more likely to have stiffness which may influence dynamic range of motion during gait and subsequently the external moments. This supposition is only speculative given that (1) conflicting results exist regarding the relationship between passive hip joint range and dynamic range during walking in those with HOA and (2) only one study to date has investigated the relationship between passive hip joint range and external moments, identifying no relationship between passive hip extension and the magnitude of the external hip flexion moment in individuals with end stage unilateral HOA [10].

Compared to controls, a lower HAM [10] and a lower peak extension moment has been identified in individuals with HOA [18, 41, 42]. Although cross-sectional study designs prohibit cause and effect conclusions, the lower HAM recorded in HOA is proposed to be an antalgic strategy to reduce compressive loads on the degenerated hip joint [42] and the lower extension moment and angle to reduce loading on the anterior aspect of the hip joint and pain [43]. Recent evidence has also shown a relationship between a higher external HAM and greater rate of disease progression [25]. It is important to note that this does not exclude the converse possibility that regional under-loading of hip joint surfaces may also be relevant for

OA [21, 44] given emerging evidence of an association between reduced knee joint loading and early osteoarthritis in individuals with anterior cruciate ligament reconstruction [45, 46].” Conversely, the large external HAM during walking in those with GT is likely to have direct clinical relevance for gluteal tendon overload. A positive relationship has been identified between the HAM and tension within the iliotibial band (ITB) [47]. This has relevance for gluteal tendon compressive overload given that ITB tension which influences compressive forces against the greater trochanter [48] into which the gluteal tendons insert [49]. Together, these data indicate that assessment and management approaches that aim to reduce the external HAM such as targeting frontal plane pelvic control [16] may be most relevant for individuals with GT than those with HOA, whereby those influencing sagittal plane moments may also be relevant for individuals with HOA.

It is tempting to speculate that the magnitude of between-group differences in hip kinematics (3.4-11.3 degrees) identified here may be detectable with visual inspection by experienced clinicians during observational gait assessment. The hips of the GT group were more adducted (corresponding with greater contralateral pelvic drop) and internally rotated during the stance phase of gait, whereas the HOA group was more flexed. The kinematic patterns associated with HOA concur with previous data of greater peak hip flexion angles [17, 19] and reduced hip extension at mid to terminal stance [10, 17-19, 21] during walking when compared to controls [10, 18, 19, 21] or those with less severe HOA [17]. Lesser hip extension during walking has been associated with disease severity on imaging [10, 18, 19, 22] and reduced passive hip range of movement [10] in those with HOA. This suggests sagittal plane kinematics are particularly relevant for HOA. Lesser hip extension is thought to reduce the surface area of cartilage that is loaded during the stance phase of gait, contributing to regional overload and under-load with potential relevance for disease progression [44]. Specifically, a 2 degree increase in hip

extension during walking has been shown to be associated with a 24% increase in anterior hip joint forces [50]. Consistent reports of changes in sagittal plane kinematics in HOA imply this is a plausible target for gait modification interventions for HOA.

Frontal plane kinematics are thought to be particularly relevant for the development and perpetuation of GT pathology [51]. In the present study, individuals with GT exhibited both greater contralateral pelvic drop and hip adduction angles throughout stance than those with HOA. Eccentric control of the pelvis in the frontal plane (hip adduction) during the stance phase of walking is considered relevant for the development and perpetuation of GT given the relationship between; (1) hip adduction angle and compressive loads on the gluteal tendons against the greater trochanter [48], into which the gluteal tendons insert [49], and (2) contralateral pelvic drop and the magnitude of the external HAM during walking [16]. Our findings provide further support for the notion that frontal plane kinematics are relevant considerations within the management plan of GT.

This study has several potential limitations. As participants with HOA did not undergo clinical or imaging evaluation to exclude GT we cannot confirm the absence or co-existence of symptomatic or asymptomatic GT in that group. The HOA group was significantly older, had a longer duration of symptoms, and more men. However, adjustment for age, symptom duration or sub-analysis for sex had little impact on between-group differences and the mean age and sex distribution of the GT and OA groups were comparable to that of previous cross-sectional data [7]. As data was collected from two different studies across four years, different researchers applied the marker set with no inter-tester reliability investigation. However, both researchers followed the same marker set application protocol of our laboratory. We did not collect passive range of movement, hip strength or muscle activation measures, so we cannot

establish the relationship between these variables and walking biomechanics in this study and our interpretations with respect to the relationship between muscle function and the external moments are presented with caution.

In conclusion, this is the first study to directly compare walking kinematics and kinetics between individuals with GT and HOA which represent distinct extra- and intra-articular hip pathologies, respectively. These conditions are comparable with respect to severity of symptoms and patient-reported functional limitations, but our findings show that kinematics and hip kinetics differ between those with GT and HOA. These disease-specific impairments may direct assessment and be targets for treatments and require further investigation.

Figure Captions:

Figure 1. Flow of participants through study.

Figure 2. Frontal and sagittal plane kinetics and kinematics of the hip, trunk and pelvis during the gait cycle of walking. (Red line represents the GT group, Black the OA group; dashed lines +/- 1 standard deviation)

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Table 1. Participant characteristics (mean (SD)) unless otherwise stated.

	Gluteal Tendinopathy (n=60)	Hip Osteoarthritis (n=73)	Mean Difference (95% CI)	P value
Age, years [‡]	53.7 (8.6)	61.2 (8.1)	-7.6 (-10.5, -4.7)	<0.001*
Height, m	1.67 (0.08)	1.67 (0.03)	0.0 (-0.04, 0.02)	0.53
Mass, kg	73.8 (13.4)	79.7 (15.2)	-5.9 (-10.8, -0.9)	0.02*
Body mass index, kg/m ²	26.4 (3.9)	28.2 (4.4)	-1.8 (-3.2, -0.3)	0.02*
Sex, n (%)				
Women	46 (77%)	40 (55%)	-	0.01*#
Men	14 (33%)	33 (45%)	-	
Symptomatic (test) hip ^a	Right = 23 (38%)	Right = 41 (56%)	-	<0.001*
Symptom duration years [‡] , median (IQR)	1.0 (2.5)	4.5 (3.7)	-	<0.001*
Pain reported during walking test ^{b‡} , median (IQR)	2 (1)	2 (2)	-	0.80

[‡] Data not normally distributed

Pearsons Chi Square

Table 2. Whole group (n=133) biomechanical data (mean (SD) unless specified)

	Gluteal Tendinopathy (n=60)	Hip Osteoarthritis (n=73)	Mean Difference (95% CI)	Unadjusted P value	Adjusted for walking velocity	Adjusted for symptom duration	Adjusted for sex	Adjusted for Age	Adjusted for sex and symptom duration	Adjusted for age, sex, symptom
Spatiotemporal variables										
Velocity	1.3 (0.2)	1.2 (0.2)	-0.1 (-0.04, 0.05)	0.05	-	0.04*	0.02*	0.40	0.01*	0.13
Step length	0.67 (0.01)	0.62 (0.1)	0.04 (0.02, 0.06)	0.001*	0.007	0.01*	<0.001*	0.06	<0.001*	0.003*
External Hip Adduction Moment (Nm/BW.Ht (%))										
1 st stance	5.7 (1.3)	4.6 (1.4)	1.0 (0.5, 1.5)	<0.001	<0.001*	<0.001*	<0.001*	<0.001*	0.002	0.003*
Mid-stance	3.5 (0.8)	3.0 (1.2)	0.5 (0.1, 1.0)	0.01*	<0.001*	0.10	0.08	0.001	0.37	0.10
2 nd stance	5.0 (1.0)	4.0 (1.5)	1.0 (0.5, 1.5)	<0.001	<0.001*	0.002	0.001	<0.001*	0.01*	0.002*
External Hip Flexion Moment (Nm/BW.Ht (%))[#]										
Peak flexion	6.7 (2.0)	6.6 (3.0)	0.2 (-0.6, 0.6)	0.34	0.35	0.37	0.37	0.36	0.38	0.35
Peak extension	6.5 (1.4)	4.0 (1.3)	2.3 (1.8, 2.7)	<0.001	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Hip Adduction Angle, degrees										
At 1 st peak HAM	8.0 (4.2)	3.2 (5.3)	4.8 (3.1, 6.5)	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
At Mid-stance	5.6 (3.4)	2.0 (4.6)	3.7 (2.2, 5.2)	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
At 2 nd peak HAM	4.8 (3.7)	1.2 (4.6)	3.6 (2.1, 5.0)	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Hip Flexion Angle, degrees										
Sagittal plane	44.9 (5.3)	33.7 (7.5)	11.3 (9.1, 13.5)	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
At 1 st peak HAM	19.6 (6.6)	24.3 (8.7)	-4.7 (-2.0, 7.3)	0.02*	0.001*	0.09	0.06	0.001*	0.18	0.03*
At Mid-stance	2.6 (6.6)	10.2 (8.8)	-7.5 (-10.3, -4.8)	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
At 2 nd peak	-8.8 (8.2)	3.3 (10.2)	-12.5 (-15.3, -9.7)	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Hip Internal Rotation Angle, degrees										
At 1 st peak HAM	2.5 (7.4)	-3.0 (9.0)	5.5 (2.6, 8.3)	<0.001*	<0.001*	0.001*	0.002*	0.001*	0.002*	0.004*

At	2.1 (7.0)	-1.3 (9.4)	3.4	0.01*	0.02*	0.05	0.02*	0.02*	0.07	0.08
Mid-stance			(0.5, 6.2)							
At 2 nd peak	1.3 (6.9)	1.0 (8.2)	0.2 (-2.5, 2.9)	0.88	0.89	0.99	0.95	0.67	0.80	0.90
Contralateral Pelvic Drop (pelvic obliquity) Angle										
At 1 st peak	3.2 (2.6)	1.3 (3.2)	1.8 (0.9, 3.9)	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	0.001*
At Mid-stance	0.4 (2.3)	-1.4 (2.7)	1.7 (0.8, 2.6)	<0.001*	0.001*	0.001*	<0.001*	<0.001*	<0.001*	<0.001*
At 2 nd peak	0.5 (2.1)	-1.0 (2.6)	1.4 (0.6, 2.2)	<0.001*	0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Frontal Plane Trunk Angle ^b, degrees										
At 1 st peak	1.0 (2.1)	2.1 (2.6)	-1.1 (0.2, 2.0)	0.02*	0.02*	0.06	0.01*	0.02*	0.05	0.03*
At Mid-stance	-0.2 (2.8)	0.3 (2.3)	-0.5 (1.4, 0.4)	0.24	0.26	0.30	0.20	0.10	0.16	0.05*
At 2 nd peak	-0.8 (2.7)	1.7 (2.7)	-2.5 (3.5, 1.5)	<0.001*	0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Sagittal Plane Trunk Angle ^c, degrees										
At 1 st peak	12.8 (6.1)	16.7 (5.5)	-3.9 (5.9, 2.0)	<0.001*	0.001*	0.01*	0.01*	<0.001*	0.02*	0.002*
At Mid-stance	2.8 (4.6)	10.0 (5.7)	-7.2 (9.0, 5.4)	<0.001*	0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
At 2 nd peak	2.4 (5.0)	11.2 (6.1)	-8.8 (10.7, 6.8)	<0.001*	0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*

Kinematic values denote angles at the time of the external hip adduction moment (HAM) first peak, mid-stance minimum and second peak.

^a Positive pelvic obliquity indicates the contralateral pelvis is dropped relative to the stance limb

^b Ipsilateral trunk lean is positive

^c Forward trunk lean is positive

* significant between group difference, P<0.05.

Data non-normally distributed; expressed as median (interquartile range) with between group comparisons performed using Mann-Whitney U tests

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